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UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR/537-2

SECOND COLLEGE ON THEORETICAL AND EXPERIMENTAL RADIOPROPAGATION PHYSICS

(7 January - 1 February 1991)

Co-sponsered by ICTP, URSI, ICSU
and with the participation of ICS

Tropospheric propagation: Present aspects and approaches

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TROPOSPHERIC PROPAGATION: PRESENT ASPECTS AND APPROACHES

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Work carried out in the framework of the agreement
between the Italian PT Administration
and the Fondazione Ugo Bordoni

Relazione 1T6190

Roma, novembre 1990

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ABSTRACT

New satellite systems and techniques are under development to satisfy the increasing demand for communication services and capacity.
New critical propagation aspects consequently arise and deserve deep investigations.
In the present lecture some particular propagation topics are discussed and their implications to communication systems are approached.

1. Satellite communication systems

The telecommunications scenario has noticeably changed today with respect to some twenty years ago, mostly due to two factors: the fast increasing demand of new services and the operative utilisation of the optical fibers.
Twenty years ago the satellite had no competitors in the intercontinental links and the traffic conditions were such to allow few big earth stations /nodes to be cost-effective, in spite of the large antennas and G/T values requested by the low-weight/low-power satellites.
To face the needs for the new services and to compete with the superior capacity of the fibers the satellite exploited its intrinsic capacities of flexibility of reconfiguration and of by-passing the high-cost segments of the earth network by directly connecting to the minor users/stations.
From the technical point of view this has been due to two factors.
Smaller and smaller components have allowed higher power on board with the same weight: therefore with higher G/T and EIRP values on the satellite, smaller and cheaper earth stations have become cost effective.
On the other hand the development of the communications techniques have assigned to the satellite a new role: no longer a simple passive transponder of signals but a sophisticated real time manager of networks.
The resulting tendency for the immediate future is therefore that of a noticeable increase of many small earth-stations, directly connected to the space segment of the satellite system, on one hand, and the development of new powerful satellites, acting as main node of wide interconnected networks by means of sophisticated adaptative techniques.

For the near future, typically the 90s, new important systems are planned such as : regional satellites, direct broadcasting television with high definition technology, mobile systems, small commercial and private terminals, high transmission capacity, on-board management of resources and many other sophisticated solutions. A fast increase of networks, users, earth-stations and consequent technical problems is therefore envisaged.
An urgent need of investigations in the radiopropagation field has arised.
The adoption of new higher frequency bands, SHF and EHF, the study of the effects of minor atmospheric components, light rain, clouds, gases, the higher occurrence of interference situations, introduce the need for a thorough research in propagation topics.
Many programmes have been prepared in view of these needs all around the world in Europe, Japan, USA and, to a smaller extent but with an even more interest, in the tropical regions where the need for measurements is more urgent.
In this lecture the attention is focussed on some relevant aspects of the propagation phenomena and on the concerned communication systems :

- the vertical structure of the rain for the prediction of rain attenuation

- the horizontal structure of the rain for the on-board adaptative systems

- the effects of the minor atmospheric components for commercial systems

2. Evaluation of the propagation phenomena

A three-step general procedure can be outlined for the study of the propagation factors:

1 -Study of the features of the phenomenon.
2 -Evaluation of the influence on radiowaves.
3 -Knowledge of the statistics of the phenomenon.

The use of statistical data might be overlooked when attention is confined only to the understanding of the mechanism as such, while it is essential when the characterization of the propagation effects for ready design application over large regions and different climates is involved.
Step 2 is in any case necessary and can be performed either by the application of the models developed in Step 1, which becomes in this case essential, or by direct measurements of the effects.
In this latter case the Step 1 might be neglected.
A strict linkage to the Step 3 should obviously be maintained when developing Steps 1 and 2. Analysis and measurements must be performed on the basis of information and data coincident or easily related to those obtainable in Step 3, in such a way to allow large applicability of the developed models and algorithms.

This procedure has been applied to analyze the effects of the rain. Studies on the characteristics of the rain have been performed regarding the vertical and horizontal structure, the shape and the size of raindrops and its behaviour with respect to the e. m. field propagation from a theoretical point of view (Step 1).

A large extent of measurements of both rain rate and of the induced attenuation and depolarization has been carried out for many years in many countries (Step 2).

Finally the assessment of the long-term statistics of rainfall, both in form of high resolution measured data and as rough standard data, has been defined (Step 3), although the scarcity of reliable data still now represents the weak ring of the chain.

3. Rain attenuation

Attenuation (fading) of the transmitted signal is the major impairment caused by different atmospheric components, among which the main role is played by rain drops. Ice and snow, in fact, do not attenuate the signals when in their proper "dry" status, while they may give noticeable fading when associated with the liquid phase: melting ice and wet snow. Rain attenuation increases with the frequency and obviously with the intensity of the rain itself, varying from tenth of dB/Km at 10 GHz with light "stratiform" rain (5 mm/h), up to some 40 dB/Km at 30 GHz in presence of heavy "convective" rain (100 mm/h).

When considering rain attenuation the classical input figure is the average yearly cumulative distribution (CD) from which the attenuation threshold exceeded for a given percentage of the time can be extracted. According to the CCIR specifications the 0.01% of the year is the mandatory availability time for traditional telecommunication services, such as the public telephony. Therefore the value exceeded for that time interval, about 1 hour per year, represents the critical figure to face with in the system design.

When assessing the attenuation characteristics of a site careful attention has to be paid to the statistical significance of the available information. Attenuation, as the effect of strongly and fast variable causes, shows marked variability both in time and space.

The time variability of the attenuation has various time scales.

The long term variability may be pronounced among years and long periods, up to 10 years or even more, may be requested for the assessment the rain attenuation characteristics of a zone.

Short term variability is also present since the main cause, the rain, may considerably vary during times of the order of few seconds. This dynamic behaviour of the attenuation must be carefully investigated, as fundamental implications are involved : such as the real time control of the up-link power to counteract the variations on the down-link.

Similarly, the spatial variability of attenuation is directly linked to the spatial variability of the rain. From site to site, even on a short scale, both the long-term characteristics and the instant features of rain attenuation might be very different. This implies careful attention devoted to the dimensioning of the systems in a wide network and, at the same time, allows the possibility of managing the resources in a flexible way.

Since accurate measurements are not widely available, the attenuation may also be evaluated through prediction techniques.

The classical procedure is that of starting from rain statistics and apply the well known relationship between rain and attenuation, assuming adeguate hypotheses for the spacial structure of rain. For earth-space paths the vertical rain profile is of great concern and is the subject of deep investigations.

When reliable attenuation data are already available in a site, attenuation statistics may be derived at a certain frequency by extrapolation from those measured for another one, generally lower (frequency scaling).

4. Rainfall features

Rain is a complex phenomenon highly variable, both in time and space.

The main parameter on rain measurements is the integration time, intended as the time during which the fallen water amount (mm) is integrated to express an equivalent average rain intensity (mm/h).

The longer this time, the higher the risk of ignoring rain intensity variations. In principles only an absolutely steady rain might be measured regardless of the integration time. For radiopropagation purposes, integration times of tens of seconds, up to one minute, are ideal, although integration times of 5-10 minutes are still indicative at least for the lowest levels of rain where the variability is much less pronounced.

As far as the space structure is concerned, it is well known that the main limitation of the point measurement is the scarce spatial representativity. Rain events in fact typically occur in forms of convective cells embedded into a stratiform plafond where they move, arise and collapse according to criteria which are random to the observer. Usually it may be assumed that convective rains (>50 mm/h) have spacial dimensions rarely larger than one kilometre, while light stratiform rains may interest wide zones, even up to some one hundred kilometres.

This property of the rain structure is the basis of the small scale site-diversity, where two stations, serving the same area, are positioned 10-20 Km apart each other, being very low the probability of high rain occurrence in the two sites simultaneously. This technique is not still effective for very high frequencies (> 30 GHz), where even light phenomena may cause deep fading and may easily interest very wide areas.

In the rain attenuation prediction techniques the short-scale features of rain is accounted for by means of a reduction coefficient which introduces equivalent horizontal path throught homogeneous rain.

The large scale structure of rain is determinant for those applications where satellite resources should be shared among very distanced stations. The implications of this property of the rain will be detailed further on.

The vertical profile of rain is critical for the rain attenuation prediction techniques on satellite links, when hypotheses should be made about the lenght of the slant path throughout the liquid rain.
The mechanisms of rain are very complex and not satisfactorily measurable in terms of their effect on radio waves. Not withstanding this, a simple scenario may be attempted by considering three main types of rain :

Stratiform rain : widespread, long lasting rain with low-medium intensity. These rains are generated by the sublimation-coalescence mechanism according to the Bergeron-Findeisen theory, which involves the ice phase. Such rains may be assumed to extend up to the 0°C isotherm height.

Warm rain : convective showers with higher intensities and more concentrated in both space and time, typical of warmer seasons/zones. Such rains produced by the condensation-coalescence mechanism can begin well below the 0°C since the ice phase is not involved.

Thunderstorm rain : convective rains which may reach high intensities with thunder and/or lightning. These rains are usually generated within cumulo-nimbus cloud systems, which may extend to heights of more than 10 km due to the presence of strong updrafts.

4.1. The vertical structure of the rain

The physical rain height, h_{PR} intended as the level up to which water drops with diameter larger than some 0.1 mm are present, may be assumed to be coincident with the effective rain height deduced from the surface rain and beacon measurements.
Any non-uniformity in the vertical profile of the rain is in fact integrated in time, provided that all the water falling inside an ideal column reaches the ground. Exceptions might occur when water droplets with size sufficient to affect radio transmissions remain aloft without falling and/or when water is removed from the radio path by the horizontal component of the wind.
The first case, corresponding to a real vertical non-uniformity, is very unlikely to occur and causes the effective rain height to be higher than the physical one.
The second situation should not affect, at least on a statistical basis, the equivalence between the physical and the effective heights, but may be very common and is related to the horizontal non-uniformity of the rain which is much more complex for the total rain attenuation effect.
As a first approximation it may be assumed that the vertical non-uniformity of rain may be disregarded when compared with the horizontal non-uniformity, except for very high elevation angles (above 60°). This is also the reason why the term "rain height" may replace that of "rain thickness", for both the physical and effective measurements of the path through rain.

As the physical height of rain is not easily measurable, the simplest approximation for rain height is to use the level of the 0°C isotherm during rainy conditions h_{FR}, which is readily available from radiosonde data.
It should be noted, however, that marked differences may occur between the 0°C isotherm height during rain, h_{FR} and the height of the rain, h_R.
In fact, with reference to the three above mentioned rain structures, the physical height of the rain h_{PR} is undoubtedly lower than h_{FR} in warm rains, while the opposite situation is expected in mature thunderstorms where rain is normally present well above the h_{FR}. In stratiform rains, the two levels should be reasonably coincident, although, especially in the cold season, the falling ice crystals may melt below the 0°C isotherm.
The equivalent rain height h_R to be taken into account in the design of radiowave links results from the combination of these events, averaged according to their respective frequencies of occurrence, which depend on the season, the climate and the considered rain rate.
For the 0.01% of the year, used as the reference point in the CCIR rain attenuation prediction method, the rainy phenomena are mostly high-intensity events, while the effects of low rain rate stratiform rain structures are prevalent for longer times, such as 1% of the year.
The validity of the assumption of h_{FR} as an indicative value for the effective h_R depends on the probability of occurrence of the various rain types and seems to be adequate only for widespread rains.
However other types of rain may occur, such as 'warm' convective rain, where rain is generated well below h_{FR} and the thunderstorms, where 'tower' shaped clouds contain supercooled rain droplets far above the h_{FR} level. In these cases h_R is not well approximated by the measured h_{FR}.
The present CCIR prediction procedure appears to over-estimate the rain attenuation in the tropical zones.
As most of the presently available data in these regions were obtained by radiometric measurements, it is not known whether the possible overestimation is due to the intrinsic limitation of the radiometer, or to the actual values of h_R being lower than h_{FR}.
On the other hand a high probability of occurrence of thunderstorms would indicate a tendency for h_R to be higher than h_{FR}, although it should be noted that thunderstorms are convective activities conventionally associated with thunder and/or lightning, but not strictly speaking with cloud towers, where $h_R > h_{FR}$ at all times.
The differences between the physical rain height, h_{PR}, and the effective rain height, h_R, due to vertical inhomogeneities (layers of rain falling separately) do not appear to justify the measured discrepancies, because of the averaging effect of the measurements.
As a conclusion, however, the physical height of the rain and that 'effective' for the vertical fraction of the path may be assumed to coincide and be tentatively equated to the height of the 0°C isotherm, which has the advantage of being a measurable parameter.

In tropical regions, however, in view of the characteristics of the different types of rain, it appears that the rain height in that region cannot be easily related to the freezing height.

So far it has not been possible to find a meteorological parameter based mainly on geophysical considerations that can adequately be used to determine the effective rain height.

A much larger data base, covering both temperate and tropical locations, of simultaneous measurements of slant path attenuation with beacon signals and point rain intensity is required than is available at present in order to obtain an empirical relation for the global variation of the effective rain height for slant path attenuation prediction.

The value of the freezing level during rain, h_{FR}, is far from being a known parameter at present and extensive measurements are required in all types of rain structures and climatic regions before this parameter can be satisfactorily utilised.

5. Clouds features and effects

Satellite communication systems operating at higher and higher frequencies will be adversely affected by the atmosphere components in an increasingly severe way, since the shorter wavelengths become comparable in size with smaller particles other than raindrops, such as cloud water droplets.

Consequently clouds attenuation on radiowave may become relevant for the lowest elevation angles and for those system designed to accept higher outage times. Clouds in fact are present for times very longer than the 1% ÷ 3% of the rain and can last continuously for many days.

Unfortunately the knowledge on the clouds characteristics is not very deep and, although a certain correlation with the better known rainy phenomena positively exists, the available statistics of clouds coverage do not allow the development of algorithms and models for propagation applications.

The study of the clouds can be carried on according to various aspects:

i) meteorological description and classification
ii) clouds dynamics and microphysics
iii) effects on radiowave propagation

This latter approach represents the goal to be met and can be developed both deriving the attenuation and depolarization effects from structural models and by means of empirical relationships to be determined from the data available for clouds, beacons measurements, radiometric measurements and other related climatological parameters.

The description and the classification of the various types of clouds have to be done accordingly to the standard meteorological criteria in order to allow the interpretation of the measurements and the extension of the findings to a statistically significant data base.

The study of the dynamics and microphysics of the clouds is, on one hand, a preliminary knowledge to be acquired and is the only way which may allow the attempt of structural electromagnetic modelling of the phenomena.

The specific attenuation produced by the clouds droplets on radiowaves may be reasonably considered to be a function of the liquid water content and of the water temperature.

Unfortunately the liquid water content is so far a really unknown parameter and the few indications are even in conflict one another.

Preliminary evaluations seem to indicate values ranging from some 0.2 dB/Km at 20 GHz for light clouds, to more than 1 dB/Km at 40 ÷ 50 GHz in presence of clouds with high water content.

The total clouds attenuation depends on the path length throughout the clouds which is a function of the elevation angle and of the height and thickness of the stratus.

Assuming low elevation angles (~ 10 °) and a cloud thickness of 1 Km it is easy to reach values of 10 dB or more for the attenuation due to clouds at some 40 ÷ 50 GHz.

The features of the clouds may be evaluated as follows : type, shape, height, height of the base and horizontal extent or coverage may be somehow measured by means of ground - based observations.

Height, thickness, lifting motion, temperature, liquid water content and presence of ice-crystals evaluations are obtained by radiometers and by radiosonde soundings.

The standard for a large extent all over the world gives four types of data directly related to the clouds:

A) monthly numbers of days with clear, cloudy, overcast sky.

B) Three-hourly value of cloudiness, (eights of the hemisphere)

C) Three-hourly values of:
 fraction of the sky with low-level or medium-level clouds
 height of the base of the lowest clouds
 details on the type and features of the three levels of clouds

D) Values of the vertical profile of temperature, humidity and wind obtained by balloon measurements.
 These data are available for a very limited number of stations.

From a system-oriented point of view the main goal is that of obtaining for any site the cumulative distribution (yearly, monthly, seasonal) of attenuation due to clouds.

In order to allow this goal to be met, the specific attenuation should be determined for each type of cloud . The statistics should be obtained with the maximum degree of significance both in terms of time stability (10 ÷ 20 years) and of spatial representativity (at least for each climatic zone).

As far as the integration time concerns the cloud coverage time variability presents typically three scales:

- slow variability of the entire hemisphere (hours)
- fast variability of parcels of clouds/sky, (minutes)
- very fast internal variability (seconds)

Available standard data, are certainly sufficient to observe the slow variability, while no data at all seem to be obtainable for following the fast phenomena of the order of minutes.
Another cloud feature to be taken into account is the space homogeneity.
Ground observations are in fact based from a point as far as the horizontal line of sight is observable. Links with very low elevation angles may be interested to very long paths throughout the clouds. The effective path length in some assumed conditions of clouds (type, density, thickness) may be very difficult to calculate, especially in the case of cumulus convective clouds which have normally a limited extent.
A useful aid in this sense, although qualitative, may be obtained by the satellite photographs over large areas, at least for the wide stratiform clouds.
For those locations/microzones where no direct data on clouds coverage/features is available it could be somehow useful, at least as a "dirty and fast" tool for evaluating the effects of clouds, to establish a sort of relationship between the clouds attenuation and the values of simple, largely available data such as ground temperature, humidity, air pressure, wind direction and velocity.
The procedure for evaluating the statistics of the attenuation due to clouds is based on the following informations :

- Single cloud observations
- Radiometric measurements
- Beacon data
- Auxiliary information
  (ground temperature, humidity, pressure, solar data)
- Clouds canonical classification
  (shape, levels, dimensions, sky - cover degree)
- Link parameters
  (elevation and azimuth angles, frequency, polarization)

The simple cloud observation, enriched in details by both simple and sophisticated information and referred to the standard classification, is transformed, by means of the radiometer and beacon data and with reference to the parameters of the link, into specific attenuation for each individual cloud situation.
Where the site cloud statistics are available, with reference to the same standard classification, the site specific attenuation statistics may be obtained and transformed into clouds total attenuation for the given link geometry.

6. On-board adaptative assignement of resources

Future advanced satellite systems that operate simultaneously to a large number of widely-spread earth stations may make use of on-board processing to allocate additional resources on a dynamic basis to those earth stations requiring additional link margin or capacity.
Various techniques could be used for the purpose : high directivity beams, lower frequency bands, adaptative allocation of time.
The main problem concerning the employment of such techniques and the actual effectiveness in terms of availability gain regards the probability of request of help from more stations simultaneously and involves the characteristics of the statistical spatial dependence and the knowledge of the joint statistics of the rain attenuation in several sites.
As attenuation data for such circumstances are rather rare even for individual sites and also considering that attenuation statistics can be rather well inferred from point rainfall intensity statistics, which are indeed more available and stable, a meaningful analysis can be reasonably attempted from the rainfall data which also allow structural models to be hypothized.
The analysis has both the design-oriented approach of determining the actual probability of joint rain events in groups of locations and the model-oriented approach of analyzing the spatial dependence of the rain structure.

6.1. Definition of the parameters

In its general terms the 'shared on-board resource' philosophy consists in a extra-margin, realizable in many possible ways, which can be temporarily allocated to those earth stations undergoing severe propagation conditions.
Outage happens whenever the satellite cannot fulfil all the requests of help due to the limited resources available.
Taking into consideration the general case of a system which can simultaneously assist M stations out of a total of N, two types of probability are of interest :

the 'probability of overrequest' P_{ovr}, which regards the system as a whole : overrequest occurs whenever more than M stations ask for 'help' ;

the 'probability of not being helped' P_{nbh}, which, in the same situation, concerns the stations singularly.
In this latter case two different situation can be envisaged :

i) no hierarchy applies among the stations

ii) a hierarchical classification is assigned to the stations

The 'probability of overrequest' P_{ovr} is given by the weighted sum of all the joint probabilities of exceeding a given rain level in a group of stations

and intending that the sum is extended to all the possible combinations (pairs, triplets, quadruplets, etc.) which can be grouped out of N stations.
The 'probability of not being helped' P_{nbh} is similar in the structure to the P_{ovr} but distinction should be made between the case when no priority classification applies, where the resource will be assigned by the satellite, simply 'upon request', until resources are available and will be denied to following users until when one of the already assisted stations releases the 'help', and the case when a hierarchy applies. To a difference of the P_{ovr} now the sums are not extended to all the possible combinations which can be obtained from N stations, but only to those combinations including the interested station, with the assigned priority, if applies.
The P_{ovr} is intuitively always higher than the P_{nbh} since the system as a whole enters into outage condition as soon as just only one station cannot be served by a common resource.
For the P_{nbh} between the case of no hierarchy and lowest hierarchy, this latter is always greater for the same station having assigned a lower priority with respect to the others.
It should be noted that both the system probabilities P_{ovr} and P_{nbh} can be expressed as opportune combinations of the joint probabilities of rain occurring in groups of two, three, four, etc., stations, which can be obtained from the data.
Considering that the truncation of the sums after the second term does not introduce heavy inaccuracies in the most practical cases, as the contributions due to the quadruplets or more, however difficult to be verified in practise, is low with respect to the former terms, a satisfactory approximation may be obtained processing only pairs and triplets of stations.

6.2. Joint probability

Let us refer to the simple case of two stations A and B, spaced of D kilometres, with given individual probabilities of rain exceeding a certain level R, P_a and P_b respectively.
The joint probability of rain exceeding R in A and B is given by :

$$P_{ab} = P_a * P_{b/a} = P_b * P_{a/b}$$

where $P_{b/a}$ ($P_{a/b}$) is the probability of rain exceeding R in B (A) when the same event has already occurred in A (B).
P_{ab} is influenced by two factors :

- the individual probabilities of rain exceeding R in each site
- the degree of structural linkage between the two sites, owing to which the rain events tend to interest both the sites simultaneously.

This latter factor takes into account the local micrometeorology and is accounted for by the distance D between the two locations.
Consequently the joint probability P_{ab} depends on :

- the rainy characteristics of the individual site
- the distance D between the sites
- the considered level of rain intensity R
- the time sample T during which the events are observed and the rain is averaged (rain integration time)

The influence of D, R^* and T on the P_{ab} and their mutual relationships depend on the features of the perturbation, on the dimensions of any rain cell embedded on it, and on the direction and the speed of the perturbation.
P_{ab} intuitively increases with the individual site probability of rain and decreases with increasing distances. For very large separations statistical independence may be assumed, provided that two or more distinct perturbations may be considered decorrelated on a large scale.
The joint probability P_{ab} decreases when the rain level increases due to the lower values of the single probabilities P_a and P_b and because of the horizontal structure of the heaviest rainfalls which tend to be concentrated within limited areas.
The integration time T is, in a sense, an artificial parameter introduced by the practical unavailability of quasi-instantaneous rain data.
The longer the time along which the rain rate is averaged, the higher the probability of observing joint events and viceversa.
Long integration times, in fact, make the total rainy time increase artificially, both for the single site and for the joint events, due to the rain averaging and to the motion of the rain perturbation.
The joint probability is the typical design figure to be used, as above shown, for dimensioning the on-board system and determining the benefits in terms of availability time for the earth stations.
From the analysis of the experimental data a first design-oriented indication for the behaviour of the average joint probability P_{ab} as a function of the distance D has been obtained for Italy according to a combined exponential and gaussian behaviour :

$$P_{ab} = A_1 \exp[-(D/D_1)] + A_2 \exp[-(D/D_2)^2]$$

where the coefficients depends on the rain level.

6.3. The statistical dependence index

A statistical dependence index is defined as the ratio of the joint probability to the same probability in the case of statistical independence :

$$X_{ab\cdot\cdot N} = P_{ab\cdot\cdot N} / P_a * P_b *...*P_N$$

The index X is high when the dependence is strong and tends to unity in case of statistical independence.

The X has the advantage of describing the spatial dependence mechanisms rather independently of the individual site rainy characteristics and may therefore be representative for a wider range of geographical zones.

It also shows high degree of stability when changing the set of the sites and a less pronounced variation with the rain threshold.

The behaviour of X with the distance shows some essential features :

The X has a sharp decrease in the first 100 km from the value for $D = 0$ to around 100 km.

From 100 to some 600 km the value of X decreases slowly and shows an high spread for the individual pairs/triplets. A tendency to re-increase around distances of some 200 Km is very often noted which might be attributed to a re-coupling effect introduced by a second rainy area after the first cluster of rainy cells.

As far as the high spread is concerned this does not seem to be due to the statistical instability of the sample, but mostly to the different orientations of the pairs conjunction lines with respect to the direction of the perturbation.

For very long distances the X tends to unity and shows that a linkage still exists up to some 800 kilometres. A new increasing tendency is sometimes observed for the X beyond 1000 kilometres which, unless due to the instability of the very scarce sample at those separations, might be caused by the presence of a second distinct perturbation.

Three meteorological scales are consequentely observable :

- a 'short-range mesoscale', 0 - 100 km (strong correlation: $X >> 1$)
- a 'short synoptic scale', 100 - 800 km, (low correlation: $X > 1$)
- a 'large synoptic scale', beyond 800 km, (statistical independence: $X \simeq 1$)

7. Low availability systems

The general propagation problem for low availability systems may be approached as follows.

Radiowaves in the SHF and EHF bands are affected by various meteorological factors such as: rain, hail, snowflakes, ice-crystals, clouds, fog, haze, dry air components (oxygen) and water vapour in its gaseous state

These causes produce on the satellite communication signals serious impairments, typically: attenuation (fading), depolarization and fast amplitude variations (scintillations).

The effects of the atmospherical variables strongly depend on the parameters of the link: frequency, elevation, station features (mainly antenna diameter) and on the requirements of the service (mainly its availability).

The availability is the one most influencing the impact of the impairments, together with the elevation angle. Their importance is higher with respect to the frequency, at least in terms of the rain-induced attenuation.

In the actual design conditions the degrees of freedom for the choice of the link parameters are in the practise reduced.

Elevation and frequency are practically imposed, so that the design concerns only the availability of the service and the electrical and geometrical characteristics of the station. These latters have moreover to obey to cost considerations.

The increasing demand for new services/bands, on one hand, and the need of covering wide areas for some services on the other, will imply the next satellites to operate at higher frequencies 20/30 GHz and 40/50 GHz and, in some cases, with low elevation angles (<30°).

For those services where the classical CCIR availability specifications (99.99 % of the time) are strictly mandatory, high-cost/technology solutions must be adopted, either on-board and for ground stations: larger antennas, high power margins, common on-board resources , etc....

For some systems, however, typically the ground stations for VSAT or small business terminals, a more economical approach may be envisaged, by relaxing the availability to lower levels: 99 % or even 95 % of the time.

In this context the scenario, in terms of meteorological factors, changes.

High rate convective rainfalls (>50 mm/h), typically occurring for less than 1 hour per year (0.01 % of the time) do not play any more the predominant role, as it is 'a priori' assumed that the low availability systems are anyway blinded for such periods of time.

For the design of low availability systems (LAS) "new" factors start to have relevant influence as they may occur for longer than 1 % of the time, such as: light rain, clouds, water vapour, the characteristics of which is almost scarce up to now.

As far as light rain is concerned, for example, both the physical structure and the way of evaluating the attenuation change with respect to the heavier rain conditions.

Low and very low rainfalls, light rain (~ 5 ÷ 10 mm/h) and drizzle (~ 1 mm/h), respectively, have a larger horizontal extent and often a lower vertical extension as they usually occurr during the winter period, when the 0° C isotherm is lower.

This structure introduces an advantage as it simplifies the geometry of the mechanism when approaching the difficult problem of the equivalent path length through the rain.

Also the temporal behaviour is more favourable : time variations are strongly reduced and the significance of lower time resolution measurements (5 - 10 minutes) is improved.

Unfortunately measured data of rain attenuation for percentages of time of 1% or higher are not available.

One classical way for evaluating the rain attenuation starting from rain data is that of applying the available prediction methods, first of all the straightforward one recommended by the CCIR.

But serious perplexities would arise when applying an algorithm as far as two decades or more from its calibration point (0.01 %).

Other methods taking into account the entire rain information or nearer points like 0.1 %, could be better performing, provided that these data are available for rain. In any case this would be an extrapolation outside the boundaries within which the present techniques have been developed.

A direct evaluation can be obtained starting from the knowledge of the rain values exceeded for 1 - 5% of the time, applying the relationship between the rain rate and the specific attenuation and taking into account all the other parameters (path length, elevation, etc).

The problem is, in any case, that reliable measured rain data are rather scarce up to 1 % and unavailable for higher percentages.

Various techniques would anyway allow an estimation of the values of rain exceeded for 1 - 5 % of the time.

For those locations where measured data of R are available for high percentages, formulas for the derivation of R at the desired percentage from the value of R at 0.3% of the time, is given by CCIR.

Another approach could be that of using the "probability of rain". P_0 as a first approximation for very low levels. This figure is available for many sites and could also be evaluated from rough data, when no reliable measurement is given.

As the inspection of the "strip-charts" records for many sites all over Europe is not an easy procedure to be followed, the values of P_0 and/or the levels of rainfall exceeded for times longer than 1 % of the year, can be evaluated by means of a time integration scaling procedure.

Due to the fact that the low-rate rain has a more stable time behaviour, the error introduced by measuring the rain with a longer integration time is smaller with respect to the heaviest levels of rain (low percentages of time).

Studies carried out in Italy have shown that the ratio between the values of probabilities of exceeding a given low value of rain, say 2 mm/h, measured with 24, 1 hour and 10 minutes integration times, is rather constant both with regard to the year-to-year and to the site-to-site variability.

As records of rain heights collected along one hour and/or one day are largely available for many zones, the rain exceeded for high percentages of time (1 - 5 %) could be evaluated according to this criterium with low error.

The most straight-forward way to obtain information on the rain attenuation levels for high percentages of time is that of applying the well-known frequency-scaling techniques starting from the values of rain attenuation measured at lower frequencies.

This technique introduces errors of some 10% against the 20 - 30% of the prediction techniques from rain data.

Three are the main limitations of this procedure.

On one hand measured values of attenuation at 0.1, 1% for the time are not widely available and no data at all are given for higher values of time.

Secondly the input values, at probabilities of some 0.1 - 1% of the time, are of the order of some 1 dB or less. This means to start from data which are already likely affected by serious percentage errors.

Finally, as said before, the meteorological scenario at these percentages of time is now affected no more by rain as a predominant factor but also by clouds, water vapour and other phenomena. At the present stage it is not known whether and how these other factors scale with frequency and it is unlikely that they scale all in the same way.

This notwithstanding the frequency scaling technique, not being affected by rain measurements errors and by the unavoidable approximations of the prediction methods, appears to be one of the most effective "rough and dirty" procedures for the evaluation of the attenuation due to light rain.

Rain is formed by falling hydrometeors. Other types of hydrometeors are suspended, such: clouds, fog and haze, and assume, at the highest frequencies and at low elevations, an important role.

As far as some 20 GHz , the role of the clouds is negligible.

For the EHF frequency bands however the attenuation due to clouds absorption becomes important and must be taken into account particularly when the signals cross the troposphere for long paths, as it happens in case of low elevation angles.

Under likely hypotheses the specific attenuation due to clouds may be evaluated as a function of the temperature and of the liquid water content of the cloud. Algorithms for such a calculation are available in the literature.

The dramatic problem for the wide-scale evaluation of the attenuation due to clouds is the knowledge of the liquid water content for each type of cloud and the statistics of cloud coverage situations in terms of available data.

Data, measurements and evaluations, of the liquid water content of the clouds are scarce and in conflict one another.

Direct, reliable measurements could be obtained by means of radiometers in terms of noise temperature/attenuation and, indirectly, as liquid water content with joint soundings at 20 and 30 GHz, separating the water phases.

Information on cloudy coverage are available in form of nomenclature rather than properly defined data.

A long-term set of information is available, all over Europe, about: cloud coverage (ratio of the hemisphere covered by clouds), lowest clouds bottom and types of clouds for three levels of height: low, medium and high.

Three parameters are needed to transform the specific attenuation into link attenuation for the various situations: horizontal extent, vertical extent and liquid water content.

As a first analysis stage the horizontal extent may be extracted from the cloud coverage, the vertical extent from the height of the bottom and the type of cloud and the liquid water content from the type of cloud, as well.

Two are the main difficulties: use of uncertain values for the liquid water content and conversion of rough information on coverage and types of clouds into ready applicable figures.

Moreover clouds "data" are affected by a further limitation: the sky coverage is referred to the entire hemisphere and the observations are made normally every six hours or, sometimes every three hours.

As a first approximation space-time structure can be exchanged, as no reason arises why different characteristics occur for different directions, at least on a significant statistical basis. This notwithstanding a better resolution both in space and time is needed for a more thorough evaluation of the fast variability of the phenomenon.

Fog and haze can be assimilated to clouds characterized by low and very low drop sizes, respectively, and by a null height of the bottom stratus.

The liquid water content is some 0.1 - 0.3 gm^{-3} for fog and two decades below for the haze.

For frequencies up to 50 GHz both their contributions may be neglected as for the fog the depth of the layer is few tents of meters and the liquid water content of the haze is too low, although the layer depth of the haze can reach heights of more than one kilometer.

Water vapour causes attenuation increasing with the frequency and with the elevation angle, as longer and denser strata are crossed. In the microwave region of interest water vapour shows a rotational absorption line at 22.235 GHz with values of some 0.15 dB/km at 15 °C, 1013 mb and a density of 7.5 gm^{-3}. At 40 - 50 GHz this value is increased by a factor 2.

For low water vapour concentration the attenuation is assumed to be proportional to the concentration and the influence of the elevation can be taken into account by simply multiplying by the cosecant of the elevation angle, under the hypotheses of a uniformly layered atmosphere.

In high relative humidity conditions the available algorithms given in the literature introduce an under estimation of the attenuation which may reach values up to 2 dB at 50 GHz at relative humidities of some 15 gm^{-3}.

Moreover it should be added that the water vapour concentration has a marked space-time variability which may strongly affect the evaluation, considering that its equivalent height is of only 2.2 kms from the sea level.

The essential input data is the actual value of the water vapour concentration along the path. This information is not widely available.

A first-approximation procedure is that of assuming rough reference values for this parameter and of applying the given algorithm, taking into account the elevation by means of the cosecant law.

For a more precise evaluation, the space-time behaviour of the water vapour concentration is needed. The best way to perform this knowledge appears that of relating the vertical structure to surface climatic parameters, largely available, by means of radiometric and/or radiosonde observations.

As a simple rule it might be assumed that, in the range 30 - 50 GHz, being the contribute of water vapour limited to some 0.1 dB/km, the evaluation of its absorption may be made with rough reference values.

The contribution to attenuation in dry air condition is mainly that of oxygen which shows a noticeable peak around 60 GHz, up to 1 - 2 dB/km.

Its influence may be on the contrary neglected up to 40 GHz.

Considering that the space-time structure of the oxygen concentration is quite constant, also with respect to temperature and pressure, the contribution of oxygen may be calculated as a fixed charge.

7.1. Design indications

The design of lower availability system disregards any impairment effects up to about 1% of the yearly time, during which the small system is accepted to be blind, and considers only those atmospheric factors occurring for 1-5% or even 10% of the time, which are mainly the light rains and the clouds.

The main design factors are the probability of occurrence of each separate phenomenon P_0, and the statistical characteristics of the duration of, and the intervals between, fades of given levels, typically the ones corresponding to the above mentioned percentages of time.

For the rain in particular, information is required according to a double approach: the probability P_{R*} of exceeding a given rain level R*, which gives the outage time of the station, and/or the rain level R_{P*} exceeded for a given percentage of time P*, which represents the effect to face with and, in terms of the corresponding attenuation, the fade margin to be given to the system to achieve the requested availability.

Typical figures of the propagation margins for small business terminals are: 2 dB at 20 GHz - 5 dB at 30 GHz, for 99% availability time.

The analisys worked out from the long term rain data of the strip-charts in Italy shows that those systems planned to operate only in non-rainy conditions are expected to have an availability time of around 95% (P_{0R} = 5%), while systems allowed to have only 1% of outage time must be dimensioned to face rain intensities of some 5 mm/h as an average, with values up to 10 mm/h in the worst month. In terms of attenuation this corresponds to some 2 - 5 dB, depending on frequency, on elevation angle and, to a minor extent, on the polarisation.

The site-to-site variability appears to be very pronounced and the year-to-year variability is more limited (30%): only 3-4 years are required to reach a statistical stability of 10% with respect to the long-term average.

As far as the seasonal variations are concerned, the average value of P_{0R} during the cold season is about two times that of the warm period, 3% and 5% respectively.

Although simple and reasonably accurate, the evaluation of P_{0R} from the strip-charts is not a really cost-effective way for the design of small systems, at least for individual cases.

The possibility of deriving P_{0R} from other readily available standard climatic data has been therefore examined.

The total rainy time can also be computed very easily on a wide basis considering either the number of rainy days N_D, which is given in many archives, or the sequence of rainy hours, also available, from many sources, provided that the relationship, typically the simple ratio between the P_{0R}'s calculated on event, day and hour basis is known.

This linkage has been analyzed but, unfortunately, due to the uncertainty on the actual time allocation of the rainy events during the rainy day/hour, a reliable estimation criteria is not evident, as this ratio shows too pronounced site-to-site and seasonal instability.

A simple prediction may be based however on the duration statistics.
The total yearly rainy time T_{0R} may be obtained as the product of the total number of rainy days in the year N_D, by the average number of rainy events in a day N_{ED}, by the average duration of the rainy events D_E, and the three parameters may be obtained from sources other than the paper records.
As the average daily number of events N_{ED} does not vary significantly both in space and time, it can be easily extracted for a given region from short-term single location rain measurements.
The average duration of the events D_E is the critical parameter that should be assigned to a zone starting from high resolution rain measurements, when available, or from strip-charts observation, limited in this case to few years as the year-to-year variability of D_E is low.
The number of rainy days in a year N_D, normally readily available in many archives on a wide basis, may be used as input parameter for the single site.
When P_{0R} has been calculated according to this procedure the value of P_{R5} can be derived by means of empirical approximating relationships and the corresponding levels of the rain exceeded for given P% of the time, typically 1% and 3%, may be consequentely interpolated.
This procedure allows simple and fast evaluation of the relevant figures of the light rains and gives a first basis for the design of low-margin systems.
As far as the clouds occurrence is of concern, as the time resolution of the traditional clouds data is very poor, one hour in the best cases, the measurements of the time intervals during which the direct radiation of the sun is present have been examined as an indirect information about the presence of clouds with an high time accuracy (some 3 min), allowing a defined description of the temporal behaviour of the presence of clouds.
This approach is equivalent to exchange the coverage fraction of the space with the coverage fraction of the time. Strictly speaking the equivalence, in this case, is not that of a fixed point against the entire emisphere, as the sun moves along a curve. In any case, apart from local micrometeorological effects, likely limited to short periods and seasons, there is no reason why this assumption is not valid, at least on a statistical basis.
Having also in mind the precious information obtained as far as the fades durations are concerned, which are critical for the low-margin systems, the space-time equivalence may be assumed for the clouds coverage.
From the analisys of the data it has been confirmed that, as already known from the meteorological literature, clouds are present for about 50% of the time as an average and up to 70-80% in the worst periods/climates. Clouds attenuation should be therefore faced by communication systems for time percentages one decade higher with respect to the rain phenomena.
Another very noticeable result is that the year-to-year variability appears very low, so that only one year of data can guarantee the time variation being limited within 10%. This means that the statistics of a site may be easily obtained just processing one or two years of data.
Unfortunately this is not true for the site-to-site variability which is higher and does not allow, at least on a simple basis, the characterization of wide regions from single site data.

As mentioned above, the total cloudy time is not the only input figure for such systems, for which the distribution of the durations of the individual events is determinant as well.
The cumulative distribution of the duration of the events 'occurrence of clouds' has been computed according to a double approach : on 'event' basis, where the number of events of a certain duration are considered, and on 'time' basis, where the attention is focussed on the time composed of events of a certain duration.
Both these statistical parameters, distinct but related each other, are of interest, but the first one has, at least in this particular case, a more intuitive interpretation.
It can be noted how the values of the former are lower with respect to the latter : this is due to the occurrence of many shorts events which in the 'event' approach are not weighted according to their duration.
The input design figure may be given by the median value : half of the clouds events last longer than 50 minutes and 5-10% of them exceeds durations of 10 hours.
Considering that the measurements are limited to the hours of the day, it may be concluded that in some 10% of the days the sky is continuously (completely) covered by clouds.
For design purposes it is very noticeable that the distribution of the durations is log-normal.
This allows the estimation of the duration characteristics by means of the parameters of the log-normal approximation: the average duration of events D_E and the standard deviation.
The obtained value from the log-normal approximation for D_E is 83 minutes in fully agreement with that found from the experimental data.
Although these results are limited for Italy, the log-normality is likely to be expectable for any region and the values of the parameters may be fitted equally well since the year-to-year variability keeps very limited.
As well as for the probability of rain P_{0R}, it might be necessary to estimate the probability of presence of clouds P_{0C} also in zones/situations where only standard climatic data are available.
It should be kept in mind that the clouds coverage probability is not as critical as the rain probability and that a first very rough indication may be obtained by simply fixing the average P_{0C} to 50% of the year, varying from 30% in the cold season/zones to 70% in the warm season/zones.
This notwithstanding some evaluation algorithms may be used to better fit the actual figures of the characteristics of clouds occurrence to other climates.
A first way could be that of calculating the P_{0C} on a daily basis by means of the information on the daily cloudiness, which is normaly readily available everywhere, and then correcting the obtained value with the value of the ratio between the P_{0C} on daily basis and the one on event basis, which may be assessed for the locations where more refined data have been processed.
This ratio has been calculated for Italy and can vary from some 1.4 - 1.6 in the coldest continental climate up to 1.8 - 2.1 for maritime zones.

The values and the ranges are quite the same for the cold and the warm season, respectively, as far as the month-to-month variability is concerned.
Although still imprecise a first evaluation may be therefore obtained by simply dividing the P_{0C} calculated from the cloudy days by 1.5 for cold climates/seasons and by 2 for warm climates/seasons.
The advantage of this procedure is that of being fast and easy and, at the same time, tuned on the local climatology.
Obviously more information is required to achieve better accuracies.
Following the same approach as for the rain the total cloudy time may be expressed as the product of the total annual number of cloudy days N_D, by the average number of cloudy events during a day N_{ED}, by the average duration of the cloudy events D_E.
As the former parameter is not exactly defined and considering that only a very small percentage of days is completely without clouds events, N_D can be, in a first approximation step, fixed to 365.
The value of D_E can be calculated from the log-normal approximation and N_{ED} extracted from only one year of refined data on clouds events.
As this latest information is not widely available, a simpler approximation may be introduced by noting that the product of $N_{ED} * D_E$ keeps rather constant at least for homogeneous zones : values around 450 for cold sites/seasons and 350 for the warm sites/seasons have been found for Italy.
Therefore by simply multiplicating this number by 365 and then dividing this product by the total number of minutes of the year (in the case of the present data by the half) the probability of clouds P_{0C} is obtained.
All these procedures, although roughly approximated, can give a first fast indication about the expected degree of cloudiness and, what is more important, the first figures for the durations of the events.

8. Radiometric measurements

Radiometry is a promising technique for sounding the atmosphere components and structure.
For propagation measurement purposes the radiometer is an excellent tool to determine the reference clear-sky level, as its sensivity is very good.
From the atmosphere point of view the radiometer may be considered the best compromise between reliability and accuracy for the determination of the water vapour content and profile, the clouds liquid water content and the temperature profile.
Other advantages of this instrument are that it is more economical with respect to the beacon receiver, that it does not require any transmitted beacon and allows complete long-term statistics of the sky.

Main disadvantages of the radiometer are that it is not reliable for high attenuation values (> 10 dB) and that is a very sensitive instrument, the interpretation and calibration of which is very critical.
The basic principle of the radiometric measurements of attenuation on slant paths is the Kirchhoff law for black body radiation, according to which, for a purely absorbing homogeneous medium of constant temperature, a simple relation exists between attenuation on a path through the medium and the thermal noise generated along that path:

$$T_A = (1 - a)\, T_M + a T_S$$

where:

T_A : noise temperature received by the antenna
T_M : temperature of the medium
a : attenuation coefficient
T_S : sky temperature

In reality, as the medium is neither purely absorbing nor homogeneous and at constant temperature, the definition of an effective T_M should be made for any simultaneous observation of T_S and a in order to determine the attenuation.
This attenuation may also be expressed as the sum of the contributions of oxygen, water vapour and liquid clouds water, as :

$$A = C_0 + C_1 V + C_2 L$$

When at least two frequencies are observed, two of these equations may be written having differents coefficients, provided that the two frequencies are enough different as far as the effects of V and L are of concern.
For the determination of the two water phases content of the atmosphere a dual-channel radiometer should be employed.
Choosing one frequency on one shoulder of the water vapour absorption peak at 22.35 GHz, typically some 21 or 23 GHz, and another frequency at 31 or 36 GHz, two different information can be obtained on the contribution of vapour and liquid water as the first line is sensitive to the water vapour, while the second mostly to the liquid water.
The same criterium is applied in the temperature profilers where some (5 - 8) lines are added in the oxygen inferior shoulder from 52 to 58 GHz, where the oxygen concentration and then absorption is a function of temperature.
By simply inverting the above equation(s) the vapour and liquid contents may be obtained respectively as :

$$V = a_{11} A_1 + a_{12} A_2$$

$$L = a_{21} A_1 + a_{22} A_2$$

where A_1 and A_2 are the attenuations measured at the two frequencies.

9. Satellite propagation experiments

Several experiments have been planned in view of these needs, mostly in Europe with the Olympus satellite, in Japan and in the United States.
To a minor extent, but with even stronger interest, experiments are being prepared also in some tropical countries, where the lack of measured data affects the design of satellite communication systems.
The experimental campaign is here presented organized in Italy by the Istituto Superiore Poste e Telecomunicazioni (ISPT) and the Fondazione Ugo Bordoni (FUB), in the framework of the national satellite communication programs and in co-operation with the similar activity of other groups, for both the Olympus experiment and for the Italian Italsat satellite which will allow even more sophisticated investigations at 40 and 50 GHz. The Olympus propagation experiments in Italy are strictly harmonized with the ESA-ESTEC Olympus propagation program (OPEX).

9.1. Objectives

The radiopropagation experiment has two main objectives. According to a design-oriented approach, the complete knowledge of the statistical characteristics of the radio channel should be performed to improve the existing prediction techniques and the design criteria.
On the other hand model-oriented investigations should be developed on the physics and the mechanisms of the propagation phenomena in the higher frequency bands.
Three main guidelines may be therefore individuated :

- space-time characterization of the rain attenuation
- definition and modelling of the radio channel propagation parameters
- analysis of the structure and the mechanisms of the atmospheric factors

9.2. Experimental set-up

The following set-up will be operative for the ISPT-FUB propagation experiments:

One 'main' receiving station, for high-accuracy measurements of all the aspects of the radio channel behaviour in the three Olympus frequency bands : 12.5, 20 and 30 GHz. Two similar stations will be installed at Spino d'Adda and Torino by CSTS and CSELT, respectively.

Twentyfive 'auxiliary' stations, variously located along Italy, receiving the 20 GHz switched beacon, where a complete characterization of the territory will be performed.

Two radiometers, at 13 GHz and 20-30 GHz (dual-band), plus one portable 20-30 GHz (dual-band) radiometer, this latter dedicated to mobile measurements of both the liquid and vapour water content and profiles.

Two 'minor' receiving 12.5 GHz stations, for both preliminary measurements and site/orbit diversity experiments.

Two 'tropical' stations for the Olympus 12.5 GHz beacon, installed in Nigeria and Brazil in co-operation with the Ile-Ife University and the Cetuc of Rio de Janeiro, respectively.

All the stations will be equipped with standard meteorological sensors and tipping-bucket rain-gauges. Radiosonde soundings will be available at six of the auxiliary stations and direct and indirect measurements of clouds coverage will be performed at the main station.
As far as the Italsat satellite is concerned, three main stations will be installed at the same sites of the Olympus main stations by ISPT-FUB, CSTS and CSELT, respectively. The Italsat propagation experiment is organized to perform similar measurements as for Olympus for frequencies up to 50 GHz, allowing sophisticated investigations on some unknown aspects useful for advanced communication techniques.

9.3. Terminal architecture description.

Main stations

The main stations, for Olympus and Italsat, have the same basic structure.
In particular measurements and recording of the in-phase and in-quadrature components of both the co-polar and cross-polar signals of the satellite beacons will be performed.
The measurements at 19, 40 and 50 GHz with the Italsat propagation payload are similar to those for Olympus at 12,5, 30, and 20 GHz respectively. Moreover Italsat offers the possibility to measure the amplitude and phase distortions suffered by the 40 GHz beacon within a bandwidth of 1 GHz.

Auxiliary stations

The auxiliary earth stations provide for reception of the Olympus beacon at a frequency of 20 GHz, with the possibility of detecting only one (X or Y) of the two orthogonal polarizations, alternatively transmitted by the satellite. The capability is also foreseen of tuning and pointing the Italsat 18.7 GHz beacon.

Tropical and minor stations

The two 'tropical' stations will operate with the Olympus B0 beacon at 12.5 GHz with a 3 mt antenna, allowing more than 30 dB of fade margin and rain rate measurements.
Moreover two 'minor' stations, with 3 mt antenna, are already operating at Roma with the 12.5 GHz Olympus beacon, for preliminary measurements.

Work carried out in the framework of the agreement between Fondazione Ugo Bordoni and the Italian PT Administration.

Radiometers

The 13 GHz and the multifrequency 20-30 GHz radiometers, manufactured by the ElektronikCentralen of Denmark, are of the noise-balancing type and provide equal beamwidths at the three frequencies, very low antenna sidelobes and automatic calibration and antenna pointing control by dedicated PC system.

The dual-channel 20-30 GHz transportable radiometer, supplied by the Radiometric Corporation (CO, USA), can provide measurements of both the total precipitable and liquid atmospheric water content in a fast and flexible way. Calibration and antenna pointing is controlled by a dedicated PC system, as well.

9.4. Themes of analysis.

Rain attenuation

The complete and detailed characterization of the territory, as far as the 20 GHz band is concerned, is one of the major output of the experiment for communication applications. The rain attenuation cumulative distribution will be provided for the various microclimates for a time period (5-7 years) sufficiently significant to characterize the year-to-year variability.

Due to the simultaneous rainfall measurements the attenuation prediction techniques from point rain data will be tested and possibly refined, also establishing the influence of any different climatic and regional factor.

Long-term frequency scaling will be also investigated as a tool for rain attenuation prediction from attenuation data, from 12.5 to 30 GHz and even to 50 GHz with the Italsat beacons, also allowing the characterization up to 30-50 GHz for 25 locations.

Fading dynamic features

The statistics of the durations of both excess and recurrence events for any attenuation level will be available for different frequencies and for several sites. The intrinsic dynamic behaviour of the fades will be analyzed in details with the associated increasing and decreasing slopes, to derive indications for a rational assignment of the outage time to the 'system availability' or to the 'signal quality' design criteria.

The high frequency sampling facilities (up to 100 Hz) and the use of radiometers and upper-air soundings, will also allow the analysis of the fast atmospheric phenomena in both clear air and rainy conditions.

Fading countermeasures

The feasibility and the parameters of the up-path power control technique will be studied both by the simultaneous sampling of more channels, typically 20 and 30 GHz, and applying the short-term frequency scaling technique to the stations where only the 20 GHz channel is received.

The advantages of short scale site diversity will be analyzed at both 12.5 GHz and at 20 GHz for the entire period of the experiment, as well.

The simultaneous data from 25 auxiliary stations will also give the opportunity of a further refinement of the spatial large scale correlation of fading phenomena and an exhaustive definition of the design criteria for the on-board real time allocation of resources will be made.

Orbit diversity measurements will be also possible by converting one of the two 12.5 GHz minor receivers to the ECS 11.4 GHz beacon.

Cross-polarization

To investigate on the interference between two orthogonally polarized isofrequential signals propagation experiments are planned at 20 GHz with Olympus and at 50 GHz with Italsat to allow a complete characterization of the electromagnetic channel transfer function by measuring amplitude and phase of the copolar and crosspolar components.

Radiometeorological studies

Careful attention will be dedicated to the structural characteristics of the rain with particular regard to the long lasting stratiform rainfalls which become critical for the very high frequencies. Joint measurements from raingauges, beacons, radiosonde and zenith-looking radiometers will furnish a unique chance for investigating both the physical and effective rain heights in various meteorological conditions. In order to define the design parameters of low-margin small business systems, investigations will be carried on about the structure and the effects of both clouds and water vapour. Radiometers, radiosonde and dedicated optical instrumentation will be employed to this aim, supported by a large amount of standard meteorological observations.

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