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Digital Video Broadcasting (DVB); LMDS Base Station and User Terminal Implementation Guidelines for ETSI EN 301 199

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Foreword

This Technical Report (TR) has been produced by Joint Technical Committee (JTC) Broadcast of the European Broadcasting Union (EBU), Comité Européen de Normalisation ELECtrotechnique (CENELEC) and the European Telecommunications Standards Institute (ETSI).

NOTE: The EBU/ETSI JTC Broadcast was established in 1990 to co-ordinate the drafting of standards in the specific field of broadcasting and related fields. Since 1995 the JTC Broadcast became a tripartite body by including in the Memorandum of Understanding also CENELEC, which is responsible for the standardization of radio and television receivers. The EBU is a professional association of broadcasting organizations whose work includes the co-ordination of its members' activities in the technical, legal, programme-making and programme-exchange domains. The EBU has active members in about 60 countries in the European broadcasting area; its headquarters is in Geneva.

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Founded in September 1993, the DVB Project is a market-led consortium of public and private sector organizations in the television industry. Its aim is to establish the framework for the introduction of MPEG-2 based digital television services. Now comprising over 200 organizations from more than 25 countries around the world, DVB fosters market-led systems, which meet the real needs, and economic circumstances, of the consumer electronics and the broadcast industry.

Introduction

LMDS as a system concept is also well-known under the expressions of "Wireless Cable", "MWS" (Multimedia Wireless Systems") and "Last Mile Distribution System". It is important to state here that LMDS shall in many cases be an extension to:

- Satellite
- Cable
- Terrestrial
- Data & Internet service
- Distribution paths

In the present document the focus is mainly on the 40 GHz range and thus in a certain sense LMDS is an extension to the RF layer of EN 301 199 [1a].

Return channels are also a planned item herein.

The capacity and number of today's satellite, cable and terrestrial network segments is increasing rapidly which will surely have its influence on the LMDS scenario. At present the resource as a whole is shared with analogue services but it is sensible to expect in future that these services will have to make way for digital ones. It is improbable that adjacent frequency resources that become free due to MPEG compression are simply given up but rather they are filled with other digital services and TV programs.

The principle structure of an LMDS cell is shown in the following drawing:

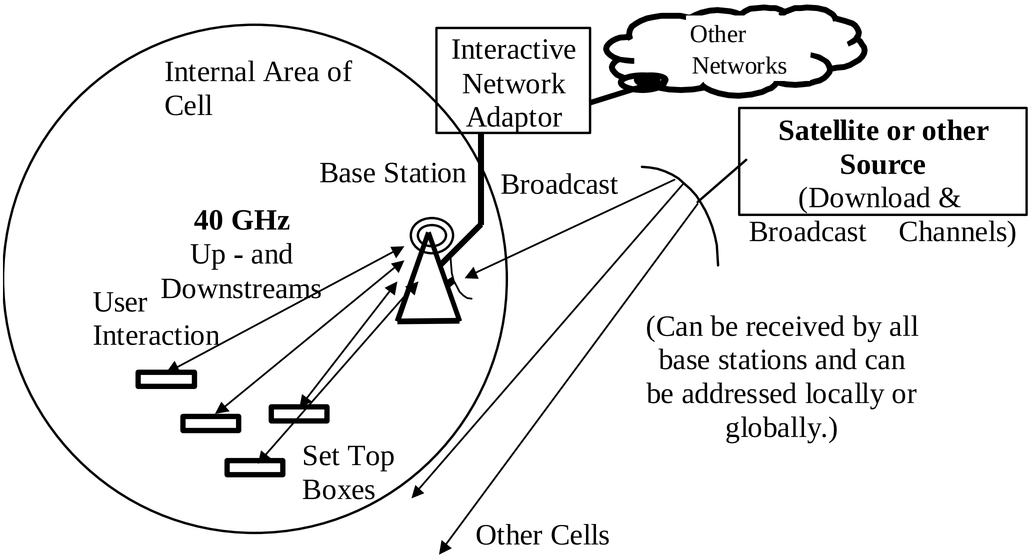

Figure 1: Principle Cell Structure (without Topology Aspects)

Essential elements of this scenario are the base station providing broadcasting as well as interaction features and the user terminals (Set Top Boxes). Both types of equipment are transmitters as well as receivers of low power radiation related to one frequency carrier.

Thus in the present document a main emphasis is laid upon power and frequency resources. Also the use of modulation is seen to be a fixed parameter.

The **protocol layer** is **not** fixed in the present document. For this refer to the DVB LMDS document EN 301 199 [1a] which also defines the possible data throughputs for the interactive channels. However some part of the spectrum occupation will be the re-broadcast of MPEG compressed television signals to which the return channel resource will be tailored as a result.

1 Scope

The goal of the present document is to give operators and manufacturers suitable advice for enabling practical operation of LMDS hardware equipment, planning antenna systems and geographical propagation.

2 References

For the purposes of this Technical Report (TR), the following references apply:

[1] ETSI EN 300 421: "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for 11/12 GHz satellite services".

[1a] ETSI EN 301 199 (V1.2.1): "Digital Video Broadcasting (DVB); Interaction channel for Local Multi-point Distribution Systems (LMDS)".

[2] Electronics & Communication Engineering Journal, April 1997: "Characterization of propagation in 60 GHz radio channels" by P.F.M. Smulders and L.M. Correia.

[3] H. Zuhrt: "Elektromagnetische Strahlungsfelder, Springer - Verlag".

[4] ITU Radio Regulations/Revised Edition 1994.

[5] DIN VDE 0848: "Sicherheit in elektrischen, magnetischen und elektromagnetischen Feldern", Teile 1 und 2.

[6] G. Matthaei, L.Young, E.M.T. Jones: "Microwave Filters, Impedance-Matching Networks, And Coupling Structures" Artech House Microwave Library Inc. Norwood.

[7] ETSI EN 300 429: "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for cable systems".

[8] ETSI ES 200 800: "Digital Video Broadcasting (DVB); DVB interaction channel for Cable TV distribution systems (CATV)".

[9] CEPT/ERC/REC 13-04: "Preferred frequency bands for fixed wireless access in the frequency range between 3 and 29.5 GHz".

3 Abbreviations

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

AGC Automatic Gain Control
AWGN Additive White Gaussian Noise
BWS Broadband Wireless Systems
DTH Direct-To-Home
EIRP Effective Isotropic Radiated Power
GPS Global Positioning System
LMDS Local Multipoint Distribution System
LNA Low Noise Amplifier
MWS Multimedia Wireless Systems
NVoD Near Video on Demand (= Time shifted equal contents)

4 Actual and Future Relations between LMDS and other Network Scenarios

4.1 Satellite Segments as an example

Nowadays the best-known satellite systems for TV transmission are the so-called geo-stationary satellite networks permitting the simple DTH distribution by using a 60 cm dish antenna for multi-program reception. The dominating frequency band is the so-called Ku band (10,7 GHz to 12,75 GHz down link) in Europe. Usual satellite segments are operating within this resource. These systems have similar transponder carrier positions and also the usable bandwidth is in most cases the same. Frequency re-use is achieved in a simple way by polarization and the directivity of the receive antenna.

It is reasonable to expect that the number of satellite systems will increase rather than decrease in addition to the fact that new multi media applications will occupy a part of the whole satellite scenario with the consequence that the terrestrial last-mile scenario has to cope with this.

E.g. the useful bit-rate I per transponder is given by:

$$I = R_{Sy} \times 2 \times \frac{n}{m} \times \frac{188}{204}$$

with R_{Sy} being the symbol rate, n/m depicting the convolutional code rate and 188/204 being the Reed-Solomon code rate in EN 300 421 [1] (DVB-SAT).

E.g. if the convolutional code rate is set to 3/4 and the symbol rate is 27,5 MSy/s we obtain a useful bit-rate of 38 Mbit/s.

4.2 CATV Networks as an example

CATV networks are determined by the QAM modulation in TV and by the in-band down-streams. This has to be noted when supplying the last mile with cable born contents. The frequency resource occupies approximately 800 MHz. The scenario of re-modulating satellite channels to cable is well-known and is done at IF. Thus no additional exotic equipment but rather truly off-the-shelf re-modulators can be implemented.

E.g. the bit-rate for an in-band downstream and QAM is given by:

$$I = R_{Sy} \times ld(M) \times \frac{188}{204}$$

with R_{Sy} again being the symbol rate. Now ld(m) expresses the number of bits used by an M-ary QAM alphabet (EN 300 429 [7] applies in this case). E.g. the symbol rate is given with 6,95 MSy/s (in an 8 MHz CATV channel) and the constellation shall be 64 QAM we also obtain a useful bit-rate of 38 Mbit/s.

Thus a satellite channel like above can be re-modulated into this CATV channel or, similarly this cable downstream channel can be re-modulated into an LMDS embedded downstream of 27,5 MSy/s.

4.3 Terrestrial Networks as an example

Terrestrial digital TV networks are operated using the so-called COFDM on-air. Despite this the "last mile" is bridged in most cases by the terrestrial service itself and situations are imaginable which require a re-modulation to LMDS.

E.g. the bit-rate for terrestrial TV channels is given by:

$$R_U = R_s \times b \times CR_{CONV} \times CR_{RS} \times \frac{T_U}{T_S}$$

with:

R_u: The useful net data rate (Mbit/s);

R_S: The symbol rate;

b: The number of bits per subcarrier;

CR_{CONV}: The inner (convolutional) code rate;

CR_{RS}: The outer (Reed-Solomon) code rate, 188/204 = 0,9216;

T_U: The duration of the useful symbol part;

T_s: The entire symbol duration, including guard interval.

E.g. if the symbol rate is 6,75 MSy/s (fitting into one 8 MHz UHF channel), the convolutional code rate is 3/4 , the modulation is QAM (4 bits/subcarrier) we obtain a useful net bit rate of 14,93 Mbit/s**.**

The maximum possible DVB-T data rate is at 64 QAM, CR_{CONV} = 7/8 and a guard interval of 1/32 indicated with 31,67 Mbit/s. In this maximum case one LMDS channel of e.g. 38 Mbit/s is filled with exactly one DVB-T channel. But due to the bad link budget for DVB-T this is expected to occur very seldom.

On the other hand, the minimum DVB-T data rate can be at CR_{CONV} = 1/2, QPSK modulation and a guard interval of 1/4 indicated with 4,98 Mbit/s.

This means that the LMDS modulation scheme is wide enough also to contain one or more DVB-T channels within one of its channels.

5 Use of the LMDS Spectral Resource

5.1 Capacity Comparison of the different Services

As described above the re–broadcast satellite or cable or terrestrial born TV channels would previously dominate the resource use. On the other hand the user of the last mile system really does not want a separate satellite antenna incorporating additional switching – and maintenance problems. Additionally the realization of interaction would become rather complicated.

This means as a consequence that re-broadcasting will be a basic element of the last-mile scenario even when, at first, interaction is not demanded (MVDS).

First, as an example, a possible bandwidth application is demonstrated which is possible to become a main candidate also for the last mile scenario.

5.1.1 Re - Broadcasting of a first satellite space segment

Low Band (SUBSEG. 1D – 1B) H – Polar: 10,7 ... 11,7 GHz, sum: 1 GHz,

Low Band (SUBSEG. 1D – 1B) V – Polar: 10,7 ... 11,7 GHz, sum: 1 GHz,

Sum: 2 GHz

High Band (SUBSEG. 1E – 1G) H – Polar: 11,7 ... 12,75 GHz, sum: 1 GHz,

High Band (SUBSEG. 1E – 1G) V – Polar: 11,7 ... 12,75 GHz, sum: 1 GHz,

Sum: 2 GHz

As a whole: 4 GHz

5.1.2 Re - Broadcasting of a second space segment

Low Band (SAT type 1,2,4, SUBSEGMENT I/II) H – Polar: 10,7 ... 11,7 GHz, sum: 1 GHz,

Low Band (SAT type 1,2,4, SUBSEGMENT I/II) V – Polar: 10,7 ... 11,7 GHz, sum: 1 GHz,

High Band (SAT type 2,3,4, SUBSEGMENT I) H – Polar: 11,7 ... 12,75 GHz, sum: 1 GHz,

High Band (SAT type 2,3,4, SUBSEGMENT I) V – Polar: 11,7 ... 12,75 GHz, sum: 1 GHz,

As a whole: 4 GHz

This means, that if today's satellite space segments are reproduced by LMDS one would obtain 2 GHz per segment and polarization. However, the problem is now being discussed at the European regulation offices to extend the range of 40,5 GHz - 42,5 GHz to 43,5 GHz. This could, as one scenario, enable one full satellite segment re-broadcasting together with return channels for a sufficient number of subscribers.

Table 1 shows an example of simulcasting a satellite transponder ("Backhaul Source", German Content) which is after transconversion laid upon one of the 40 GHz downstream channels. In this case the transponder "65" is alternatively shared by NVoD services and car race events ("Formel 1 Konfiguration") consuming certain highlighted bit rates. The NVoD services consist of time-shifted videos (feed 1 to 5) with 4,22 Mbit/s, the car race contents reveal different views of the race scenery like "Supersignal" (= Overview), "Cockpit" etc. with less compressed (5,44 Mbit/s) pictures. Tables like "Renndaten" (= race results) only carry very slow motion contents and are compressed to 2,44 Mbit/s. It is clearly shown that the whole data transport stream composes up to 38 Mbit/s at a convolutional FEC of 3/4 and a symbol rate of 27,5 Msy/s including Operating System Downloads for different set top boxes and data overheads for System Information (SI) and, optionally, Conditional Access (CA). In both cases a residual bandwidth ("Restbandbreite") is open for additional service insertion, intermediately filled with stuffing bytes.

Table 1: Satellite Re-Broadcast

<table>
<tr><th>SATELLITE</th><th>TRANSPONDER</th><th>SERVICE</th><th>Provider</th><th>Bit Rates</th></tr>
<tr><td rowspan="20">ASTRA 1E
(Backhaul
Source)</td><td rowspan="10">65
Down-Link
Frequency
11,7195 GHz

Polarization: II
Symbol Rate:
27,5 Msy/s
FEC: 3/4</td><td>DSF Plus</td><td>Provider A</td><td>6,72 Mbit/s</td></tr>
<tr><td>NvoD feed 1</td><td>Provider A</td><td>4,22 Mbit/s</td></tr>
<tr><td>NvoD feed 2</td><td>Provider A</td><td>4,22 Mbit/s</td></tr>
<tr><td>NvoD feed 3</td><td>Provider A</td><td>4,22 Mbit/s</td></tr>
<tr><td>NvoD feed 4 (ab 1.11. Option f. 2. Stereokanal)</td><td>Provider A</td><td>4,22 Mbit/s
(4,44 Mbit/s)</td></tr>
<tr><td>NvoD feed 5</td><td>Provider A</td><td>4,22 Mbit/s</td></tr>
<tr><td>Daten – Overhead (SI/CA)</td><td>Provider A</td><td>5,0 Mbit/s</td></tr>
<tr><td>OS-Download 1/1 u. 2/3 QAM (Kabel)</td><td>Provider A</td><td>0,6 Mbit/s</td></tr>
<tr><td>Restbandbreite</td><td>Provider A</td><td>4,58 Mbit/s
(4,36 Mbit/s)</td></tr>
<tr><td>Summe:</td><td></td><td>38 Mbit/s</td></tr>
<tr><td rowspan="10">65

Formel I
Konfiguration</td><td>Supersignal</td><td>Provider B</td><td>6,94 Mbit/s</td></tr>
<tr><td>Verfolgerfeld</td><td>Provider B</td><td>5,44 Mbit/s</td></tr>
<tr><td>Cockpit</td><td>Provider B</td><td>5,44 Mbit/s</td></tr>
<tr><td>Boxengasse/Höhepunkte</td><td>Provider B</td><td>5,44 Mbit/s</td></tr>
<tr><td>Renndaten</td><td>Provider B</td><td>2,44 Mbit/s</td></tr>
<tr><td>Multisignal</td><td>Provider B</td><td>5,44 Mbit/s</td></tr>
<tr><td>Daten – Overhead (SI/CA)</td><td>Provider B</td><td>5,0 Mbit/s</td></tr>
<tr><td>OS-Download 1/1 u. 2/3 QAM (Kabel)</td><td>Provider B</td><td>0,6 Mbit/s</td></tr>
<tr><td>Restbandbreite</td><td>Provider B</td><td>1,26 Mbit/s</td></tr>
<tr><td>Summe:</td><td></td><td>38 Mbit/s</td></tr>
</table>

Thus an LMDS base station can act as a satellite-like device providing the transmission service for different providers by using a plenty of backhaul sources.

5.2 Bandwidth On-Demand

Another possible spectrum use may be the broadcast of content to a user individually.

This option is feasible because of the frequency re-use from one cell to another: the goal of this mode may be to use the resource most efficiently when e.g. contents being demanded very seldom can be transmitted via an individual small-bandwidth carrier instead of broadcasting the content to everybody. The remaining resource can then be used for other applications to provide contents.

For this either individually a server is necessary in the base station or the content is downloaded e.g. during night time slowly from remote.

Not included in this mode is content which has acceptance in the mass market i.e. when a large group of customers watches a famous film. In this case it is more efficient to give the event a common starting time i.e. a broadcast mode in the conventional sense. Also NVOD (Near Video On Demand) can then be used occupying a reasonable amount of spectrum.

5.3 The Implementation of Return Channels for User Interaction

The implementation of return channels goes ahead with the worldwide trend for multimedia applications. At the present time when the present document is being laid out the situation is that certain return channel concepts exist. E.g. the cable return channel referred to ES 200 800 [8] is completely defined. Other concepts as e.g. the Satellite Return Channel are under work. ADSL is also a technique being promoted by some telcos but warnings concerning the electromagnetic impairments to the environment are being voiced. Thus, also LMDS must be tailored to this, expecting a large amount of user terminals and data throughput and with this, resource bandwidth.

A specific statement about exact applications and numbers cannot be made at the present time, but it is certain that interactive traffic will be much more than only a "call from the user" to demand e.g. a film via a voice channel. Some examples of more wideband applications to be expected are:

- Video real time interaction.
- Data download for entertainment purposes with customer friendly loading times.
- Internet like applications with good real time behaviour.

More similar applications are possible.

The interaction process from the base station's site can appear either as a part of the broadcast downstreams, which is often referred to as embedded interaction, or as a separate radiated message called non-embedded interaction.

Regardless of the progress being made in video compression techniques there will always be:

- A limit for the reduction of picture data,
- an immediate filling of resources by new services or subscribers being freed by additional compression capability.

This shows that the return channel resource should be planned generously and with a certain future proof ness.

6 LMDS Channel Use

6.1 Modulation and Channel Coding

MWS is a term associated with the pan-European band of 40,5 GHz ... 43,5 GHz. In concept it is similar to the earlier term LMDS which applies specifically to the US scenario being sited at 28 GHz ... 30 GHz.

The first interest when exploiting a new spectral resource in the sense of MWS (Multimedia Wireless Systems) is compatibility to existing technology to keep the additional effort and costs for carrier translation and re-modulation small.

Further a balanced quality and availability shall be envisaged for both forward and return path.

In a certain sense this is guaranteed when it is referred to DVB compliant signal generation and distribution. This is technically given and well approved for the DVB systems below 40 GHz as described in EN 300 421 [1].

In the present document it shall also be recommended for 40 GHz applications.

6.1.1 Channel Characteristics at 40 GHz

To decide on a modulation system it is noted that at 40 GHz nearly Gaussian propagation characteristics are to be expected. This is due to the granularity of surfaces which in most cases are coarser than the order of wavelength (7 mm). Thus all reflections will have strong attenuation while the direct path has to be without obstruction since even refractions at borders are not significant (the strict directivity of user terminal antennas included in consideration).

In addition a strong atmospheric attenuation compared to lower terrestrial frequency applications has to be expected. Thus significantly less multipath effects as well as true line-of-sight operation can be spoken of.

The Gaussian characteristic makes it similar to a satellite channel and implies the use of the DVB-S codec for broadcast. The only significant difference is that one has to envisage the enhanced thermal noise caused by the lower elevation of user and base station antennas in some cases. Thus e.g. QAM as used in CATV is not recommended due to the link budget.

The following specifications are recommended for coding and modulation:

- EN 300 421 [1]
- EN 301 199 [1a]

Today the specification EN 300 421 [1] is widely applied standard via worldwide space segments. A special property is the low C/N (carrier-to-noise ratio) being applicable to the system within AWGN (Additive White Gaussian Noise) channels, based on the implementation of a so-called convolutional codec incorporating a VITERBI Decoder at the receiver site for extracting the signal out of a noisy environment. A second facility, the so-called puncturing, enables the codec to adopt its error correction performance to the channel quality status.

In clause 7.2 a link budget calculation will be presented as being the basis for determining the transmit power for achieving a sufficient C/N.

6.2 Definition of a Possible Spectrum Structure

6.2.1 The First Way To Exploit the Resource at 40 GHz

The present document proposes operation in the 40,5 GHz ... 43,5 GHz range.

Spectrum allocation at 40 GHz means the on one hand a most optimum exploitation of the resource and on the other hand technical feasibility in terms of bi-directional channelization equipment. In the present document two possible kinds of spectrum structure are introduced allowing operation in 40,5 GHz ... 43,5 GHz range.

The first one is designed with the goal of keeping the frequency bands for up and downstreams consistent and reducing the guard bands to a minimum according to possible future technology. The symbol rate is supposed to be a variable for optimum tailoring of operation to actual demand.

Further QPSK modulation is envisaged with either differential or non-differential mapping, because this kind of modulation is:

- intrinsically bandlimited;
- of high characteristic bandwidth efficiency of 2 bit/(s x Hz);
- suitable for quasi-Gaussian channels as is the case at 40 GHz.

With a variable symbol rate, i.e. for wideband as well as for narrowband applications the spectrum allocation up to 43,5 GHz can be specified as shown in figure 1a (Frequency Raster see annex A).

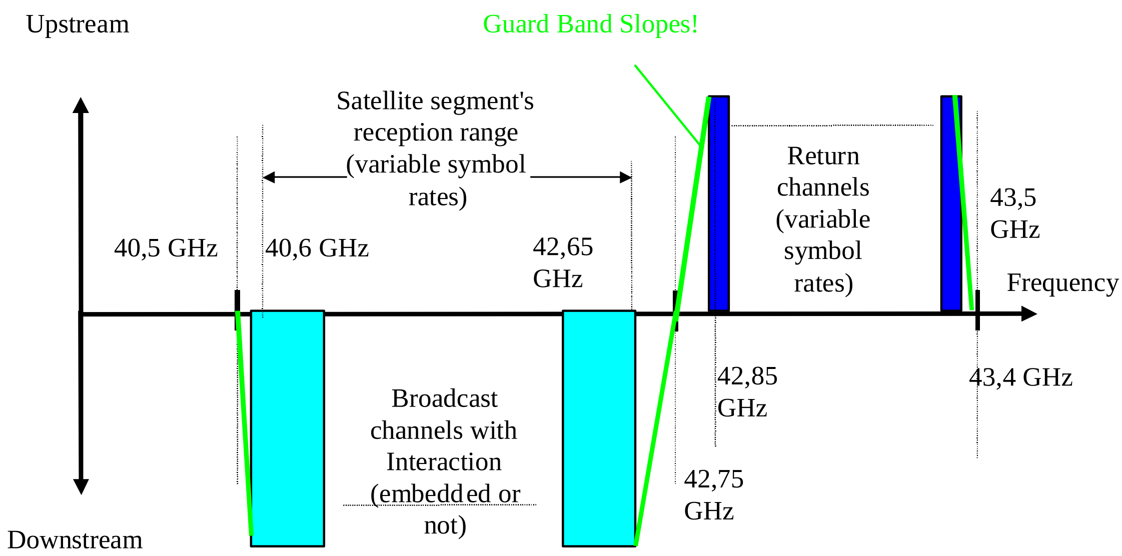

Figure 1a: First Proposal: Use of Actual Resource for LMDS up to 43,5 GHz

For the sake of understanding the spectrum with customer direction "Downstreams" are drawn upside-down.

Broadcast & Interaction (Downstream): 1 x 2,05 GHz = 2,05 GHz,

Return channels (Upstream): 1 x 550 MHz = 550 MHz.

Overhead:

Centre guard bands: 1 x 200 MHz = 200 MHz

Border guard bands: 2 x 100 MHz = 200 MHz

The equipment shall be able to accept spectrum in the RF layer in the inverted or non-inverted form.

6.2.2 Alternative Use of the Resource

As was explained in clause 4, the re-broadcast of satellite segments will be a possible contribution to spectrum use.

The number of return channels will also increase (e.g. by the growing implementation of telephony) with the consequence that there must be found a sufficient compromise between broadcast and interactivity aspects.

Thus the following structural alternative shall be proposed (figure 2):

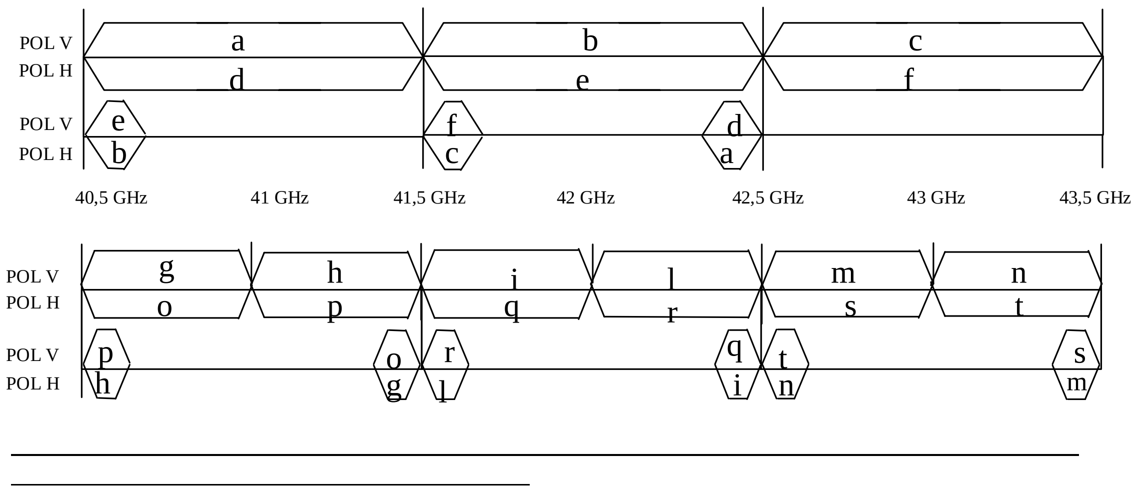

Figure 2: Alternative Spectrum for LMDS Respecting the Future Use of Interaction/Broadcast up to 43,5 GHz

The spectral resource displayed here shows up the following bands:

Table 2: 40 GHz Frequency Plan Proposal - Wide Bands

SERVICES	DOWNSTREAM		UPSTREAM		T/R SPACING (MHz)
	Frequency (GHz)	POL.	Frequency (GHz)	POL.	
WIDE BAND CH.					
Sub-Band a	40,5 – 41,48	V	42,3 – 42,5	H	820
Sub-Band b	41,5 – 42,48	V	40,5 – 40,7	H	800
Sub-Band c	42,5 – 43,48	V	41,5 – 41,7	H	800
Sub-Band d	40,5 – 41,48	H	42,3 – 42,5	V	820
Sub-Band e	41,5 – 42,48	H	40,5 – 40,7	V	800
Sub-Band f	42,5 – 43,48	H	41,5 – 41,7	V	800

Table 3: 40 GHz Frequency Plan Proposal - Narrow Bands

SERVICES	DOWN-STREAM		UP-STREAM		T/R SPACING (MHz)
	Frequency (GHz)	POL.	Frequency (GHz)	POL.	
NARROW BAND CH.					
Sub-Band g	40,5 – 40,99	V	41,4 – 41,5	H	410
Sub-Band h	41 – 41,49	V	40,5 – 40,6	H	400
Sub-Band i	41,5 – 41,99	V	42,4 – 42,5	H	410
Sub-Band l	42 – 42,49	V	41,5 – 41,6	H	400
Sub-Band m	42,5 – 42,99	V	43,4 – 43,5	H	410
Sub-Band n	43 – 43,49	V	42,5 – 42,6	H	400
Sub-Band o	40,5 – 40,99	H	41,4 – 41,5	V	410
Sub-Band p	41 – 41,49	H	40,5 – 40,6	V	400
Sub-Band q	41,5 – 41,99	H	42,4 – 42,5	V	410
Sub-Band r	42 – 42,49	H	41,5 – 41,6	V	400
Sub-Band s	42,5 – 42,99	H	43,4 – 43,5	V	410
Sub-Band t	43 – 43,49	H	42,5 – 42,6	V	400

6.2.3 Other RF Resources

Besides the 40,5 GHz – 43,5 GHz (MWS) range there also exist some older and already regulated so-called FWA (Fixed Wireless Access) ranges. These ranges consist of the following resources and are covered by CEPT/ERC Recommendation 13-04 [9]:

3,4 GHz – 3,6 GHz, [Together with mobile services, fixed satellite and amateur radio]

10,15 GHz – 10,3 GHz, [Together with mobile services and amateur radio]

10,5 GHz – 10,65 GHz, [Together with radio astronomy, mobile, earth satellite (passive) space research]

24,5 GHz – 26,5 GHz, [Together with mobile, inter-satellite]

27,5 GHz – 29,5 GHz. [Together with earth exploration-satellite (space-to-Earth)]

The characteristic of these resources is that many CEPT countries have already granted licenses or are planning to do so. The problem with this is that in some countries there are other primary services operated in parallel which means that in case of interferences MWS is not or only hardly possible.

Thus we take the opportunity here to recommend an operation in the 40 GHz range which is only used by radio astronomers in parallel.

6.2.4 Mesh Systems

In parallel to the point-to multipoint structure which is the main structural subject being discussed in the present document there are coming up so-called "meshed systems" with a more de-central network organization.

These structures comprise point-to-point microwave links between "Nodes" at customer premises, forming a distributed network. Traffic routing through the radio network has to employ a TCP/IP or ATM transport platform and thus it is no longer a broadcasting network. Broadcast tasks have in this scenario to be performed by addressing the customer on-demand like it is the case in the internet. It is expected that the effort for routing higher bit rates through this network will be somewhat higher than in the point-to multipoint system, because in a meshed system the data stream must pass through a plenty of customer nodes with the consequence that a high reliability is required at each of these nodes.

The Mesh network architecture requires a novel form of multi-directional antenna array at each radio node. Designs for switched arrays and steerable arrays have to be developed.

Concerning EN 301 199 [1a] the protocol layer must be widely modified when the transition and/or adoption of this specification to meshed networks is focused upon.

Thus, in the present document, it can only be stated that the radio link budget becomes much more simple since point-to-point links are on the one hand in most cases shorter than in the point-to-multipoint case and on the other hand the antennas are of an equal structure of construction on both sides, i.e. they will previously have equal gains and directional diagrams at lower radiation powers.

However, the advantage of meshed systems can be found in the more flexible and redundant routing procedure but a disadvantage obviously will be the overall link delay due to the repetitive demodulation/processing/remodulation at each node. Another aspect might be that each node comes up as a kind of bottleneck if several broadband data streams are routed in parallel. Thus the "broadband" wireless access may be in a certain sense limited in such systems compared to the central system with the base station transmitting e.g. a plenty of broadband streams in parallel to many users.

7 Propagation Parameters and Cell Size

The purpose of this clause is to prove the parameters of these guidelines by physical and mathematical models and/or to support them by measurement and experiences. In the case of LMDS this is urgently indicated, first because it is a wireless system and second because it shall have despite this a defined reach. Thus it is not only the interest of the local regulating offices but also of the provider to ensure an interference free signal distribution.

7.1 The Propagation of Millimetric Waves

7.1.1 Atmospherical Attenuation

From the physical point of view millimetric waves behave in vacuum like every other electromagnetic radiation i.e. the power flux density is given by the so-called Poynting Vector (W/m^2).

$$\underline{S} = \underline{E} \times \underline{H}$$

This power flux density is given by the vector product of electric and magnetic field vectors and thus reaches a maximum in case of mutual orthogonality when far field distance is reached. This condition is approximately fulfilled in the so-called distant field area R_F which is approximately calculated for specular antennas by:

$$R_F = 2\, D^2/\lambda$$

with D being the aperture width of the antenna and λ being the wavelength.

If e.g. D = 10 λ the distant field area begins at 200 λ.

Thus at a wavelength of 7,5 mm (40 GHz), and using a specular antenna with a diameter of 7,5 cm, we expect the distant field area beginning at 1,5 m, i.e. from this distance the radiated wave behaves like being yielded by a spherical radiator.

For the vacuum case this means a dependence on the distance r by the following law assumed that a sufficient height of the antenna above ground is used:

$$S = \frac{P \times G}{4\pi \times r^2}$$

where the product $P \cdot G$ is called EIRP (Effective Isotropic Radiated Power) because of the virtual isotropic decrease.

In atmosphere the propagation can normally be calculated similar to the vacuum case when using frequencies in the UHF range (note that reflections/refractions must then be taken into account!). In the range of several tens of GHz a certain atmospheric attenuation has to be part of the calculation.

From the satellite communication world there exist valid and well-known tables and diagrams of parameters on propagation which can be used for short slant paths through the atmosphere as e.g. occur within LMDS.

Diagram 3 shows a diagram for a frequency range running from 10 GHz to 1 000 THz with three essential marks (black dots):

- A loss of 0,2 dB/km for an arid atmosphere

- A loss of 7 dB/km for medium precipitation (25 mm/h)
- A loss of 30 dB/km for very strong precipitation (150 mm/h)

It is very clear that the propagation loss can vary on a large range dependent on the actual weather conditions.

When expressed by the equation the propagation loss shows up as an additional dependence on distance as an exponent in the denominator.

$$S = \frac{P \times G}{4\pi \times r^2} \times \frac{1}{10^{r \times (7+0,2) dB / 10km}}$$

with r being inserted with the unit "km".

In this equation the medium precipitation (7 dB/km) has been chosen (as an example) together with the arid atmosphere propagation (0,2 dB/km), which in each case must be taken into account in terms of a basic exponent offset.

Thus the law of propagation now has an exponent characteristic that dominates the free space loss, begins from a certain distance and overrides the squared decrease significantly.

Diagram 2 shows the propagation characteristics of S referred to the equation above for different rain attenuations. Two properties are highlighted very clearly. First the steepness converges for small distances towards the $1/r^2$ characteristic according to a 6 dB per duplication of distance. Secondly the exponent decrease begins to dominate at a distance of approximately 1 km.

In clause 7.2 the figures are treated in somewhat more detail when the link budget is explained.

However on this occasion it shall be anticipated that the signal level of 30 dBpW/m^2 (= 1 nW/m^2) is the flux density necessary for 1 km coverage at 15 dB rain attenuation. It is an interesting fact that a decrease of the rain attenuation by e.g. 5 dB from 15 dB to 10 dB does not really yield a dramatic change in gain in distance as one could expect. The signal level has again decreased to the limit after some hundred metres. Thus the expression "wireless cable" is really true. This can be verified by comparing the curves with a cable or waveguide characteristic that decreases also by N dB/m which corresponds to an exponent decrease in the linear notation! (see diagram 2).

Nevertheless it is recommended that the base station as well as the user terminals power is controlled to avoid interference with adjacent LMDS cells!

This power control may be performed by continuously measuring the flux density or the C/N at the worst case remote location where users are established. All other cell locations are then covered by stronger signals and treated by the AGC (Automatic Gain Control) of the user terminals.

From diagram 2. it can be clearly derived that the AGC of the user terminal reception front end shall cover a gain variation range of 60 dB to cope with all signal levels occurring in an LMDS cell.

7.1.2 Reflection/Refraction

Reflections and refractions of waves at an obstacle result in unwanted impairments due to multipath reception. These effects act like comb filter characteristics (selective fading) when exceeding a certain magnitude. In this case the channel modelling must be drastically changed from a Gaussian to a Rice or Rayleigh one. However, it is shown here that in most cases Gaussian modelling is valid for the 40 GHz ranges.

Since many activities are ongoing in the 40 GHz range and higher there exist some investigations into propagation. An example is given [2]. The main difference in propagation between the 60 GHz and the 40 GHz ranges is that at 40 GHz no oxygen absorption is observed. The other properties as e.g. rain attenuation and refractional/reflectional behaviour are nearly the same.

It was attempted to build physical and mathematical models for the distance - dependent decrease showing that there exists (without rain attenuation) a theoretical breakpoint distance given by:

$$d_{bp} = 4\, h_t h_r / \lambda$$

where:

h = Antenna height (transmit or receive); and

λ = Wavelength

Beyond this distance the decrease runs as the fourth power of the radius. This is supposed to be caused by multipath propagation mechanisms.

If e.g. d_{bp} is calculated for 40 GHz (7,5 mm), a distance value of 4,8 km is obtained when the reception antenna height is set to 1,8 m and the transmission antenna height is 5 m. On the other hand it is shown in the link budget that quite different causes (rain attenuation) forbid a cell radius being significantly greater than 1 km. Thus within this distance the $1/r^2$ law is obviously dominating as for the vacuum case, added to by certain atmospheric attenuation laws, if sufficient antenna heights are assumed.

Further it is reported that diffuse reflections as e.g. are caused by trees or other coarse granular surfaces can be totally neglected. The dependence on antenna height (e.g. supported by [3]) can be explained to be due to the ground absorption of wave: diagram 1 (extrapolated to 40 GHz, λ = 7,5 mm) shows once more a decrease of the field strength by $1/r^4$ at ground vicinity according to 40 dB per decade of distance.

Thus in general the free space propagation laws apply at sufficient antenna heights.

Further supposing that a directional user terminal antenna of 35 dBi gain and –3dB angle of ±1° is applied it can be assumed that in most cases the residual reflections will attenuate by 20 dB. If the fact that a reflected signal is itself attenuated by more than 10 dB by the reflection process is additionally taken into account then the conclusion is that nearly every reflection or refraction contributes less than –30 dB compared to the useful signal.

Because the QPSK signal in each case is PRBN energy dispersed before transmission an RFI jamming situation with selective fading due to echoes can be nearly totally excluded.

Conclusion: It is adequate to treat the 40 GHz directional radio link like a Gaussian channel and therefore to apply a specification like is known from satellite links. Special terrestrial modulation schemes like e.g. COFDM are not obligatory.

7.2 Link Budget

7.2.1 General

Link budgets are well-known from satellite communications and are suitable to make a statement about the reception C/N at the destination point of the link.

The so-called path loss is one of the most important effects treated by the budget. It determines widely the system operating distance if a certain availability is supposed.

In this link budget consideration the path loss is treated separately from the antenna aperture despite this is not being done in the literature in most cases, i.e. both are very often combined, resulting in a frequency dependent "free space loss" which shall not be mixed up here (the vacuum is really not "low pass"!). This is done for the sake of clear propagation influence demonstration.

Antennas and first amplifier stages contribute their noise figures in a well-known manner too. Nevertheless at 40 GHz these noise figures are somewhat increased which requires an utmost exact verification.

7.2.2 Basic Relations

7.2.2.1 C/N Margin

In the following considerations the embedded downstream is firstly taken into account. The modem and codec of [1] is supposed which is for no loss in general. Later-on the link budget for other modems/codecs can easily be scaled according to their different coding gains or Nyquist filter bandwidths.

[1] indicates that for the satellite scenario the following C/N values apply for the so-called quasi error free reception at a BER = 10^{-11} ... 10^{-10} at the input of the MPEG2 demultiplexer.

Code Rate	C/N (dB)
1/2	4,1 (4,38)
2/3	5,8 (6,08)
3/4	6,8 (7,08)
5/6	7,8 (8,08)
7/8	8,4 (8,68)

These values have been calculated for a symbol rate of 25,776 MSy/s according to a Nyquist filter bandwidth of 12,888 MHz (-3 dB). The signal bandwidth at carrier level is therefore:

$2 \cdot f_n$ = 25,776 MHz which is relevant for noise considerations.

In practice the implementation on satellite today is realized with a signal bandwidth of 27,5 MHz which is slightly different from the values above which refer to a transponder bandwidth of 33 MHz (-1dB) and are implemented with a form factor of 1,2 between transponder and signal bandwidth. This change results in a modification of:

$$10 \cdot \log \frac{27{,}5}{25{,}776} = 0{,}28\ dB$$

The new values are written within brackets in the table.

For the down streams 27,5 MSy/s is assumed and the link budget is calculated. Further we base this calculation on a sufficient margin with a minimum C/N of 10 dB to cope with the weakest code rate of 7/8 respectively. In addition to this 5 dB are recommended to adopt to implementation influences such as e.g. antenna mispointing. This C/N of 15 dB must be valid at the demodulator input (down-converter output).

Another very important aspect is the fact that cases of "multiple budgets" are possible, e.g. when a satellite transport stream is purely back-hauled and up-converted rather than re-modulated which means that the LMDS radio link is not the only one but it is preceded by e.g. a satellite up – and down-link.

The C/N Values then behave according to the law:

$$\frac{C_{ges}}{N_{ges}} = \frac{1}{\frac{1}{C_1/N_1} + \frac{1}{C_2/N_2} + \ldots + \frac{1}{C_n/N_n}}$$

This means that the total C/N of course becomes worse than the worst one in the chain. In such scenario, consequently the particular budgets should be significantly better than the overall link budget because if e.g. two systems figure up with approximately similar budgets the link will be worse by 3 dB as a whole.

7.2.2.2 Antennas

It was already mentioned that the antenna gain at the user site should contribute with approximately 35 dBi to receive the base station signals but, on the other hand, with not too critical angular pitch. The situation concerning this is then similar to satellite reception scenarios where 35 dBi antennas apply, in this case with diameters of approximately 60 cm.

The difference about this is the effective aperture of the antenna which decreases proportionally to the squared wavelength. This must be strictly taken into account when exploiting the power flux density at the reception site.

Further it is important that reciprocity is valid, i.e. the same antenna gain must be supposed for reception as well as transmission at the same location.

7.2.2.2.1 Antenna of the User Terminal

Shall the aperture of an elementary Hertzian dipole be given by:

$$A_{HD} = \frac{3}{8\pi} \times \lambda^2$$

the antenna has at a gain of 35 dBi and a wavelength of λ = 7,5 mm an effective aperture of:

$$A = A_{HD} \times 10^{3,5} = 212\ cm^2$$

This aperture collects, at correct pointing state, the signal power:

$$P = S \times A$$

from the air. (S being the pointing vector magnitude).

This power results at the so-called "antenna flange" and it is further transported to the Low Noise Amplifier by using a waveguide adaptor.

In transmission direction the gain is the same, i.e. the antenna yields a power flux density being $10^{3,5}$ times stronger than that for an elementary dipole would do.

7.2.2.2.2 Antenna of the Base Station

The antenna technique of the base station differs profoundly from that for a user site one. In the latter case the following criteria are valid:

- High antenna gain.

  => Narrow main lobe.

  => Extinction of interferences by high antenna directivity.

- "Only base station visible".

For the base station itself the following criteria are valid:

- Radiation of sufficient power.

- Sufficient area coverage.

  => Lower directivity.

  (=> "All wanted users visible".)

The antenna gain definition can only be made by including the required foot print to define the area covered. This foot print is strictly correlated with the spacial angle cutting a piece of area out of the theoretical spheric area of an omnidirectional radiation pattern.

It shall be supposed that at the base station site a so-called horn antenna is applied, i.e. an antenna with neglectable sidelobes [3].

Horn antennas belong to the group of so-called waveguide antennas having very homogeneous power flux density distribution. Therefore the footprint coverage calculation can be made by using the spacial angle without introducing significant error.

The forming of the footprint in the area envisaged will be done according to the details of the landscape and user distribution. Field trials or sample measurements may also influence the result. The position of the antenna (i.e. the height above ground and its elevation or whether it is covering the interior of a valley or a plane), also determine the shape of the optimized footprint.

In each case the resulting gain is important for the link budget.

If the shape of the coverage area is an arbitrary oval, the spacial angle forming can be made by using spheric integration with the azimuth and elevation maxima being the limits.

Thus, the area being cut out of the isotropic sphere becomes:

$$A = \int_{\upsilon_1}^{\upsilon_2} \int_{\varphi_1}^{\varphi_2} R_0 \times r \times d\varphi \times d\upsilon$$

With υ being the elevation angle, φ being the azimuth angle, R_0 being the sphere radius and r being the cylindric radius within the sphere (see figure 3).

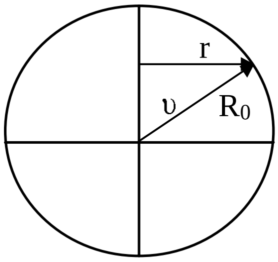

Figure 3

Where: r = R_0 sin υ.

And the integration results:

$$A = R_0^2(\varphi_2 - \varphi_1) \times (\cos \upsilon_1 - \cos \upsilon_2)$$

Now we can calculate the approximate antenna gain by using the ratio of the whole isotropic sphere and the particular area A:

$$g = \frac{4\pi \times R_0^2}{A} = \frac{4\pi}{(\varphi_2 - \varphi_1) \times (\cos \upsilon_1 - \cos \upsilon_2)};$$

or written in logarithmic notation:

$$G = 10 \times \log \frac{4\pi \times R_0^2}{A} = 10 \times \log(\frac{4\pi}{(\varphi_2 - \varphi_1) \times (\cos \upsilon_1 - \cos \upsilon_2)});$$

Further it shall be supposed that the shape of a cell will in many cases be a quarter of a circle, which means that the azimuth spot angle will be approximately 90°. This situation can become valid e.g. in case of an area coverage with the base station being located on a hill. The elevation spot angle, on the other hand, is determined by several parameters of the location (e.g. the spacial extension of the area being covered, the height of the base station, etc.).

In this example the elevation opening angle is assumed to be 30°.

If these values are applied to a horn radiator (referring to spheric coordinates):

φ_2-φ_1 = π/2 (90°),

υ_1 = 90° - 15°,

υ_2 = 90° + 15°,

12 dBi antenna gain can be obtained for the base station antenna. This is shown schematically by figure 4**.**

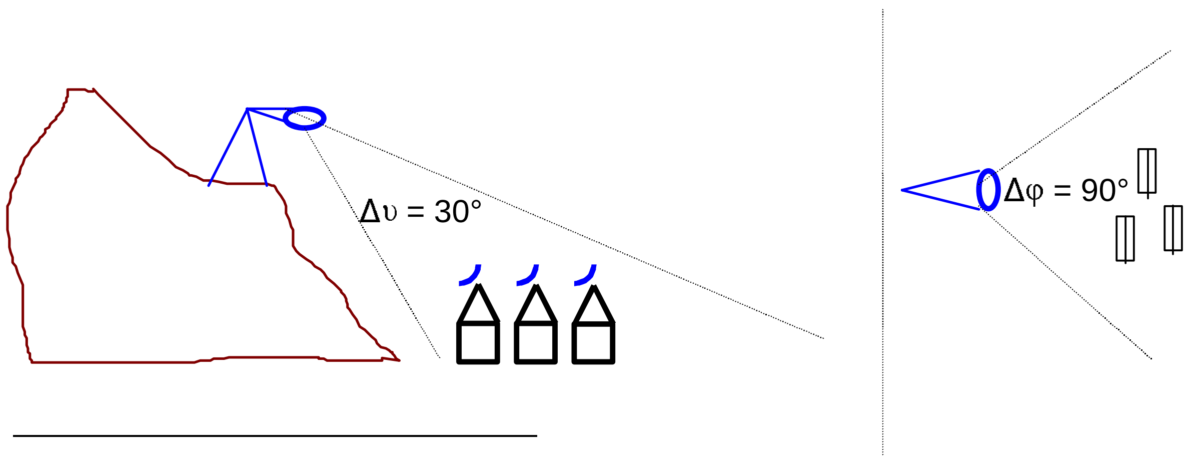

Figure 4: An example for antenna height and spot

If the scenario is changed to cover an area from a low hill spot angles such as:

$\varphi_2 - \varphi_1 = 90°$,

$\upsilon_2 - \upsilon_1 = 10°$,

would result in an antenna gain of 16,6 dBi.

However, in this case the shadowing by the buildings must be taken into account by installing the user site aerials on roof tops.

The situation is quite different in case a narrow valley is to be covered (mountain terrain). Thus the angles of:

$\varphi_2 - \varphi_1 = 20°$,

$\upsilon_2 - \upsilon_1 = 20°$,

(symmetric circular horn) must be implemented resulting in an antenna gain of approximately 20 dBi .

For the link budget calculation of the base station the worst case value of 12 dBi shall be supposed.

7.2.2.3 Waveguides

Waveguides for TV satellite communications (Uplink 17/18 GHz, Downlink: 10,7 GHz ... 12,75 GHz) have a typical loss figure of approximately 0,16 dB/m.

Waveguide transitions contribute with somewhat greater losses: Usually a value of approx. 0,3 dB is supposed within the so-called LNB unit ("feed waveguide") of consumer equipment.

In the 40 GHz ranges we can suppose for the sake of a safe calculation 3 dB due to possible parasitic influences like extreme skin effects and/or moisture, oxydation or pollution. Assumptions in this order of magnitude are also made by manufacturers of those components.

The decisive fact for the link budget is that this feed waveguide has its location before the low noise front end amplificator and thus shows up its influence by:

$$F = \frac{1}{G}\text{; (F = Noise figure, G = "Gain" < 1)}$$

as a noise source.

In this example the noise figure has to be put to:

$$F = 3\text{ dB}$$

in the logarithmic notation.

7.2.2.4 Low Noise - Amplifier

Providing sufficient amplification, with adequate bandwidth, and stability is in most cases a question of circuit layout as well as geometry. In the literature, standard methods of calculation are known [6].

Semiconductor technology, on the other hand, is nowadays capable of handling these frequencies (25 ps duration period!). The transistors applied are mainly of the GaAs type or, alternatively, indium-phosphide FETs, sometimes occurring as a mixed-type technology with GaAs being the base material.

An amplifier unit as a whole is in most cases produced in the shape of small wafers being directly bonded onto the PCB circuit layout to avoid parasitic inductors and capacitors as well as mismatched lines (wavelength 7,5 mm!). Despite these precautions there are remaining effects of attenuation which increase the noise figure, especially at the low noise amplifier input.

In the link budget – again for safety reasons – a value of F = 5 dB is assumed as the worst case.

The values of total amplification are supposed to be in the range of approx. 40 dB ... 50 dB (as for satellite LNBs) because higher values would lead to unstable operation.

7.2.3 Link Budget/Details

Under the conditions listed in clause 7.2.2 above the link budget for the up/downstream can be calculated.

7.2.3.1 Downstream

First, the so-called in-band downstream shall be regarded (see table 4), i.e. the scenario of the base station covering a defined area by a 12 dB horn antenna with a defined power flux density, measured in W/m^2 and being linked to the user terminals operating with a 35 dB equivalent antenna aperture. The result shall be that even at the cell border the carrier-to-noise ratio C/N is sufficient great to ensure safe reception according to e.g. the margins required by EN 300 421 [1] (DVB) or another specified modem/codec. The margins are themselves defined by e.g. the geographical rain statistic and the basic atmospherical attenuation.

We proceed step by step along the signal path.

Let's suppose a generated RF power of P = 30 mW in the base station HPA. With an antenna gain of G = 12 dBi an EIRP of:

$$EIRP = 10 \times \log(P) + G = 26{,}77\ dBm$$

is yielded. The transmission path is illuminated with this power. The maximum length has been found to be approx. 1 km in 7.1.1.

The signal power density undergoes (8.1.1.) a quasi-spheric propagation attenuation according to $1/r^2$, downgraded by the rain attenuation according to the exponential law. A basic air (clear sky) attenuation of 0,2 dB/km has also been taken into account:

$$S = \frac{P \times G}{4\pi \times r^2} \times \frac{1}{10^{r \times (15+0{,}2)/10}} = 1{,}1\ nW / m^2$$

The value of 15 dB for the rain attenuation was in this example taken as being a compromise between the cases of "medium precipitation" (25 mm/h, 7 dB) and "very strong precipitation" (150 mm/h, 30 dB) to obtain a realistic availability figure of the system.

According to [4] central Europe belongs to rain zone 3 with a rainfall rate of 37 mm/h for 0,01% of the time (year), i.e. the availability is calculated by:

$$A = \frac{operational\_time}{out\_time + operational\_time} = 100\ \% - 0{,}01\ \% = 99{,}99\ \%$$

The reception antenna has a worst-case elevation of 0° which implies that for the equivalent background noise temperature a figure of 300 K (27°C) must be supposed (see note). The equivalent noise temperature of the antenna matter is in most cases assumed to be in the range of 20 K. Further, the so-called system bandwidth, which is the bottleneck bandwidth for the noise and which is in most cases provided by the so-called Nyquist filter (matched filter) in the modulator/demodulator baseband processing, is assumed to be 27,5 MHz according to 7.2.2.1.

NOTE: This is really the worst case. Normally the user antenna will have a slight positive elevation due to the enhanced position of the base station.

With these values the noise power at the antenna flange is calculated as:

$$N = k_0 \times \Delta f \times (300\ K + 20\ K) = 0{,}121\ pW$$

On the other hand the signal power flux density S will be collected by the effective antenna aperture A_{eff} with the antenna flange signal power being the result (G = gain, A_{HD} = elementary hertzian dipole aperture):

$$A_{eff} = G \times A_{HD}$$

$$C = S \times A_{eff} = 24{,}2\ pW$$

Thus the expected **C/N** at the antenna flange becomes:

$$C/N[Antenna_{Flange}](dB) = 10 \times \log \frac{24{,}2}{0{,}121} = 23\ dB$$

This value undergoes further additional degradations due to feed waveguide losses and LNA stage noise figure F_{LNA} as well as the downconverter noise figure F_{DOWN}:

$$\frac{C}{N}[DOWNCONV_{OUT}] = \frac{\frac{C}{N}[Antenna_{Flange}]}{F_{waveguide} + \frac{F_{LNA}-1}{G_{waveguide}} + \frac{F_{DOWN}-1}{G_{waveguide} \cdot G_{LNA}}} = \frac{\frac{C}{N}[Antenna_{Flange}]}{F_{waveguide} \cdot F_{LNA} + \frac{F_{DOWN}-1}{G_{waveguide} \cdot G_{LNA}}};$$

$$\text{with } F_{waveguide} = \frac{1}{G_{waveguide}};$$

- logarithmically evaluated:

$$C/N[DOWNCONV_{OUT}] = 15\ dB$$

The C/N interface loss at the feed waveguide output is also shown in table 4 as 3 dB. The LNA noise figure has a very important influence upon the result while it is clear that the downconverter noise figure (supposed to be 8 dB) is neglectable compared to this. This is well-known and is related to the fact that the noise figure of every consecutive stage is denominated by the cumulative gain of the predecessors. Thus, the noise figures of the IF path are not relevant for the link budget.

Consequently the C/N value of 15 dB can also be approximated for the demodulator input. It contains, in addition, enough margin for implementation losses as e.g. slight antenna mispointing, losses due to suboptimum feed mounting, etc.

The transmitted EIRP is in this case approx. 26,8 dBm as shown in table 4.

An interesting fact is that, with these link budget assumptions, the flux density value at a distance of 1 km becomes 1,1 nW/m^2 and exceeds the satellite flux density of a satellite DTH downlink (10 ... 20 pW/m^2) by a factor of approx. 100 in the footprint centre. This factor is due to the enhanced rain margin calculation and on the other hand to the smaller elementary aperture at 40 GHz.

Radio links of different frequencies are unlikely to be interfered because in regular cases they are off axis and, if they are despite of this, the spin-off level is low enough to avoid mixing products.

The danger of cellular over-spill can be minimized by suitable beam forming (spot definition) and geographically enhanced positioning of the base station as well as by qualified power control to cope with weather changes.

Additionally mentioned shall be the so-called "Figure of Merit" G/T with a value of approx. 2,2 dB/K for this system in the downstream. This figure depicts the ratio of antenna gain and the overall noise temperature. The interesting fact about this is that the value is positive related to the high user terminal antenna gain which is similar to the gain of a satellite in-orbit dish pointing onto the "warm" earth.

For the Out of band downstreams, EN 301 199 [1a] supposes a channel raster of 2 MHz.

The rolloff is defined to be 30 % with the consequence that the pure signal bandwidth becomes:

2 MHz/1,3 = 1,54 MHz

which is also the OOB downstream QPSK symbol rate.

Since the system noise bandwidth is determined by the Nyquist rolloff matched filter in the receiver, the C/N can be scaled according to this proportionally. On the other hand, if the C/N shall be kept at the same value, the transmission power can be scaled.

Following this, the EIRP values for different bandwidths are:

14,3 dBm at 1,54 MSy/s (2 MHz raster, "Grade B" with 3,088 Mbit/s), For the flange power at same antenna gain we obtain:

1,68 mW at 1,54 MSy/s (2 MHz raster, "Grade B" with 3,088 Mbit/s).

Of course these values are understandable in terms of orders of magnitude and can vary according to additional conditions. In clause 7.2.3.3 it is proved that the omission of the convolutional codec does not lead to a change of these figures.

7.2.3.2 Upstream

For the upstream link budget calculation the same weather conditions as well as equipment parameters in terms of waveguides and amplifiers shall be supposed. Only the reception and transmission antenna gains are mutually exchanged (see also 7.2.2.2). We first calculate the link budget regardless of the different codec used.

Table 5 shows the budget calculation result. One essential difference to the downstream is the far higher EIRP of approx. 47 dBm which is calculated for the same system bandwidth but, on the other hand, for a base station reception antenna being now far smaller due to the wider spot required. A law for scaling according to different upstream bandwidths is given in 7.3.2. The spot design laws are explained in 7.2.2.2.2.

The now very negative figure of merit G/T of -21 dB/k is similar to those of isotropic reception systems as e.g. GSM base stations.

At 40 GHz, implementation losses are the main source for the enhancement of the equivalent noise figure. However, they are reduced with progress in manufacturing.

In this case it is supposed that the transmission antenna flange of the user outdoor unit is loaded with 15 mW. Then, at the base station site, a C/N of approx. 12 dB is left which provides enough margin in relation to e.g. the value of 8,7 dB for code rate 7/8 at 27,5 MHz system bandwidth (symbol rate).

The reciprocity is well visible here: If 30 mW were chosen for antenna flange power the C/N would increase to 15 dB but the 15 mW value is a good compromise according to user consumer electronics and it is easy to implement.

The case of a return channel symbol rate of 27,5 MHz has been chosen for example to verify bi-directional link budgets and as a guideline for measurement.

In context with the DVB LMDS document EN 301 199 [1a] an upstream channel raster of 2 MHz is provided in a first step. The rolloff is defined to be 30 % with the consequence that the pure signal bandwidth becomes:

2 MHz/1,3 = 1,54 MHz

which is also the upstream QPSK symbol rate.

Since the system noise bandwidth is determined by the Nyquist rolloff matched filter in the receiver, the C/N can be scaled according to this proportionally. On the other hand, if the C/N shall be kept at the same value, the transmission power can be scaled.

Following this, the EIRP values for different bandwidths are:

34,5 dBm at 1,54 MSy/s (2 MHz raster, "Grade C" with 3,088 Mbit/s),

37,5 dBm at 3,08 MSy/s (4 MHz raster, "Grade D" with 6,176 Mbit/s).

For the flange power at same antenna gain we obtain:

0,84 mW at 1,54 MSy/s (2 MHz raster, "Grade C"),

1,68 mW at 3,08 MSy/s (4 MHz raster, "Grade D").

Of course these values are understandable in terms of orders of magnitude and can vary according to additional conditions. In the next clause it is proved that the omission of the convolutional codec does not lead to a change of these figures.

Figure 2a contains as an example the link budget for 1,54 MSy/s.

Nevertheless, it is recommended that the outdoor unit power amplifier stage should be designed for higher bandwidths in future, i.e. a power of 15 mW at antenna flange should be possible.

A special aspect of the user outdoor unit is that the spot beam of the transmitted signal is with a value of approx. ±1°, far narrower than the bas station beam which ensures that the risk of impairing foreign services is effectively minimized. Since, in addition to this, the base station has in most cases a raised location, a situation similar to satellite uplinking is given, i.e. the user outdoor aerial will have a raised elevation ensuring that beam overspilling disperses into the atmosphere. In clause 9 the electromagnetic safeness topic is treated in somewhat more details.

7.2.3.3 Codec Influence

The link budget calculated below did not incorporate convolutional and Reed-Solomon codec properties. This was omitted intentionally to give a basis for bandwidth scaling. Thus, it seems to be reasonable to calculate the link budget on a C/N basis and then to compare it to actual codec requirements.

The codec supposed here for downstream is the DVB EN 300 421 [1] one which was shown in clause 7.2.2.1 when estimating the C/N margin. In the upstreams, no convolutional codec is used which means that its coding gain is missing. Despite of this, a certain gain is achieved due to the reduced bandwidth form 27,5 MHz down to e.g. 1,54 MHz. This means that an additional margin of:

$$10 \times \log\left(\frac{27{,}5}{1{,}54}\right) = 12{,}5\ dB$$

is gained, as calculated above (7.2.3.2).

If we omit, on the other hand, the codec (see 7.2.2.1), approximately 5 dB are lost in case of taking the rate 1/2 as a basis (this is the approximate coding gain of the rate 1/2 K = 7 133 171 DVB standard convolutional code).

If the rate 7/8 (see 7.2.2.1) is taken as a reference we only loose approx. 5 dB – 4,3 dB = 0,7 dB when omitting the punctured convolutional codec (the influence of the reed-Solomon codec is nearly the same in both systems).

As a result there remain approximately 12,5 dB – 5 dB = 7,5 dB or 12,5 dB – 0,7 dB = 11,8 dB gain compared to the DVB EN 300 421 [1] application which is achieved in case the 2 MHz raster for up – and downstreams is used.

In 7.2.2.1 the weakest code rate of 7/8 was taken as a basis, i.e. the EIRP values from above (7.2.3.2) for the "Grade C/D" – bandwidths need not to be corrected dramatically because the loss of 0,7 dB due to codec omission does not influence the system anywhere and a sufficient margin was incorporated in the link budget.

7.3 Specification of Power and Frequency Resource

The results obtained can be now used to generate a scaling rule for the power flux densities in the given frequency resource. The main goal is to keep the spectral power density constant in terms of W/Hertz ant to tolerate local changes only.

7.3.1 Downstream

The signal of one modulated carrier radiated by a base station in the 40 GHz ranges shall have a power flux density at the worst-case borders of a cell coverage of:

$$S = S(27{,}5\ MHz) \times \frac{f}{27{,}5\ MHz}$$

with S being the Poynting vector magnitude and S(27,5 MHz) = 1,2 x 10^{-9} W/m^2.

Within the whole LMDS cell the power flux density may be higher.

The radiation shall be performed with two possible polarizations, depending on the requirements in terms of services as well as adjacent cell signal separation and/or frequency re-use where possible.

7.3.2 Upstream

The signal of the modulated carrier radiated by a user terminal outdoor unit in the 40 GHz ranges shall have a power flux density at the base station reception antenna of:

$$S = S(27{,}5\ MHz) \times \frac{f}{27{,}5\ MHz}$$

with S being the Poynting vector magnitude and S(27,5 MHz) = 100 x 10^{-9} W/m^2.

Within the whole LMDS cell the power flux density may be higher.

The radiation shall be performed with two possible polarizations, depending on the requirements in terms of services as well as adjacent cell signal separation and/or frequency re-use where possible.

The user shall be recommended to radiate his signal with the aid of a directional antenna with at least 35 dBi gain referring to the elementary Hertzian dipole aperture at 40 GHz (6,7 x 10^{-6} m^2). The off axis EIRP shall be **similar to or better** than the off axis radiation according to the radiation mask of a conventional satellite **35 dBi** specular reception Ku band antenna.

7.3.3 Power Control

Power control of upstreams is provided in order to avoid severe near-far problems of the signals arriving at the base station. The problem of receiving a composite entity of individually modulated carriers increases in scenarios given in LMDS since the wide spectral resource allows a very large number of carriers being received. These carriers of course load the low noise amplifier of the reception stage for this polarization in parallel with the consequence that on the one hand a signal level being too great results in enhanced beat frequency components overranging the linear characteristic, on the other hand a signal level which is too small for one individual carrier results in a degraded signal-to-noise/crosstalk ratio for this signal envisaged.

The minimum signal level for one carrier is given by the required C/N, as it has been described by the link budget in tables 5/5a. It is clear that the signal bandwidth directly influences the absolute level linearly as it has been described in the clause before, i.e. narrow band carriers do not need the reception power wideband carriers need due to the Nyquist Filter Noise Bandwidth limiting the incoming noise budget. Thus, the power control algorithm not only has to tailor the absolute signal amplitude but also has to incorporate the signal bandwidth.

With the link budget given in tables 5/5a an example of determining the power of an individual carrier can be shown here:

The level of a narrowband (2 MHz) return channel carrier (TDMA) has been calculated to yield a power flux density of 6 080 pW/m^2 to fulfil signal-to-noise ratio requirements. If this is received by the 12 dB – horn antenna it comes out as a flange power of 0,65 pW. This is attenuated by the feed waveguide by 3 dB to 0,325 pW occurring at the LNA input. If in the upstream resource (figure 1a) of 550 MHz one polarization and sector is loaded with 275 carriers (see 8.2 "Cell Planning") the LNA input observes a composite power of 275 x 0,325 pW ≈ 89 pW. But this is not the real upper limit capability the LNA must cope with. Due to the beat frequencies occurring by linear superposition of a plenty of single carriers there must be a headroom reserved in the LNA amplitude characteristic as follows (all figures in dB):

$$P_{head}\ (dB) = P_{peak} - P_{comp};$$

where

$$P_{peak}\ (dB_{pW}) = P_{single} + 20 \times \log(N);$$

$$P_{comp}\ (dB_{pW}) = P_{single} + 10 \times \log(N);$$

This headroom is due to the squared behaviour of signal voltages in relation to power ($P \sim U^2$!) to avoid distortions (like in the audio) based on beat signal overranging.

E.g. when 275 carriers are active in parallel (regardless whether TDMA or not) the headroom of the LNA must be tailored to:

$$P_{head}\ (dB) = 10 \times \log(275) \approx 24\ dB;$$

the true average power load is 10 x log(275) + 10 x log(0,325) dBpW = 19,5 dBpW.

Consequently the total input peak power capability of the LNA comes out as:

$$20 \times \log(275) + 10 \times \log(0{,}325)\ \text{dBpW} \approx 44\text{dBpW}.$$

This is equivalent to approx. 25 nW (1,37 mV @ 75 Ω, 1,1 mV @ 50 Ω) and must be linearly guided through the LNA and to the further stages. Thus, power control becomes very important to keep each carrier within certain limitations of the link budget requirement.

Now let us assume that one user terminal is transmitting from a point having a certain distance to the base station. Then it has to limit its power (like each terminal) according to diagram 2 at the beginning of the transmission by using the <MAC> Ranging and Power Calibration Message (5.5.4.3 in EN 301 199 [1a]) since the AGC of the base station can only calibrate the composite incoming signal.

The following procedure is then initialized: On a so-called "Provisioning Channel" the NIU receives the so-called <MAC> Default Configuration message and configures according to this among other parameters the default power level of upstream transmission. The range of this power level is generally defined by the two parameters Max_Power_Level and Min_Power_Level (8 Bit unsigned integers). It is expected that the location distance from the base station will determine these two parameters. From a distance of e.g. 1 km, as described in the link budget (table 5a), the NIU has to provide an EIRP of 34 dBm worst-case, that means with 15 dB rain attenuation. In the best case the rain attenuation becomes zero ("clear sky", only 0,2 dB atm. att., see diagram 3) and according to this the power level has to be reduced by this value.

Thus, the two parameters become at a distance of 1 km (antenna flange values!):

Min_Power_Level = 19 dBm – 35 dBi(Antenna Gain) + 109 dB = 93 dBμV;

Max_Power_Level = 34 dBm – 35 dBi(Antenna Gain) + 109 dB = 108 dBμV (see notes).

NOTE 1: 109 dB is the offset for transforming dBm to dBμV in 75 Ω systems, 107 dB for 50 Ω systems.

NOTE 2: The transformation to values into dBμV is only due to the definition of the "Power_Levels" in EN 301 199 [1a] as "unsigned integer at 75 Ω"!)

And at arbitrary distances (generally, different from 1 km) the two power levels have to be calculated according to the distance equation:

$$S = \frac{P \times G}{4\pi \times r^2} \times \frac{1}{10^{r \times (15+0,2)\,dB/10\,km}}$$

where only the relative change is important. Thus, the Poynting vector magnitude itself has not to be calculated rather than the variation caused by the exponential term and $1/r^2$:

Min_Power_Level (r) = 19 dBm – 35 dBi(Antenna Gain) + 109 dB + 20 x log(r/1km) + (0,2 dB/km) x (r/1km) =
= 93 dBμV + 20 x log(r/1km) + (0,2 dB/km) x (r/1km); (without rain);

Max_Power_Level (r) = 19 dBm – 35 dBi(Antenna Gain) + 109 dB + 20 x log(r/1km) + (15,2 dB/km) x (r/1km) =
= 93 dBμV + 20 x log(r/1km) + (15,2 dB/km) x (r/1km); (rain included);

It can be verified by inserting r = 1km that the Max_Power_Level becomes approx. 108 dBμV and for every different radius values accorded. For a different rain attenuation (rain zone, availability) only the 15 dB/km has to be replaced by a suitable value.

E.g. if the availability is set to 99,90% instead of 99,99% the correction factor reveals as a subtraction (at 40 GHz) of approximately 1 dB in the equations [4].

Warning: This means that a misalignment of the power, regardless whether base station or user terminal, comes very sensibly out as a changed availability!

This enforces the necessity to control the power of both sites very carefully.

The tentative upstream transmission power should lay between these two power levels, regardless that it is in a single case (only one carrier requiring participation) it is previously not critical since the composite 25 nW are not significantly over-ranged (one carrier only equals 0,325 pW as calculated above). The only aspect about this is that in case many new carriers are coming up the two power levels should not be over – resp. under-ranged.

A few words shall be said upon the base station power control topic: The same that is told above also goes for the base station signal radiation, i.e. if no rain attenuation is in the transmission path the signals radiated become stronger according to this. To avoid, especially in a multi-cell environment (cluster) overspill interferences it is recommended to attenuate the transmitter power according to the ceasing rain attenuation since the link budgets (tables 4, 5, 5a) are calculated for 15 dB. Thus, a mathematical and physical model should run in the base station computer exploiting the upstream link budgets for tailoring also downstream power.

7.3.4 Frequency Control

Providing a wireless service always implies a certain quality of precision concerning the on-air signals since broadcasting and point-to-point links have been existing with high quality standards a long time before LMDS was considered. Thus, LMDS shall continue this tradition of quality especially under the aspect of spectral resources becoming narrower in future due to steep increase of digital services, regardless that national and international regulation offices define particularly strict limits for carrier drifts and out – of – band emissions.

In EN 301 199 [1a] e.g. 0,1 ppm are required for the OOB downstreams which means that a carrier radiated at e.g. 40 GHz by the base station must not deviate in frequency more than 4 kHz over the whole time of operation. The base station (INA) carriers have to cope with this (see EN 301 199 [1a], 5.2.1.7) which is in this case easy to realize by locking the equipment to a fixed frequency reference being available by GPS or backbone facilities. For the IB downstreams ±5 MHz are specified to be tolerated on-air. In the present document it shall be recommended to specify this tolerance in practice much better than ±5 MHz since the user outdoor unit downconverter itself previously has a tolerance within this magnitude. This would result in a tuner acquisition range of worst-case ±10 MHz which would require a more expensive receiver than usual.

However, if the OOB downstreams are realized with 0,1 ppm, as defined in EN 301 199 [1a], it is of minor effort to do so for the IB downstream carriers, too. Carrier frequency precision is not a question of content.

The new aspect about LMDS is that now return channels are introduced into the transmission scenario from the user site which has traditionally been known as consumer – level equipment with the requirement to be sufficient cheap.

Performing frequency control in a consumer-like environment with cheap NIUs requires an aid by the base station. The so-called ranging process (EN 301 199 [1a], 5.5.4.6) is an interactive tentative process using the protocol of the ranging and calibration signalling. In EN 301 199 [1a] it is described how the ranging process guides the NIU to the base station demodulator window by hopping the upstream frequency with several attempts and increasing steps until the window is matched.

Besides this the upstream frequency must be controlled during the whole transmission time because of e.g. thermal drift of the conversion oscillators. In this case the Ranging and Power Calibration Message contains a "range_frequency_control-field" with a boolean value "frequency_adjustement_included" which is set to logical "1" if a correction is necessary. The Frequency_Offset_Value is a 32 bit signed integer representing the upstream carrier offset frequency compared to the centre IF frequency in Hz. It is clear that less messages are necessary if the equipment hardware is of higher quality resulting in a slower or smaller drift behaviour in the upstream.

7.3.5 Other Modulation Schemes

In the present document QPSK is treated to be a suitable modulation scheme because this is widely applied for satellite and radio links with critical link budgets.

Since LMDS is a terrestrial distribution system, also closer distances between transmitter (base station) and receiver (user terminal) occur in practical operation. In these cases it can be considered to exploit the improved link budget to enhance data throughput for selected customers.

When searching a modulation scheme with a higher ratio of bit/s/Hz QAM is a well-known configuration since it is, first, also a quadrature modulation, and second, modulation equipment is widely available on the market. A further aspect is the spectral shaping of the signal: The spectrum is a finite one due to the fact that it is AM-related and does not need any additional shaping beyond the Nyquist Filtering. The link budget in general remains the same, only the resulting C/N must be changed according to the values required by QAM (no additional channel coding):

16 QAM:	18 dB,
32 QAM:	21 dB,
64 QAM:	24 dB,
128 QAM:	27 dB,
256 QAM:	30 dB.

These values are all > 15dB which shows clearly that the link budgets in tables 4, 5/5a must be changed in terms of an increased signal power since the noise power remains the same at similar noise bandwidth conditions. On the other hand it is not recommended to solve the problem by simply increasing the transmitter power because in this case the overall signal scaling (frequency power density) in the cell is violated, i.e. the cell size planning, AGC ranges of user terminals as well as return channel power should in this case be under review.

If the same power conditions as with QPSK (table 4, Downstreams) are kept we get the following distance limits if additional 3 dB are supposed for antenna mispointing and other implementation margins (rain is assumed with 15 dB as usual, symbol rate = 27,5 Msy/s):

16 QAM:	750 m,
32 QAM:	650 m,
64 QAM:	550 m,
128 QAM:	450 m,
256 QAM:	350 m.

If the symbol rate is decreased the transmission power must be decreased, too (see also 7.3.1). Thus the distance limitations remain the same.

8 Cell Cluster Structures and Cell Planning

In clause 7.2.2.2.2 the antenna spot beam forming was generally discussed. As an important parameter, the shape of the coverage area was highlighted at the examples of an enhanced base station on a hill or a "narrow valley" to be covered.

Generally, the shaping of a coverage area will depend on natural conditions as e.g. landscape forms, buildings and vegetation. This goes for the cell shape itself as well as for the cluster structure made up of several adjacent cells.

In the LMDS system one fixed location is assumed for the base station as well as for each user. Mobile applications are not considered in a first instant. To include them, additional assumptions must be made in terms of omnidirectional antennas and doppler-safe modulation schemes. At this point of time there is no fixed standard defining scenarios like this.

8.1 Cluster Structures

"Wireless Cable", or more general, BWS systems draw their main advantages from the fact of the so-called frequency re-use which means that each carrier frequency used in one cell can be re-used in the neighbour cell. To enable this facility certain limits in terms of power and geometry must be introduced. Generally, the laws for re-using a frequency in a neighbour cell can be formulated by the following:

- Define a minimum C/N ratio at the cell border ensuring excellent reception of downstreams within the wanted (own) cell.
- Control the base station power to adopt the power flux density to changing weather conditions. E.g. if the maximum power is tailored to a rain attenuation of approximately 15 dB in the worst case (see also diagram 2) and clear sky is being expected the transmission power must be dynamically lowered by 15 dB with the in-running new conditions. Else the neighbour cell might be impaired by over-radiation and the frequencies must not be used again.

Since the polarization diversity shall serve for a re-use of the spectrum within the same cell this parameter should not be used for neighbour cell protection. Thus, the directivity of the user outdoor unit antenna in combination with its actual geometric direction shall be the means for establishing a line-of-sight with the wanted base station only. Other neighbour base stations being in this line shall have a multiple distance of one cell radius. If despite of this, Interferences are observed due to an in-line array of a user terminal and two base stations this shall be solved by individual measures, i.e. for such users e.g. another frequency (than this of the neighbour base station interfering) shall be used. This e.g. can be in a range where the neighbour base station radiates narrowband carriers with respective backoff, or in a range where the neighbour base station does not radiate anything or only at opposite polarization momentarily. Further a special coordination in the sense of a customer-friendly reaction upon the problem can be made together with the neighbour base station: A carrier could be removed to another frequency/polarization. But in most cases the user antenna directivity cancels other signals being not exactly in line-of-sight.

A possible cluster structure fulfilling these conditions is shown below:

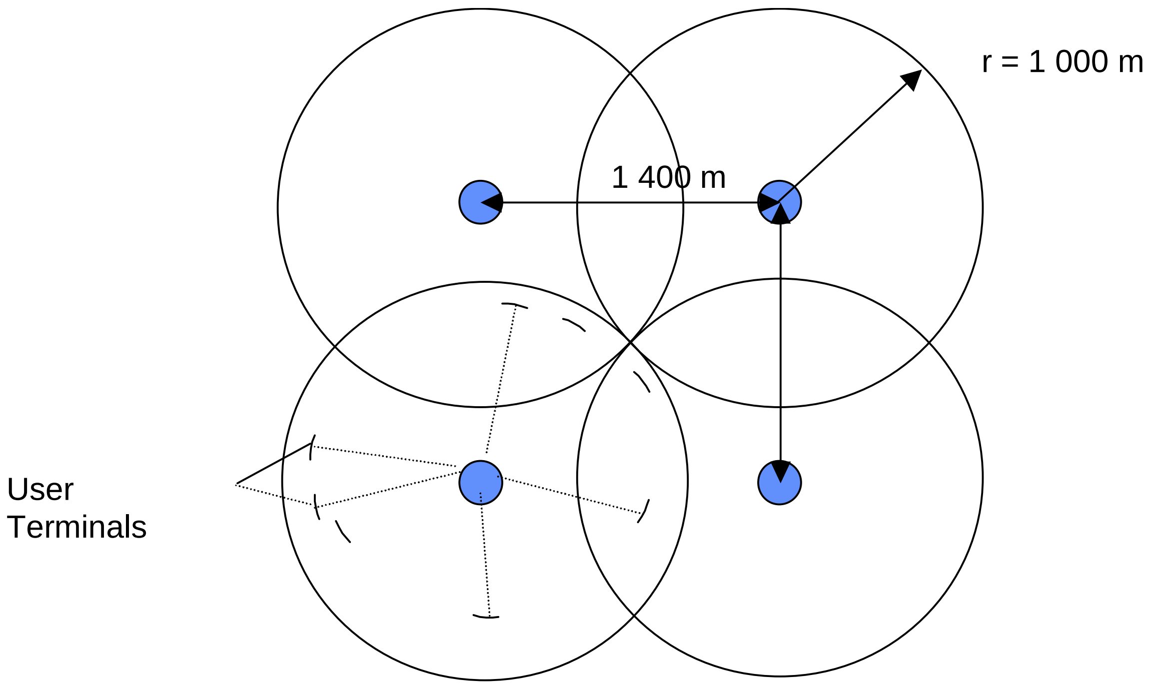

Figure 5: Example of a Cell Cluster

As it is shown here, this array consists of a planar and symmetric packaging of the base stations and their transmission/reception radius with the consequence that the users within one cell only directly point upon their wanted base station. Of course, within one line of sight there may be other base stations but their antennas are located at a distance of at least 1 400 m if the cell radius is 1 000 m (square root of 2). Also the reason for the narrow user antenna directive characteristic can be clearly seen here: Despite the cell areas are overlapping the user antennas do not receive/radiate any energy (or only neglectable portions) from/to the neighbour base station. Since this characteristic is narrow (approx. 1° for 35 dBi antennas) in azimuth as well as in elevation user antennas being located close to the wanted base station also do not receive significant portions from the next in-line base station because of their enhanced elevation (they are looking "upwards" and not "straight-on" to the neighbour!).

Adjacent sector overlap within one cell is the only problem to be solved: This occurs e.g. four times when using a 90° sectoral horn antenna for transmission/reception.

In the reception case (from the user terminal to the horn) the ambiguous signal of the user terminal carrier in two horns can be cancelled in one sector by communication between the components of the two sectors, providing thus a certain antenna diversity feature, but in the transmission case (from the horns to the user terminal) the reception of two carriers coming from the base station may cause problems if not precisely distinguished by the user antenna. To overcome this it is recommended to use in a narrow range of angle (e.g. 2°... 3°) different polarizations as drawn below:

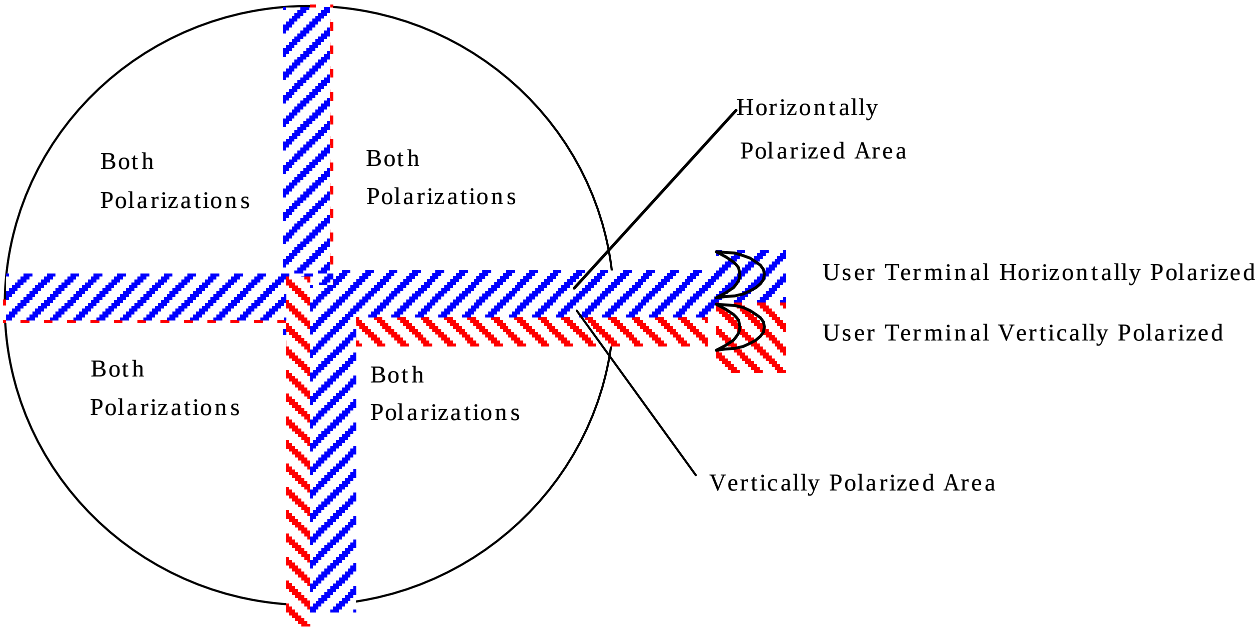

Figure 6: Overlap Polarization Organization

The idea behind the restriction to the use of one polarization only within a narrow particular sector is a most efficient exploitation of the frequency resource by polarization re-use. If a 90° sector as a whole is used by only one polarization the loss of spectrum is 50% compared to a full polarized system, i.e. the spectrum is principally wasted since there is no critical overlap within the sector centres requiring this restriction. If e.g. only 2° are used for polarization restriction we only loose:

$$100 \times 2/90 = 2,2\ \%$$

of the resource if "the resource" is interpreted to be the spectrum exploited within an area ($\pi\, r^2$) of inhabitants living inside.

The realization of these "border spots" can be done either by small additional single-polarized antennas at the sector borders or by a specially higher sophisticated spot-tailored antenna providing a directional diagram with two single polarized side lobes.

The restriction to one polarization within the small sector border areas has to be taken into account when logging in these terminals and during the whole time of operation, i.e. the base station has to know (by analysing the MAC address) the geographic location of the user terminal. Together with this, the permission/restriction to receive certain polarizations is fixed. Despite of this the user will in most cases not recognize this restriction because the bandwidth of a service is independent of the polarization used. At high traffic there only might be sometimes a slight longer log-in waiting time due to the limited resource in the narrow border sectors.

8.2 Cell Planning

The planning of a cell incorporates a plenty of actions being necessary. First, the propagation of the signals must be assured which is done according to the previous clauses treating the link budget and the antenna sizes/spots. Another parameter is the traffic being throughput by the base station. An example of a cell with a plenty of users is given here. It is assumed that the cell is a circular one, i.e. no line-of-sight obstructions require a non-homogeneous beam distribution and/or gap fillers (which may become necessary in certain situations as e.g. shadowing by very high buildings!). Table 7 then describes the spectral throughput being possible as a whole. Smaller scenarios can be scaled down to sizes being envisaged. However, the backbone must in each case be tailored to this.

It is a big town assumed (like Munich) which shall be covered by LMDS on both polarizations and with circular cells. Supposing sectorized antennas with approx. 90° azimuth spot angle four base stations must be provided to cover a full cell (i.e. one base station operates ideally spoken at both polarizations if they need not to be used for cancelling interferences). The total number of base stations comes then out as to be 392 within 98 cells.

The average number of households is taken from official statistics and leads to the number of houses resp. households per cell of 7 050. If the spectrum allocation example of figure 1a is taken as a basis the upstream frequency resource is 550 MHz. With both polarizations and four sectors the total resource becomes approx. 3,38 GHz if the rolloff is set to 30% (EN 301 199 [1a]). Further, a certain percentage of parallel use is supposed and for ATM the effective payload rate (Reed-Solomon, unique word and guard byte strapped) calculates as 53/64 = 0,828. Thus the bit rate per household can be estimated by:

$$\frac{\text{Frequency Ress/Cell} \times \text{Bits/Symbol} \times \text{Payload Rate (ATM)}}{\text{Perctg of Time parallel Use} \times \text{Av No Households/Cell}} = \text{Bit Rate/Household}$$

This comes out with approximately 2,54 MBit/s when supposing all these parameters and 31,2 % parallel use and shows clearly the facility of the 40 GHz range simply under the upstream resource's aspects. Since EN 301 199 [1a] basically deals with 3 Mbit/s – channels (net rate 2,54), shared by TDMA users, it is clearly visible that with a parallel use of less than 31,2 % TDMA can be switched off (steady-state operation). On the other hand, TDMA has to be switched on again when a number of households (one carrier/one household assumed) reaches a parallelism in operation of 31,2 % because the bit rate per household begins then to exceed approximately 2,54 Mbit/s which is equivalent to one effective continuous upstream bit rate. In other words: A number of users of 550 MHz/2 MHz = 275 is transmitting continuous upstreams within one segment and one polarization according to the basic EN 301 199 [1a] upstream channel bandwidth.

Of course this is only valid when imagining a base station serving the whole possible resource or, at least, when a business model is supposed with a base station being operated like a satellite on the whole resource, and which is leased to a plenty of users dealing with a subset of spectrum.

The calculation for the downstreams is done according to the equivalent parameters in EN 301 199 [1a], i.e. also an ATM frame of 53 bytes is assumed to be the payload. The payload rate is then calculated as the ratio of 10 x 53 bytes to the whole number of bits within the so-called Extended SuperFrame (ESF, see 5.3, table 9 and figure 17 in [1a]) of 4 632, resulting in 4 240 bits/4 632 bits = 0,915. The total spectral resource is now assumed (according to figure 1a) to be 2,050 GHz and the parallelism is again assumed to be 31,2 %, i.e. the same users transmitting the upstreams are receiving the downstreams.

EN 301 199 [1a] describes these carriers to be also within a 2 MHz raster which means that with a parallel and individual interaction use of 275 downstream carriers per segment and polarization the resource is really not entirely exploited by this kind of interaction, as table 7 shows, and theoretically, 10,5 Mbit/s could supply every household. Of course, with EN 301 199 [1a], this is possibly done in the form of particularly supplying in-band downstreams according to the EN 300 421 (DVB-SAT, [1]) modem with - optionally - TV contents as an addition. In general a mixed type of operation - in-band and out-of-band - will take place.

9 Connectivity to other Networks

An LMDS cell features in a certain sense as a special single communication system interacting with other networks like e.g. telecom's networks etc.

Depending on customer's requirements the link to a satellite segment might be one of the first interconnections for the sake of re-broadcasting. This is the real manifestation of the "wireless cable" application comparable to the scenario of satellite programmes being distributed by cable headends. In the LMDS case, a remodulation can be omitted due to the large resource in case no transport stream change is provided.

However, the network interconnection will surely not be restricted to satellite segment use and thus in most cases digital data are re-ordered and remodulated at the base station.

The networks being served in this sense by LMDS can e.g. be:

- Satellite Networks (Broadcast & Interaction).
- Cable Networks (Broadcast & Interaction).

- GSM - Network (mobile telephone).
- UMTS - Network (mobile data).
- ISDN/PSTN (telephone & internet).
- ATM - Networks.
- PDH/SDH - Networks.

10 Backbones

An additional network is the so-called backbone interconnecting the base stations with one another.

The complexity of the base station will be driven by the number of connections being served.

Mainly it will be the customer's wishes as well as the legal regulation facilities in a region determining this.

11 Radiation Safety

It is a self-understanding item that new wireless networks come up with a new problem of radiation safety. In classical regulations like the German one values of 10 W/m^2, which is equal to 1 mW/cm^2, are fixed for an enduring exposition.

From this a security distance can be defined and it is briefly shown here that with some care to be taken the risk for health of persons is kept rather low. Since this is a free space propagation it is generally referred to the power flux density which is defined by the so-called Poynting Vector S (see clause 7.1.1).

Other field magnitudes can be calculated by the use of the so-called:

free space impedance $Z = 120\ \pi\Omega$

The electrical and magnetic field strength are then given by:

$$E = \sqrt{S \times Z}$$

$$H = \sqrt{\frac{S}{Z}}$$

Since the magnitudes are quasi-stationary the RMS values are to be taken when estimating the situation for the environment.

E.g. in ([5], Bild 3) it is recommended for exposition times ≥ 6 min:

Exposition range 1: 50 W/m^2,

Exposition range 2: 10 W/m^2.

In the following we can refer to exposition range 2 because it covers civil dwelling scenarios without any consciousness of the public of the service provided by wireless radiation. This is really the LMDS situation.

The main task is then to figure out the areas with power flux densities greater than the maximum tolerable value of 10 W/m^2.

The basis for this shall again be the link budgets defining the transmission power in terms of a sufficient C/N. The radiation power source is always the transmitting antenna and thus the maximum flux density will occur on the main radiation axis of it. Consequently, everything being closer to the antenna than the distance of the 10 W/m^2 point describes, also being referred to as the "security distance", shall be out of the reach for persons.

First, the security distance for the base station aerials shall be estimated.

To get on this scope valid figures it is reasonable to assume the base station being fully loaded with wide-band RF carriers on each polarization, e.g. if it is shared by multiple operators which means that the whole resource of 2 x 2,05 = 4,1 GHz is filled with approximately 100 QPSK carriers at a frequency raster of 39 MHz.

Basing e.g. this upon the requirement [5] the overall carrier powersum must be calculated and the security distance is then derived.

Table 7 shows the relations being important for this calculation: The downstream powers are multiplied with the number of frequency channels to obtain the resulting power at antenna flange. The whole table is partitioned in three sub tables to perform the same calculation for:

- the base station site,
- the user terminal transmitting at return channel wideband operation (27,5 Msy/s),
- the user terminal transmitting at EN 301 199 [1a] operation (1,54 Msy/s.).

The power flux densities are also finally calculated. It comes out that for this value the base station figures up with a security distance of 60 cm for 100 channels and an antenna gain of 12 dB. So does the user terminal for wideband operation and an antenna gain of 35 dB (only one carrier). At EN 301 199 [1a] operation this distance reduces to only 14 cm. However, the aerials must in each case be positioned at unreachable places for public.

The important thing about this is that despite the regulation offices will generally add a local flux density offset due to other transmitters operating in the vicinity, the security distance will not exceed the value of 1 m in most cases.

Annex A: Recommended Frequency Raster

Based upon regulation efforts concerning a MVDS (Video-) distribution from 1997 there exists a frequency raster with 39 MHz carrier spacing adopted to the usual digital satellite space segments.

In the present document the spectrum structure of figure 2 is proposed and with table 6 a proposal with a frequency raster of 100 kHz shall be supplied. This raster adopts to the narrow band OOB downstreams as well as to the upstreams according to EN 301 199 [1a] and it is extended to the future resource up to 43,5 GHz. This raster also covers exactly the edges of the 39 MHz raster and thus there is no inconsistency when migrating to the new one. Each regulated bandwidth can be composed of 100 kHz segments, but it is strictly to note that the precision of transmission shall cope with the values fixed in EN 301 199 [1a].

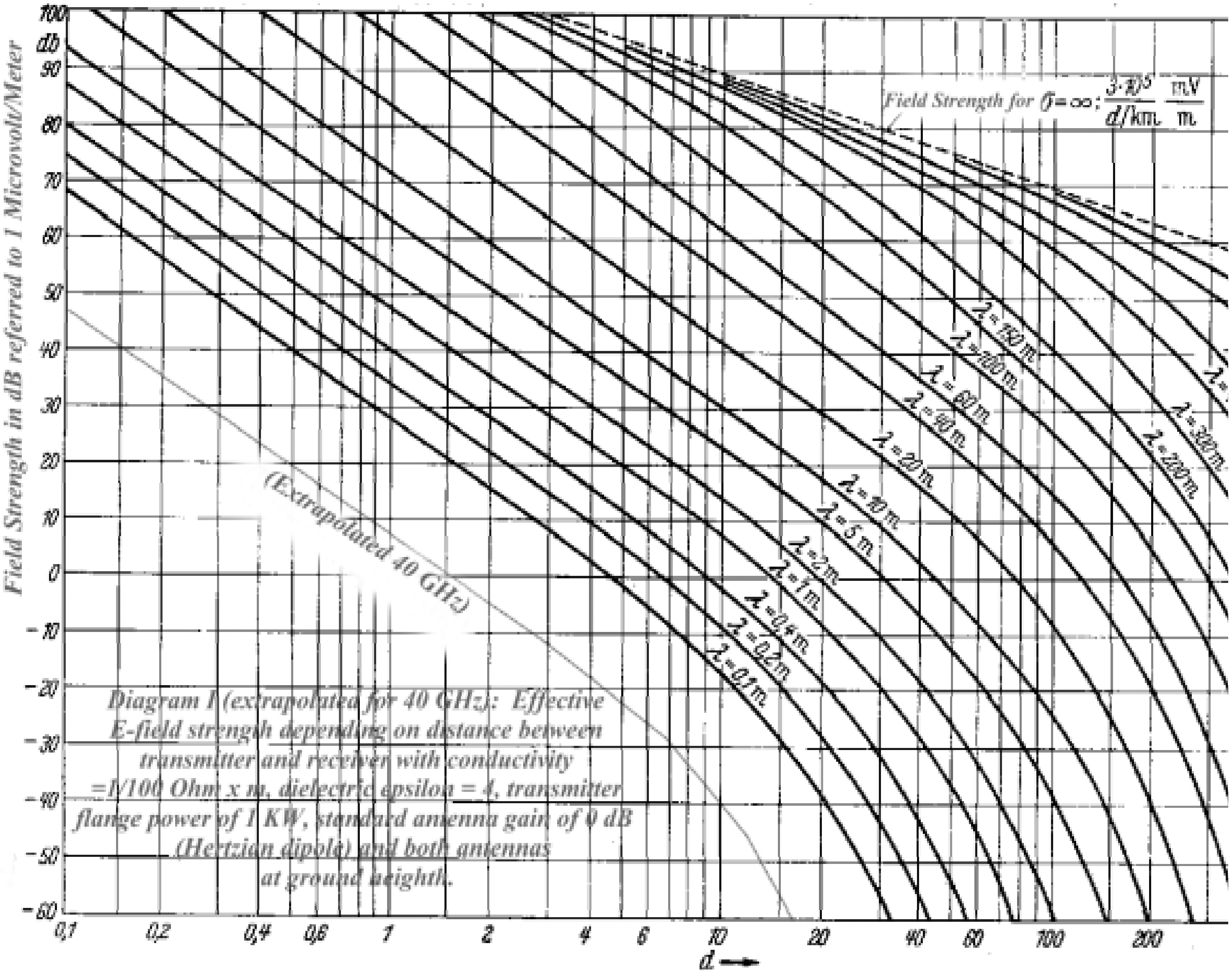

Diagram 1 (Ground Absorption alone)

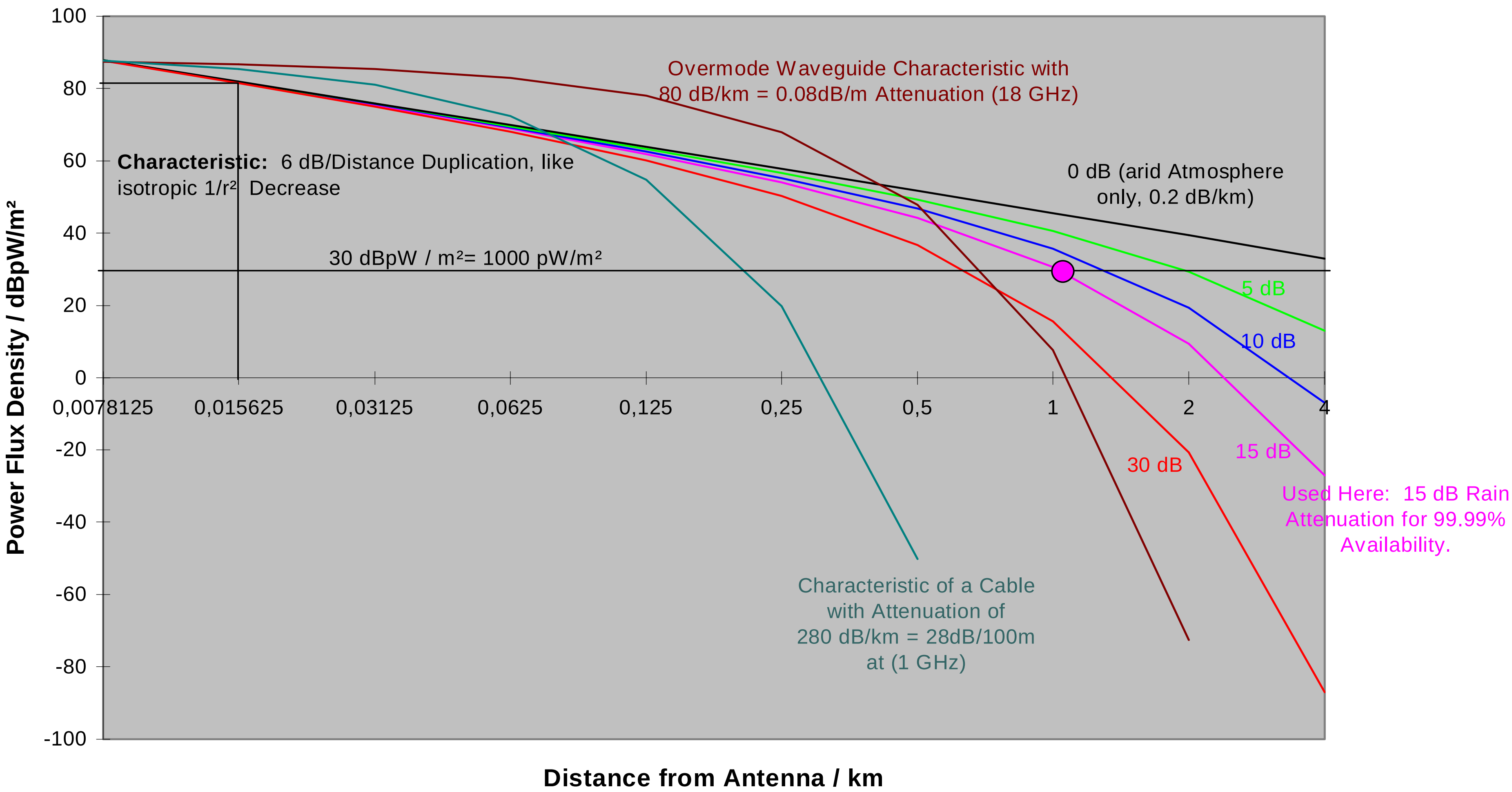

Diagram 2: Signal Propagation at 40 GHz and different Rain Attenuation

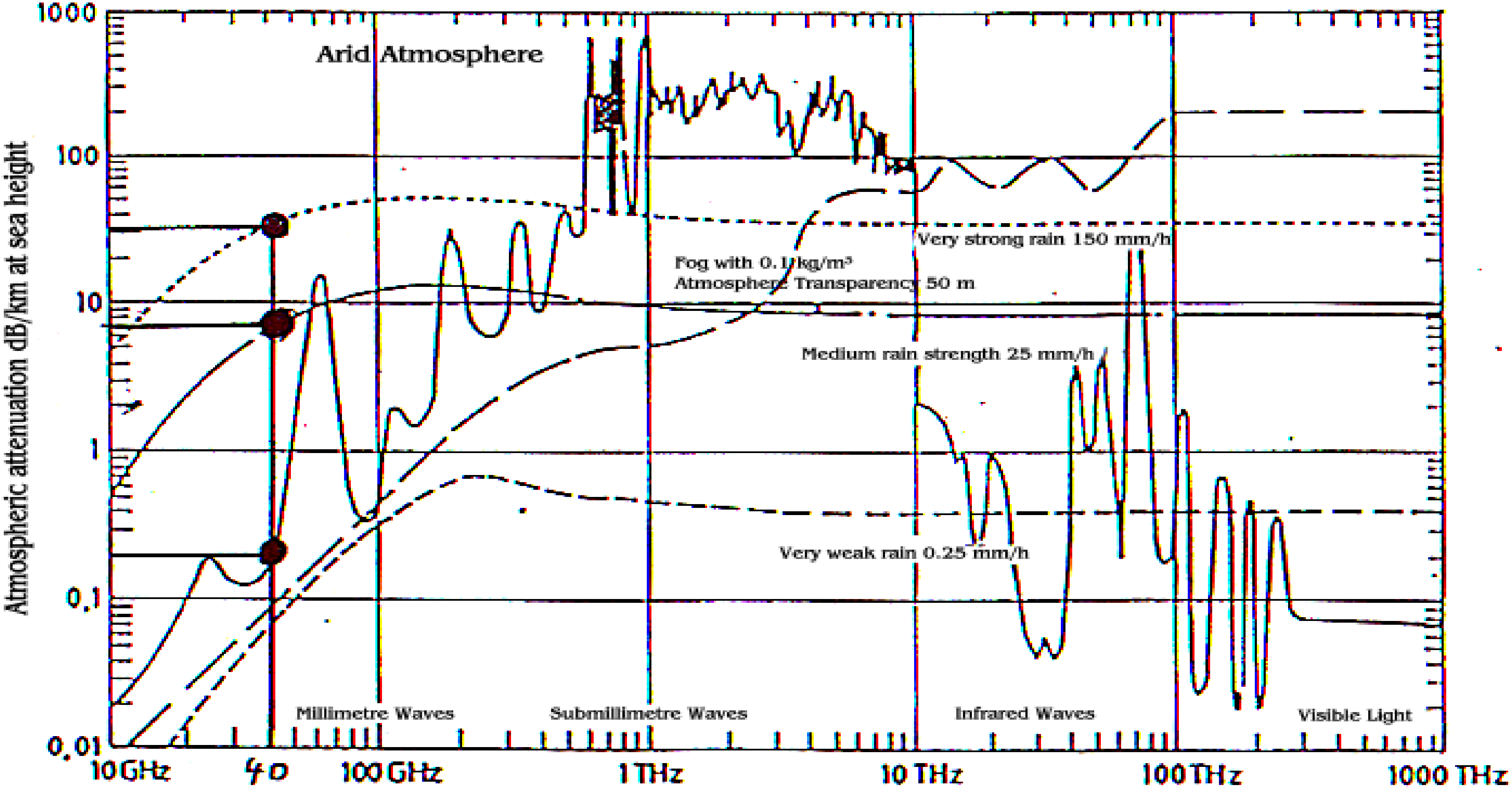

Diagram 3: Atmospheric Attenuation versus Frequency
(E.g. Central Europe: 0,01 % of the year with 37 mm/h; ITU)

Table 4: Link Budget/Base station -> User Terminal at 40 GHz

P (W) at Antenna Flange / Base Station	0,03	Red = Transmission
Antenna Gain, Transmission / dB	12	
EIRP (dBm)	26,77	
Path Length / Km	1	Green = Path influence
Rain Attenuation / dB/km	15	
Power Flux at Reception Site /pW/m²	1142,65	
Background Noise Temperature / K	300	
Aperture Hertzian Dipole / 40 GHz / m²	6,7E-06	Blue = Reception
Antenna Gain, Reception / dB	35	
Equivalent Antenna Noise Temperature	20	
Signal Power / Antenna Flange (pW)	24,26	
System (2 x Nyquist-) Bandwidth / MHz	27,5	
Noise Power / Antenna Flange (pW)	0,12	
C / N (dB) / Antenna Flange	23,01	
Feed Waveguide Attenuation / dB	3	
C / N (dB) / Feed Waveguide Output	20,01	
Gain / LNA (dB)	40	
Noise Figure of LNA / dB	5	
C / N (dB) / LNA Output	15,01	
Noise Figure of Downconverter / dB	8	
C / N (dB) / Downconverter Output	15,00	
Environment Temperature / k	300	
Equivalent System Noise Temperature / k	1913,19	
G / T (dB/K)	2,18	

Table 5: Link Budget/User Terminal -> Base Station at 40 GHz

P (W) at Antenna Flange / User Terminal	0,015	Red = Transmission
Antenna Gain, Transmission / dB	35	
EIRP (dBm)	46,76	
Path Length / Km	1	Green = Path influence
Rain Attenuation / dB/km	15	
Power Flux at Reception Site /pW/m²	113994	
Background Noise Temperature / K	300	
Aperture Hertzian Dipole / 40 GHz / m²	6,7E-06	Blue = Reception
Antenna Gain, Reception / dB	12	
Equivalent Antenna Noise Temperature	20	
Signal Power / Antenna Flange (pW)	12,13	
System (2 x Nyquist-) Bandwidth / MHz	27,5	
Noise Power / Antenna Flange (pW)	0,12	
C / N (dB) / Antenna Flange	20,00	
Feed Waveguide Attenuation / dB	3	
C / N (dB) / Feed Waveguide Output	17,00	
Gain / LNA (dB)	40	
Noise Figure of LNA / dB	5	
C / N (dB) / LNA Output	12,00	
Noise Figure of Downconverter / dB	8	
C / N (dB) / Downconverter Output	11,99	
Environment Temperature / k	300	
Equivalent System Noise Temperature / k	1913,19	
G / T (dB/K)	-20,82	

Table 5a: Link Budget/User Terminal -> Base Station at 40 GHz @ 1,54 MSy/s

P (W) at Antenna Flange / User Terminal	0,0008	Red = Transmission
Antenna Gain, Transmission / dB	35	
EIRP (dBm)	34,03	
Path Length / Km	1	Green = Path influence
Rain Attenuation / dB/km	15	
Power Flux at Reception Site /pW/m²	6079,67	
Background Noise Temperature / K	300	
Aperture Hertzian Dipole / 40 GHz / m²	6,7E-06	Blue = Reception
Antenna Gain, Reception / dB	12	
Equivalent Antenna Noise Temperature	20	
Signal Power / Antenna Flange (pW)	0,65	
System (2 x Nyquist-) Bandwidth / MHz	1,54	
Noise Power / Antenna Flange (pW)	0,01	
C / N (dB) / Antenna Flange	19,78	
Feed Waveguide Attenuation / dB	3	
C / N (dB) / Feed Waveguide Output	16,78	
Gain / LNA (dB)	40	
Noise Figure of LNA / dB	5	
C / N (dB) / LNA Output	11,78	
Noise Figure of Downconverter / dB	8	
C / N (dB) / Downconverter Output	11,78	
Environment Temperature / k	300	
Equivalent System Noise Temperature / k	1913,19	
G / T (dB/K)	-20,82	

Table 6: Frequency Raster Future Ressource up to 43,5 GHz

Frequency Raster 40,6 - 42,65 GHz (20 500 Segments à 100 KHz)						Frequency Raster 42,85 - 43,4 GHz (5500 Segments à 100 KHz)					
Lower Ressource Edge:			40600	MHz		Upper Ressource Edge:			43400	MHz	
Edge Guard Band:			100	MHz		Edge Guard Band:			100	MHz	
Starting at/MHz:		40500,05				Stopping at/MHz:		43499,95			
Raster - Increment/MHz:		0,1				Raster - Increment/MHz:		0,1			
(=Segment Width)						(=Segment Width)					
Segment Number:		Segment Centre Frequency:		Lower Edge	Upper Edge	Segment Number:		Segment Centre Frequency:		Lower Edge	Upper Edge
1		40500,1	MHz	40500,05	40500,15	23500		42850	MHz	42849,95	42850,05
2		40500,2	MHz	40500,15	40500,25	.	Sum:				.
3		40500,3	MHz	40500,25	40500,35	.	5500	Upstreams			.
.						.	Segments				.
.		Guard Band				28999		43399,9	MHz	43399,85	43399,95
.											
740		40574	MHz	40573,95	40574,05			Beginning of Guard Band			
						29000		43400	MHz	43399,95	43400,05
						.	Sum:	.	.	.	.
741		40574,1	MHz	40574,05	40574,15	.	1000	.	.	.	.
742		40574,2	MHz	40574,15	40574,25	.	Segments	.	.	.	.
743		40574,3	MHz	40574,25	40574,35	29999		43499,9	MHz	43499,85	43499,95
.	Sum:							End of Guard Band			
.	195	Guard Band									
.	Segments										
935		40593,5	MHz	40593,45	40593,55						
936		40593,6	MHz	40593,55	40593,65						
937		40593,7	MHz	40593,65	40593,75						
938		40593,8	MHz	40593,75	40593,85						
.	.	.	.	.	.						
998		40599,8	MHz	40599,75	40599,85						
999	Sum:	40599,9	MHz	40599,85	40599,95						
	195	End of Guard Band									
1000	Segments	40600	MHz	40599,95	40600,05						
1001		40600,1	MHz	40600,05	40600,15						
1002		40600,2	MHz	40600,15	40600,25						
.					.						
.		Downstreams			.		Sum Downstreams:				
.					.		20500	Segments			
1130		40613	MHz	40612,95	40613,05						
1131		40613,1	MHz	40613,05	40613,15						
.	Sum:				.						
.	20369	Downstreams			.						
.	Segments				.						
21499		42649,9	MHz	42649,85	42649,95						
		Beginning of Guard Band									
21500		42650	MHz	42649,95	42650,05						
.	Sum:	.	.	.	.						
.	1000	.	.	.	.						
.	Segments	.	.	.	.						
22499		42749,9	MHz	42749,85	42749,95						

Table 7: Security distance for 10 W/m^2 at full load conditions

Security Distance and Power Flux Density								**Security Distance and Power Flux Density**				
Base Station								**User Terminal**				
Number of Channels					100			Number of Channels				
P(W) per Carrier @ 27.5 Msymbols/sec					0,03			P(W) per Carrier @ 27.5 Msymbols/sec				
Comp. Power (W)/Antenna Flange/Base St.					3			Comp. Power (W)/Antenna Flange/Base St.				
Antenna Gain / dB					12			Antenna Gain / dB				
EIRP (dBm)					46,77			EIRP (dBm)				
Distance to Antenna / m					**0,6**			**Distance to Antenna / m**				
Power Flux /W/m^2					**10,22**			**Power Flux /W/m^2**				

Table 7a: Frequency Ressource of a Cell

ATM Framing					
Area of a big Town/km²		310,5	(Munich/Germany)		
Cell Area km²		3,14			
Number of Cells		98			
Number of Base Stations		392			
Number of Houses		123478	(status: 2000)		
Av No Households/House		5,6	(status: 2000)		
Av No Households		691476,80			
Av No Houses/Cell		1259			
Upstreams					
Assumed Spect Ress/MHz		550			
No of Polarizations		2			
No of Sectors/Cell		4			
Nyquist Rolloff		1,3			
Perctg of Time parallel Use		31,20%	(assumed, Limit of TDMA Operation)		
Frequency Ress/Cell/MHz		3384,62			
Bits/Symbol		2			
Payload Rate (ATM)		0,83			
Av No Households/Cell		7050,4			
Bit Rate/Household/Mbit/s		2,55			
Downstreams with ATM OOB Channels					
Assumed Spect Ress/MHz		2050			
No of Polarizations		2			
No of Sectors/Cell		4			
Nyquist Rolloff		1,3			
Perctg of Time parallel Use		31,20%	(assumed)		
Frequency Ress/Cell/MHz		12615,38			
Bits/Symbol		2			
Payload Rate (ATM)		0,92			
Av No Households/Cell		7050,4			
Bit Rate/Household/Mbit/s		10,50			

History

Document history		
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