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Title: **Transmit Power for TDMA Systems**

Agenda item: **HA PHY**

Document for:

Decision	X
Discussion	X
Information	X

Decision/action requested

BRAN (or maybe other relevant standardization bodies) should specify the maximum permitted transmit power and power flux density for HA systems.

Abstract

Broadband TDMA systems require high transmit power not only for base stations but also for terminals due to the burst-mode operation in the uplink, even if the user data rates are low. The requirements depend on cell radius, frequency range, bandwidth, rain zone, availability, modulation scheme, etc. However, a high transmit power has two major drawbacks:

- **the power amplifiers in the terminals are expensive**
- **the maximum power flux density at the terminal antenna might be too high and maybe above the limit.**

BRAN should specify as soon as possible the maximum permitted power figures for the HA terminals. If BRAN can not specify any limits, this task should be forwarded to other relevant radio standardization bodies.

1. Introduction

We consider a PMP architecture with TDM/TDMA using FDD. For the transmission in downlink from the base station to the terminals as well as for the uplink a single broadband carrier is supposed. Hence high transmit powers are required for the base station as well as for the terminals, even if the data rates to be transmitted at the terminal in the uplink could be very small. This could be critical for the terminals, both from cost aspects as well as due to limits on the maximum human exposure to electromagnetic fields. The latter point has to be checked very carefully by BRAN, otherwise a broadband transmission in uplink is not possible at all. The downlink seems less critical, since HPA costs in the base station might be acceptable and humans are typically far away from the base station antenna.

2. Required Transmit Power

The transmit power P_{TX} is calculated as follows

$$P_{TX} = a_{pathloss} + P_{noise} - G_{TX\_antenna} - G_{RX\_antenna} + a_{rain} + offset + C/N,$$

where

- $a_{pathloss} = 10 \cdot \log_{10}\left(\frac{4\pi f_c}{c} \cdot d\right)^2$ is the line-of-sight path loss, where
  f_c is the carrier frequency,
  c is the velocity of light,
  d is the distance.
  Hence $a_{pathloss}$ = 132.1 dB for 3 km, 136.5 dB for 5 km @ 32 GHz,
  $a_{pathloss}$ = 134.4 dB for 3 km, 138.9 dB for 5 km @ 42 GHz.

- $P_{noise} = F \cdot N_{thermal} = F \cdot KT \cdot B$ is the noise power at receiver input, where
  F = 8 dB is the receiver noise figure,
  $K = 1.38 \cdot 10^{-23}$ Ws/Kelvin is the Boltzman constant,
  T = 293 Kelvin (20 degree C) is the temperature,
  B is the bandwidth.
  Hence $P_{noise}[dBm] = 8 + 10 * \log_{10}(1.38 \cdot 10^{-14} \cdot 293) + 10 * \log_{10}(B[MHz])$,
  so P_{noise} = -94.5 dBm @ 14 MHz, -91.5 dBm @ 28 MHz.

- The antenna gains for transmitter and receiver could be replaced by base station and terminal station in order to be independent from uplink and downlink.
  G_{BS} = 17 dBi for a base station with 45 degree sectors.
  G_{TS} = 28 dBi for a terminal with 5 degree planar antenna
  (with an aperture area of $A_{antenna}$ = 0.15 x 0.15 = 0.0225 m^2),
  G_{TS} = 34 dBi for a parabolic antenna (with a diameter of 30 cm), and
  G_{TS} = 40 dBi for a parabolic antenna (with a diameter of 60 cm).

- a_{rain} is the rain fading. The values are given in Table 1 for rain zone H [1] :

Distance	**32 GHz**	**42 GHz**
2 km	15 dB	20 dB
3 km	21 dB	29 dB
4 km	27 dB	37 dB
5km	33 dB	45 dB

Table 1: Rain attenuation for rain zone H and 99.99% availability

Some slightly different figures can be found in [3].

- *offset* = 7 dB in total (3 dB for interference margin, 3 dB for system tolerance, 1 dB radom rain attenuation).

- *C/N* = 7 dB for QPSK with convolutional coding of rate 1/2 @ BER=10^{-7}.

The results on the required transmit power are given in Tables 2 and 3:

Distance	**32 GHz**		**42 GHz**	
	14 MHz	**28 MHz**	**14 MHz**	**28 MHz**
3 km	27.6	30.6	38.0	41.0
5 km	44.0	47.0	58.4	61.4

Table 2: Required transmit power [dBm] for terminal planar antenna

Distance	**32 GHz**		**42 GHz**	
	14 MHz	**28 MHz**	**14 MHz**	**28 MHz**
3 km	21.6	24.6	32.0	35.0
5 km	38.0	41.0	52.4	55.4

Table 3: Required transmit power [dBm] for terminal parabolic antenna (30 cm)

Distance	**32 GHz**		**42 GHz**	
	14 MHz	**28 MHz**	**14 MHz**	**28 MHz**
3 km	15.6	18.6	26.0	29.0
5 km	32.0	35.0	46.4	49.4

Table 4: Required transmit power [dBm] for terminal parabolic antenna (60 cm)

Conclusion: More than 30...33 dBm for the HPA in the terminal is a technical challenge and has great influence on the overall terminals costs. For 42 GHz, parabolic antennas may be required and the distance should be restricted to 3 km.
It should be noted that the ETSI TM4 spcification for 26 GHz allows a maximum nominal transmit power of 33 dBm.

Some remarks on the sensitivity with regards to the most important parameters:

- Increasing the bandwidth by a factor of 2 increases the required transmit power by a 3 dB (via noise power)
- Increasing the distance by a factor of 2 increases the path loss by 6 dB, but this is negligible compared to the huge increase in rain attenuation.
- The availability has extreme influence on the rain fading: An increase from 99.99% to 99.999% requires about 30 dB more power (@ 5km @ 42 GHz), a reduction to 99.9% saves about 10 dB.
- Modulation: Increasing the convolutional code rate from 1/2 to 7/8 costs 3 dB additionally. Reducing the BER from 10^{-7} to 10^{-5} saves 1 dB.

- Base station antenna: Increasing the sector angle from 45 degree to 90 degree costs 3 dB, reducing to 15 degree saves 3 dB but is very expensive.
- Terminal antenna: Reducing the parabolic antenna from 60 cm to 30 cm costs 6 dB.

3. Power Flux Density and Maximum Transmit Power

The limits on the power flux density are 50 W/m^2 for professionals and 10 W/m^2 for normal people according to [2]. This is applicable for a continuous exposure of at least 6 min (i.e. less than the percentage of time where the system is not available in case of 99.999% availability).

We consider only the terminal in this section. The power flux density PFD for the far-field is calculated as

$$PFD = \frac{G_{antenna} \cdot P_{TX}}{4\pi d_{safety}^{\ 2}} \quad \text{(far-field)},$$

where d_{safety} is the safety distance between a person and the terminal. The transition distance from the near-field to the far-field is given by

$$d_{near\_far} = \frac{2D^2}{\lambda},$$

where λ denotes the wave length and *D* the maximum aperture distance.As a worst-case assessment, this PFD is regarded as four times higher than that for a uniform power distribution over the antenna aperture area:

$$PFD = \frac{4 \cdot P_{TX}}{A_{antenna}} \quad \text{(near-field)},$$

where $A_{antenna}$ is the antenna aperture area. The antenna parameters are summarized in Table 5.

Antenna type	**Gain** [dBi]	**Aperture area** $[m^2]$	d_{near_far} [m]	
			32 GHz	**42 GHz**
planar	28	0.0225	4.8	6.3
parabolic, 30 cm	34	0.0707	19.2	25.2
parabolic, 60 cm	40	0.2827	76.8	100.8

Table 5: Terminal antenna parameters

From the near-field worst-case assumption, the limit on the power flux density implies an upper bound on the maximum transmit power as summarized in Table 6.

Antenna type	P_{TX} [dBm]
planar	24.5
parabolic, 30 cm	29.5
parabolic, 60 cm	35.5

Table 6: Maximum permitted transmit power
(for a power flux density of 50 W/m2)

Using the P_{TX} figures from Table 6 and PFD = 10 W/m^2 for normal people and the antenna gains from Table 5, the minimum safety distance d_{safety} can be calculated from the far-field equation at the top of this section. Table 7 shows the results. It seems questionable that such a great safety distance as implied by the 60 cm parabolic antenna could be acceptable.

Antenna type	d_{safety} [m]
planar	1.2
parabolic, 30 cm	4.2
parabolic, 60 cm	16.8

Table 7: Safety distance
(for a power flux density of 10 W/m2)

4. Summary

The comparison of required transmit power and permitted transmit power delivers the following results for a bandwidth of 28 MHz:

- For 32 GHz, a distance of 3 km is possible with 30 cm parabolic antenna.
- For 32 GHz, a distance of 5 km is possible with 60 cm parabolic antenna.
- For 42 GHz, a distance of 3 km is possible with 60 cm parabolic antenna.

References

[1] CEPT/ERC Input Paper from Germany: Proposal for a Working Document towards a Draft ERC-Recommendation for point-to-point and point-to-multipoint digital radio relay systems operating in the frequency band 31.8 GHz to 33.4 GHz, October 1999.

[2] CENELEC Specification: Human Exposure to Electromagnetic Fields, 10 kHz to 300 GHz. ENV 50166-2.

[3] ACTS Project 215 CRABS: Propagation Planning Procedures for LMDS. Deliverable Report D3P1B, January 1999.