

# Impact of regulations on feasible distance between 60 GHz devices

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## IMPACT OF REGULATIONS ON FEASIBLE DISTANCE BETWEEN 60 GHz DEVICES

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**Abstract - In this paper we address the impact of the current world-wide safety and interference regulations with respect to the 60 GHz band on the feasible distance between a transmitting and a receiving device assuming a beam-forming array antenna at both ends of the link. From these considerations it occurs that these regulations impose severe constraints in terms of allowable antenna gain at the transmitter as well as allowable levels of transmit power in case of non-line-of-sight operation. Therefore, these regulatory constraints necessitate an additional amount of beam-focusing at the receiving end. The feasible separation distance is determined assuming a balanced distribution of antenna gain between transmit antenna and receive antenna and technically well-feasible levels of transmit power. Furthermore, the propagation conditions that typically occur in the 60 GHz band are taken into account as well as the relevant user and system requirements as formulated in current design and standardization documents.**

## I. INTRODUCTION

There is a growing interest in low-power low-cost high-speed radios for the support of a large variety of speed-demanding applications such as uncompressed high-definition video streaming, ultra-fast wireless personal area networks and ultra-fast download over short distances [1]. This interest is reflected in the current standards for high rate applications [2-4]. These standards define a number of physical layers using the 60 GHz frequency band. This band provides the best opportunity for supporting multi-Gbps due to its bandwidth of many GHz which is a unique feature when compared to the lower bands for short-distance wireless communication. However, due to the high frequency, the 60 GHz band exhibits a high path-loss. In addition, severe shadowing is encountered as soon as the direct line-of-sight (LOS) path becomes blocked. Therefore, the standards prescribe the use of trainable high-gain antennas for non-LOS (NLOS) operation for the support of “high-end” devices. As soon as the direct LOS path becomes blocked the antenna beams will be redirected towards one or more strong reflections. So, under NLOS conditions, the connection is maintained via at least one reflection. Then, more effective isotropic radiated power (EIRP), i.e., transmit power times antenna gain, is needed to compensate for the increased path length and the additional reflection losses. In case the link is maintained by only one dominant reflection, the antenna

beams at both ends of the link are aligned with this reflection by the training feature of both antennas. However, the increase of transmit power and/or transmit antenna gain should be limited to an allowed level in order to avoid the occurrence of thermal and, eventually, non-thermal effects in biological tissues as well as electromagnetic interference. These allowed levels are laid down in world-wide exposure and interference regulations in terms of transmit power, antenna gain and EIRP [5] – [8].

In Section II, we give an overview of the current regulations in the world as regards the 60 GHz band. In the two subsequent sections we address the limitation imposed by these regulations as regards the maximum acceptable separation distance, i.e., the maximum feasible distance between a transmitting device and a receiving device with still acceptable outage probability. Section III addresses the most restrictive category of devices, i.e., those that are “portable” according to the definition given in the US regulations. In Section IV we consider the regulatory restrictions for “mobile” devices as defined by the US regulations and for other regions in the world. Finally, in Section V, we present the conclusions.

## II. REGULATIONS

Figure 1 summarizes the exposure and interference regulations for the 60 GHz band in terms of allowable level of transmit power and antenna gain for different regions of the world.

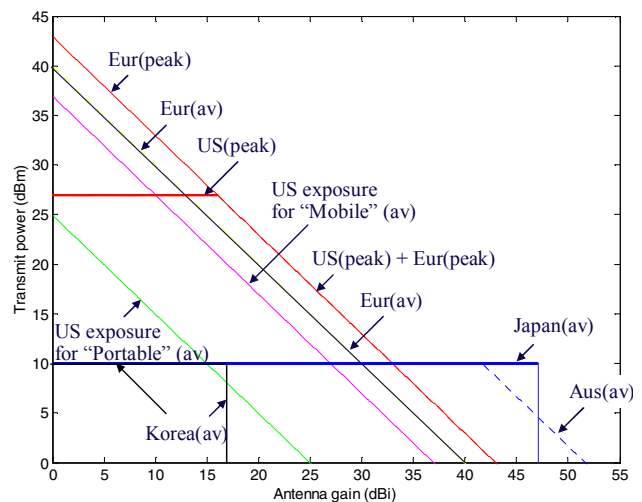


Fig. 1: 60 GHz regulations on average and peak power limits versus antenna gain.

In Fig. 1, the term “Portable” refers to the definition of a “portable device” according to US regulations [5] which reads “a transmitting device to be used so that the device is within 20 centimeters of the body of the user”. Clear examples are notebooks and Personal Digital Assistants (PDA’s). These devices have a limitation in average EIRP of 25 dBm. The term “Mobile” refers to the US definition of a “mobile device” according to [5], which reads “a transmitting device designed to be used in other than fixed locations and to generally be used in such a way that a separation distance of at least 20 centimeters is normally maintained between the transmitter’s radiating structure(s) and the body of the user or nearby persons”. Devices that are not physically secured at one location and are able to be easily removed to another location like plasma screens, blu-ray disk players and set-top boxes are considered to be mobile devices. Note, that devices that transmit with a significant peak-to-average-power-ratio (PAPR) may be limited in transmit power by the peak-power limits rather than the average- power limits. In particular if Orthogonal Frequency Division Multiplex (OFDM) is used, without particular PAPR reducing measures, the PAPR can be considerable. The IEEE 802.15.3c standard prescribes the use of OFDM with 512 subcarriers for its high speed interface (HSI) mode as well as its audio/video (A/V) mode [2]. With such a high number of subcarriers, and no particular countermeasures, the PAPR of OFDM becomes 8.3 dB for 99% of the time independent of the carrier constellation [9]. The IEEE standard also includes a single carrier (SC) mode supporting, among others,  $\pi/2$ -shift BPSK/ (G)MSK,  $\pi/2$ -shift QPSK and  $\pi/2$ -shift 16 QAM exhibiting a PAPR of 2.1 dB, 5.3 dB and 7.1 dB, respectively [10].

### III. REGULATORY IMPACT FOR “PORTABLE” DEVICES

Now let us consider a prominent example of a 60 GHz application; namely a wireless link for the transmission of uncompressed high definition video and let us assume that the system parameters comply with the mandatory mode of the audio/video physical layer as defined by the IEEE 802.15.3c standard [2] (HRP mode index 0). These parameters are listed in Table I. The 10 dBm value for the average transmit power has been chosen because it is the maximum allowed level for Korea, Japan and Australia. This 10 dBm, in combination with a 15 dBi transmit antenna gain, just complies with the limit for “portable” devices, which is the most restrictive US EIRP limit. The transmit antenna gain figure of 15 dBi is of particular significance since it is the maximum allowed value for worldwide operation. Table I also contains the maximum “acceptable” separation distances between transmit and receive antenna for LOS as well as NLOS operation. The term “acceptable” refers to the maximum separation distance at which the link has an acceptably low outage probability. This maximum distance has been determined on the basis of the log-distance path-loss model with parameterization

according to the generic 60-GHz path-loss model for indoor environments presented in [13]. It is assumed that the shadowing component has a normal distribution. A margin of two times the standard deviation of the spread in the shadowing component has been taken into account. This corresponds to an outage probability of about 2%. If we consider this as “acceptable” then we can calculate the maximum acceptable separation distance  $r_{\max}$  with

$$10n \log r_{\max} = P_t + G_t + 20 \log \left( \frac{\lambda}{4\pi} \right) + G_r - P_{r,\min} - 2\Omega, \quad (1)$$

in which  $P_t$  represents the average transmit power in dBm,  $G_t$  the transmit antenna gain in dBi,  $\lambda$  the wavelength in free space in meters,  $G_r$  the receive antenna gain in dBi,  $P_{r,\min}$  the receiver sensitivity in dBm,  $\Omega$  the standard deviation of the spread in the shadowing component in dB and  $n$  the path-loss exponent. Note, that in the calculation of  $r_{\max}$ , the losses due to imperfections of the transmitter are incorporated in  $P_t$  and  $G_t$  whereas the losses due to imperfections of the receiver are incorporated in  $P_{r,\min}$ . The only non-ideality that has not been taken into account is the loss due to misalignment of the antennas, so we assume ideal antenna alignment.

TABLE I  
Link parameters of the 60 GHz audio/video physical layer defined by IEEE Std 802.15.3c.

Parameter	Ref.
Application	Uncompressed high definition audio/video [2]
Propagation conditions	LOS/NLOS operation. [14]
Center frequency of mandatory channel.	60.48 GHz [2]
Data rate	0.952 Gbps [2]
Modulation	OFDM/QPSK [2]
Channel coding	Conv. and RS [2]
Average Tx power $P_t$	10 dBm This
Tx antenna gain $G_t$	15 dBi This
Path-loss exponent $n$	LOS: 1.7 [13] NLOS: 3.3 [13]
Shadowing margin $2\Omega$	LOS: 3.6 dB [13] NLOS: 9.2 dB [13]
Rx antenna gain $G_r$	15 dBi This
Receiver sensitivity $P_{r,\min}$	-50 dBm [2]
Maximum distance $r_{\max}$	LOS: 12 m NLOS: 2.4 m

With current 60 GHz device technology, an average transmit power of 10 dBm can be produced by one single power amplifier with sufficient linearity. An antenna gain as high as 15 dBi is also readily feasible. In [11], a realization of a 60 GHz six-element antenna array is

presented having a gain of 14 dBi and a 3 dB scan-range of  $50^\circ$ . This means that steering the beam to  $50^\circ$  from perpendicular direction (with respect to the array plane) goes with a gain reduction of 3 dB of the main beam leaving 11 dBi in that direction. This can be increased by implementing more antenna elements. Using more antenna elements also implies a more complicated feed structure and, as a consequence of that, more losses in the feed. The gain increase is therefore not the theoretical 3 dB per doubling of antenna elements but somewhat lower. In [12] a figure of about 2 dB per doubling of antenna elements is observed. This indicates that 4 dB additional antenna gain can be achieved with four times as much antenna elements. Note, that with the resulting 24-element antenna the transmit power has to be decreased when the scan angle becomes smaller. With a proper adaptation of transmit power the maximum allowed EIRP can be used within the whole scan range. This is a desirable feature in an EIRP-limited system as we consider here. The technological feasibility of more than 25 dBm of EIRP implies that the EIRP limitation is imposed by the regulations. Fortunately there are no regulatory restrictions for the receiving end and we can increase the performance by implementing receive antennas with larger antenna gain.

Now let us examine how many dB's we actually miss in the link-budget. For that, we compare the outcomes of  $r_{\max}$  in Table 1 with the corresponding distances of the relevant user scenarios defined by the IEEE 802.15.3 task group 3c. This task group selected five usage models, which are described in [14]. One of them (UM1), targets our example of uncompressed high speed video streaming over 5 to 10 meters under LOS as well as NLOS conditions. Since  $r_{\max}$  equals 12 meter there is no problem for LOS situations provided that the pointing loss remains below 2 dB. For NLOS situations, however, the calculated maximum distance does not meet the requirement of 5-10 meters. According to (1) we encounter a shortage of about 10 and 20 dB in the linkbudget for bridging 5 and 10 meters, respectively.

Where and how can we gain these dB's in the linkbudget? As we already indicated, a doubling of antenna elements yields roughly 2 dB of additional antenna gain, so we need to implement antenna arrays with  $2^5$  and  $2^{10}$  times as much elements for gaining the required 10 and 20 dB, respectively. In practice, we can create an additional gain of 4 dB or so by implementing 4 times as much (=96) antenna elements but a further increase would lead to a prohibitively large antenna array. With the resulting 19 dBi (at the 3-dB edge of the receive antenna scan-range) in combination with the 25 dBi of EIRP the maximum "acceptable" separation distance would become  $r_{\max} = 3.2$  m. So, with practical antennas, it is still not possible to meet the "5 to 10 meters" specification under NLOS conditions. Therefore, it would make much sense for the task group 3c to reconsider the receiver sensitivity figure for this application. In this context it is remarkable that for another defined mode, i.e., the Single Carrier mode, a 5

dB more stringent receiver sensitivity requirement is posed whereas the maximum separation distance requirement for the intended application (UM5 Kiosk downloading with similar data rate under LOS and NLOS conditions) is only 1 meter.

Finally, it should be noticed that, for NLOS situations, a distance claim of 10 meters corresponds with a 10 dB more stringent linkbudget when compared with a distance claim of only 5 meters and not 6 dB as for LOS situations under free-space conditions. This is a unfortunate consequence of the high path-loss exponent of 3.3 instead of 2. So, it makes much sense to differentiate the distance claim for NLOS and LOS and to alleviate the distance claim to 5 meters (or 3 to 5 meters or so) for NLOS operation. Under LOS conditions there is no problem to bridge 10 meters.

### III. REGULATORY IMPACT FOR "MOBILE" DEVICES

For devices in Europe, Japan, Australia and for "mobile devices" in the US it is possible to further increase the EIRP by increasing the transmit antenna gain by the same amount as the receive antenna thus gaining 8 dB in total antenna gain. Furthermore, the transmit power can be readily increased. With a multiple antenna architecture as presented in [15] each transmitting antenna element has its own power amplifier. In such way the radiated power of all these amplifier-antenna combinations (branches) "mix in the air" so that the power combining comes for free. If all branches produce the same power, the total transmitted power equals the power produced by one single branch times the number of branches. So, with 96 branches each having a power amplifier producing 10 dBm, we have a total transmit power of  $10 + 10\log(96) = 29.8$  dBm. Thus, with the 19 dBi transmit antenna gain, this yields an average EIRP of 38.8 dBm. With this level of EIRP in combination with the formerly determined 19 dBi of receive antenna gain the maximum "acceptable" separation distance under NLOS conditions amounts to 8.4 meters. Taking into account the PAPR of OFDM this EIRP is only allowed in Japan and Australia. The Korean limit allows only 27 dBi of average EIRP whereas for Europe and the US the regulations for peak levels are the limiting factors as far as it concerns devices that transmit OFDM signals; with OFDM exhibiting a PAPR of 8 dB, the maximum allowed average transmit power with 19 dBi transmit antenna gain amounts to  $43 - 19 - 8 = 16$  dBm which corresponds to an average EIRP of  $16 + 19 = 35$  dBm. For NLOS this implies that  $r_{\max} = 6.5$  meters. Hence, the often- mentioned minimum distance the 5 meters can be bridged with these devices. However the often-mentioned requirement of 10 meters is not feasible.

### V. CONCLUSIONS

- It is shown that the world-wide regulations of the 60 GHz band in terms of EIRP, transmit power and transmit antenna gain are not restrictive as regards

the operation of 60 GHz devices under LOS conditions.

- However, it is also shown that the US regulations as well as the European and Korean regulations restrict the maximum feasible separation distance between transmitting and receiving device under NLOS conditions.
- In particular “portable” devices in the US have a limited range of up to 2.4 meters at maximum (with acceptable outage probability) in NLOS situations due to the stringent regulatory constraints that apply for these kind of devices. This is significantly lower than the figures of 5 and 10 meters which are often mentioned in user scenario and system design documents. This has substantial consequences for an important class of user scenarios since notebooks and PDA’s fall within this category and, as such, the development of prominent appealing applications like ultra high-speed WLAN and “PC on TV” is jeopardized.
- It is advised not to claim the proper operation of 60 GHz devices at up to 10 meters separation distance in NLOS situations. A claim of only 5 meters instead gives an alleviation of 10 dB in the linkbudget for NLOS operation.

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