Development of Path Loss Model for 802.11n in Large Conference Rooms

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***Abstract*—In this paper, a path loss (PL) model for 802.11n in large conference rooms is determined, based on PL measurements. The PL can be described accurately by a one-slope model with one standard deviation. PL exponents varying from 1.2 to 1.7 are found. Based on this PL model, the effect of frequency (2.4 vs 5 GHz), configuration (SISO vs MIMO (spatial diversity)), bandwidth (20 vs 40 MHz) and transmit power on number of access points, total power consumption and possible (physical) throughputs is investigated. According to the determined PL model, a higher range (by tuning the transmit power) requires less access points, as well as a lower total power consumption, due to a PL exponent lower than 2.**

I. Introduction

The Wireless LAN Standard IEEE 802.11n, released in 2009, is an amendment to the previous standards 802.11a and 802.11g to provide higher throughputs [1]. Modifications to the physical layer comprise MIMO (Multiple-Input Multiple-Output), the 2.4/5 GHz band and a bandwidth of 20 or 40 MHz. Video streaming in large conference rooms, such as the European Parliament, requires throughputs of 55 Mbps (up to 24 video channels) and more. 802.11n might be suitable for this application.

In literature, no much path loss (PL) models can be found specifically for large conference rooms. The IEEE 802.11 TGn channel model could be applicable [2]. However, this model applies to very different types of environment (from residential to large space (indoors - outdoors)), and possibly does not take into account the specific geometry of large conference rooms (e.g. hemicycles). In this paper, a PL model for large conference rooms is determined, based on PL measurements. This model will be compared with the TGn channel model.

Based on this PL model, the effect of typical 802.11n features (including frequency, bandwidth and MIMO configuration) on number of access points, total power consumption and possible (physical) throughputs will be investigated, with the focus on large conference rooms. This evaluation will be compared again with the TGn channel model.

II. Path loss measurements

The path loss measurements were carried out in a large conference room in the European Parliament in Brussels. This room has a hemicycle geometry and contains about 350 seats (Fig. 1). The measurements were done at frequencies 2.4 and 5.4 GHz, corresponding to the 2 bands of 802.11n.

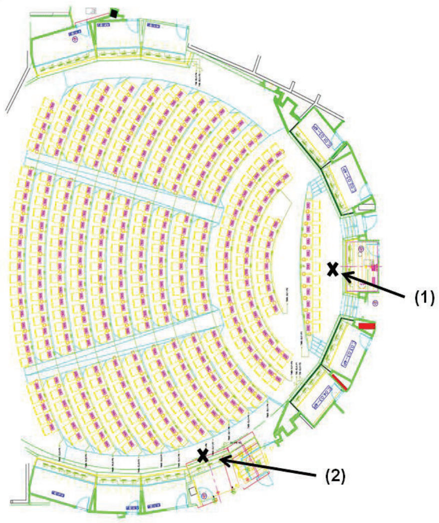

Fig. 1. Plan of conference room in European Parliament (Brussels), where PL measurements were carried out. (Plan taken over from Televic)

We considered 2 transmitter (Tx) positions. The first one is near the centre of the hemicycle ((1) in Fig. 1), at a height of 2 m and at a distance of 1 m from the wall. The second position is at the side of the room ((2) in Fig. 1), at a height of 3.5 m and about 10 cm from the wall. The Tx positions were chosen to get a LOS condition for all the seats. The receiver (Rx) was positioned just above the desks (i.e. the actual position of the clients). The measured trajectories, which the receiver moved along, included all rows of desks.

As measurement equipment at the Tx side, we used the Rohde&Schwarz signal generator SMJ100A, connected to a transmitting antenna. The equipment at the Rx side included a receiving antenna, connected to the Hewlett Packard spectrumanalyzer 8561B, and a tachometer. The spectrumanalyzer and the tachometer were connected to a laptop, which saved the received power and the distance along the Rx trajectory as a function of time. We used the omnidirectional MAT-JAYBEAM antenna MA431Z00 for 2.4 GHz, and the European Antennas antenna EVD2-5300/1285 for 5.4 GHz.

During the measurements, there was no people in the room. Consequently, these measurements allow to determine a PL model (including shadowing), but no temporal fading.

III. Path loss model

From the measurement data, we calculate the path loss [dB] by

$$PL = -\langle P_R \rangle + P_T + G_T + G_R - L_T - L_R, \quad (1)$$

where $\langle P_R \rangle$ is the averaged received power (P_R) [dBm], P_T is the transmit power [dBm], G_T (G_R) is the transmitter (receiver) gain [dBi], and L_T (L_R) is the transmitter (receiver) feeder loss [dB].

From the measurement data, we get the P_R samples and their corresponding position (distance along measured trajectory). To calculate $\langle P_R \rangle$, we average the lineair interpolation of the P_R samples over a distance of $10\,\lambda$, where λ is the wavelength.

During the measurements, we used a transmit power of 15 dBm. We determined experimentally the feeder losses: L_T is 4.1 dB at 2.4 GHz and 7.6 dB at 5.4 GHz; L_R is 2.2 dB at 2.4 GHz and 3.5 dB at 5.4 GHz.

We determine the gain (G) of transmitter and receiver as follows:

$$G = G_{max} + F(\theta), \quad (2)$$

where G_{max} is the gain [dBi] in the horizontal plane, and F, defined by G - G_{max}, depends on θ, the angle with the horizontal axis. It is necessary to consider an angle-dependent gain, since there are angles θ up to 47°, and the 3 dB beamwidth is 40° and 80° for the 2.4 GHz and 5.4 GHz antenna respectively. For the antennas used at 2.4 GHz, we use G_{max} and F(θ) from the datasheet. For the antennas used at 5.4 GHz, we know G_{max} from the datasheet, but have no data for F(θ). Therefore, we determine F by a theoretical approximation, applying to thin wire antennas, proposed in [3]:

$$F = 10 \log \left(\left(\frac{\cos(k\,L\,\sin(\theta)) - \cos(k\,L)}{\cos(\theta)(1 - \cos(k\,L))} \right)^2 \right) \quad (3)$$

where k = $2\,\pi/\lambda$, and 2 L is the length of the antenna. The 3 dB bandwidth (given in the datasheet) allows to determine the parameter k L in equation 3: k L = 1.426.

We determine PL models for the different cases (2 frequencies, 2 Tx positions), based on PL samples calculated with equation 1, in positions (along the trajectory) with a separation of λ/40. We describe the path loss [dB] versus distance d [m] between Tx and Rx by a one-slope model, with one standard deviation σ [dB]:

$$PL = PL_0 + 10\,n\,\log(d), \quad (4)$$

where PL_0 is the path loss at a distance of 1 m, and n is the PL exponent. The parameters PL_0 and n, determined by the method of least squares, are shown in Table I, as well as the region where the PL could be experimentally determined. The determined PL exponents vary from 1.2 to 1.7, which is lower than the free space PL exponent of 2.

For all cases, we found that it is possible to describe the path loss accurately by a one-slope model with one standard deviation. This is illustrated in Fig. 2, where local percentiles, based on PL samples from a local region of 4 m, are shown. The median can be modeled by a one-slope model, with a deviation less than 1 dB. The shift between the 75th percentile and the median is almost constant, which suggests one standard deviation.

TABLE I
Parameters of PL model, based on PL measurements in a large conference room.

frequency	Tx position	n	PL_0 [dB]	d_{br} [m]	σ [dB]	considered region
2.4 GHz	front	1.4	43	3.9	2	5 - 24 m
	side	1.7	40	1.2	2	5 - 26 m
5.4 GHz	front	1.2	51	3.0	2	5 - 24 m
	side	1.2	53	4.9	2	5 - 27 m

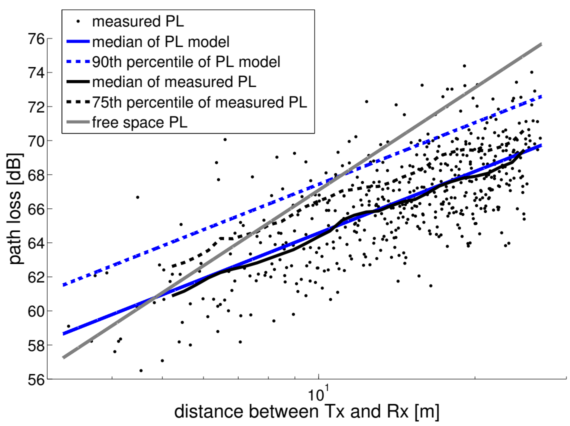

Fig. 2. Measured PL and PL model in large conference room (at 5.4 GHz, Tx position at the side). Percentiles based on the measured PL samples show that the PL can be described accurately by a one-slope model with one standard deviation. For purpose of review, only PL samples of positions separated by $10\,\lambda$ are shown.

It is usefull to express the PL model by

$$PL = PL_{free,0} + 10\,n\,\log(d/d_{br}), \quad (5)$$

where breakpoint d_{br} is the distance [m] between Tx and Rx where the one-slope model intersects with the free space path loss, and $PL_{free,0}$ is the free space path loss [dB] at distance d_{br}. The corresponding breakpoint parameters, shown in Table I, vary from 1 to 5 m.

According to the IEEE 802.11 TGn channel model [2], the PL can be modeled by the free space PL for d $<$ d_{br}, and by a one-slope model with exponent 3.5 for d $>$ d_{br}. The TGn model predicts a breakpoint of 20 m for large office and 30 m for large space (indoors - outdoors). Compared to the TGn channel model, the PL model, determined for a large conference room, has a lower breakpoint and a lower PL exponent for d $>$ d_{br}. This results in a much lower PL.

IV. Range, number of access points and total power consumption

Based on the determined PL model, the range R [m] can be calculated by the link budget relation:

$$P_T - P_{sens} + G_T + G_R - L_T - L_R = PL(R) + M_S + M_F, \quad (6)$$

where P_{sens} is the receiver sensitivity [dBm], PL(d) is the PL model [dB] versus distance d between transmitter and receiver, M_S is the shadowing margin [dB] and M_F is the temporal fading margin [dB].

We estimate the number of access points (#AP) as

$$\#AP = S/(\pi R^2), \quad (7)$$

where S [m^2] is the area of the room. The power consumption P [W] is calculated as

$$P = \#AP\, P_T, \quad (8)$$

where P_T is the transmit power [W].

Equations 6 to 8 allow to investigate the influence of the frequency (2.4/5 GHz band), configuration (SISO (Single-Input Single-Output)/MIMO 2×2), bandwidth (20/40 MHz) and transmit power on the required number of access points, total power consumption and maximum physical throughput (TP_{max}).

For this calculation, receiver sensitivities of the 'reference' receiver from [1] are used. Compared to SISO, the sensitivities are decreased by $n_T \cdot n_R$ [dB] for MIMO, where n_T is the number of antenna elements of the transmitter, and n_R is the number of antenna elements of the receiver. Compared to a bandwidth of 20 MHz, the sensitivities are increased by 3 dB for 40 MHz.

Figs. 3 to 5 show the calculated range, number of access points and total power consumption vs transmit power for a sensitivity of -64 dBm (for the 'reference' receiver with a SISO configuration, a bandwidth of 20 MHz, Modulation & Coding Scheme (MCS) 7), G_T = 2 dBi, G_R = 2 dBi, L_T = 0 dB, L_R = 0 dB and M_F = 5.8 dB. The margin M_F for temporal fading is based on K-factors varying from -12 dB to -6 dB, as proposed in [4] for large office environments. The calculation is done for 2.4 and 5.4 GHz with the determined PL model (Tx position in front). We consider a coverage percentage of 90% to determine M_S. We assume an area S of 2,500 m^2.

Based on this calculation, the influence of the different link parameters on #AP, P and TP_{max} is evaluated assuming a *fixed range* of 15 m (by tuning the transmit power) and 1 spatial stream (MCS 0 to 7). The results are summarized in Table II. Unless otherwise mentioned, the results apply to 2.4 GHz. A higher frequency gives a higher required P, because the PL is approximately proportional to $1/\lambda^2$ (see equation 5). Compared to SISO, MIMO 2×2 gives a lower required P, due to a better (lower) sensitivity. Compared to a bandwidth of 20 MHz, 40 MHz requires a higher P (due to a worse sensitivity), but allows a higher TP_{max}. A higher (fixed) range requires of course less access points, but a lower P as well. This is due to a PL exponent lower than 2, which results in a decreasing relation of P vs P_T (see Fig. 5). Due to a PL exponent of 3.5, the TGn channel model predicts that a higher (fixed) range requires a higher P.

The determined PL model predicts maximum ranges (i.e. for the maximum allowed transmit power) higher than 139 m. Therefore, TP_{max} is not influenced by the configuration, bandwidth or (fixed) range (see Table II). As mentioned before, the TGn channel model predicts lower maximum ranges, which can result in an influence on TP_{max} for a (fixed) range from 40 m.

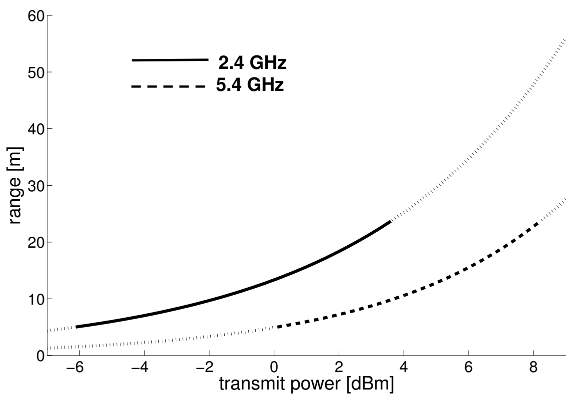

Fig. 3. Calculated range vs transmit power, based on the PL model, determined for a large conference room. The dotted line indicates that the range is out of the region where the PL model could be experimentally determined.

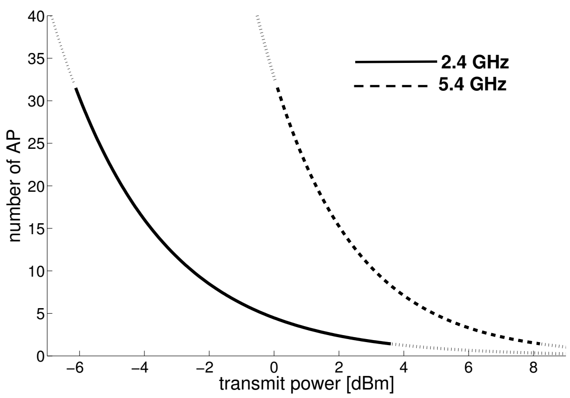

Fig. 4. Calculated number of access points vs transmit power, based on the PL model, determined for a large conference room. The dotted line indicates that the range is out of the region where the PL model could be experimentally determined.

V. Conclusions

We determined a PL model for 802.11n in large conference rooms, based on PL measurements. The PL could be described accurately by a one-slope model with one standard deviation. PL exponents varying from 1.2 to 1.7 were found.

Based on this PL model, the effect of frequency (2.4 vs 5 GHz), configuration (SISO vs MIMO (spatial diversity)),

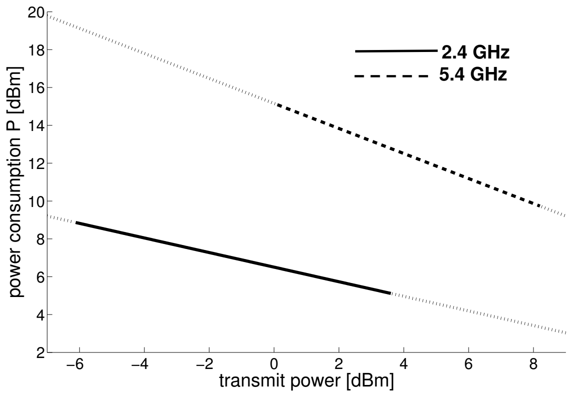

Fig. 5. Calculated total power consumption vs transmit power, based on the PL model, determined for a large conference room. The dotted line indicates that the range is out of the region where the PL model could be experimentally determined.

TABLE II
THE EFFECT OF DIFFERENT LINK PARAMETERS ON #AP, TOTAL POWER CONSUMPTION (P) AND TP_{MAX}. THE INFLUENCE IS EVALUATED FOR A **FIXED RANGE** OF 15 M (UNLESS OTHERWISE MENTIONED). THE EFFECT IS CALCULATED FOR THE 2 TX POSITIONS, WHICH CAN GIVE DIFFERENT VALUES, INDICATED BY (1) IN TABLE.

	#AP	P [mW]	TP_{max} [Mbps]
frequency 2.4 → 5.4 GHz	=	× 3.2 - 4.6 $^{(1)}$	65 → 65
SISO → MIMO 2×2	=	× 0.25	65 → 65
bandwidth 20 → 40 MHz	=	× 2	65 → 135
range 15 → 30 m	× 0.25	× 0.5 - 0.8 $^{(1)}$	65 → 65

bandwidth (20 vs 40 MHz) and transmit power on number of access points, total power consumption and possible (physical) throughputs has been investigated. Compared to SISO, MIMO is advantageous in every aspect. Compared to 2.4 GHz, 5 GHz is worse. A higher range (by tuning the transmit power) requires less access points, as well as a lower total power consumption, due to a PL exponent lower than 2.

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