Estudo sobre BEL

Rec. ITU-R P.2109-0 Prediction of building entry loss

– The BEL distribution is given by a combination of two lognormal distributions.
– The building entry loss not exceeded for the probability, P, is given by:

$$L_{BEL}(P) = 10\log(10^{0.1A(P)} + 10^{0.1B(P)} + 10^{0.1C}) \text{ dB}$$

$$A(P) = F^{-1}(P)\sigma_1 + \mu_1$$

$$B(P) = F^{-1}(P)\sigma_2 + \mu_2$$

$$C = -3.0$$

$$\mu_1 = L_h + L_e$$

$$\mu_2 = w + x\log(f)$$

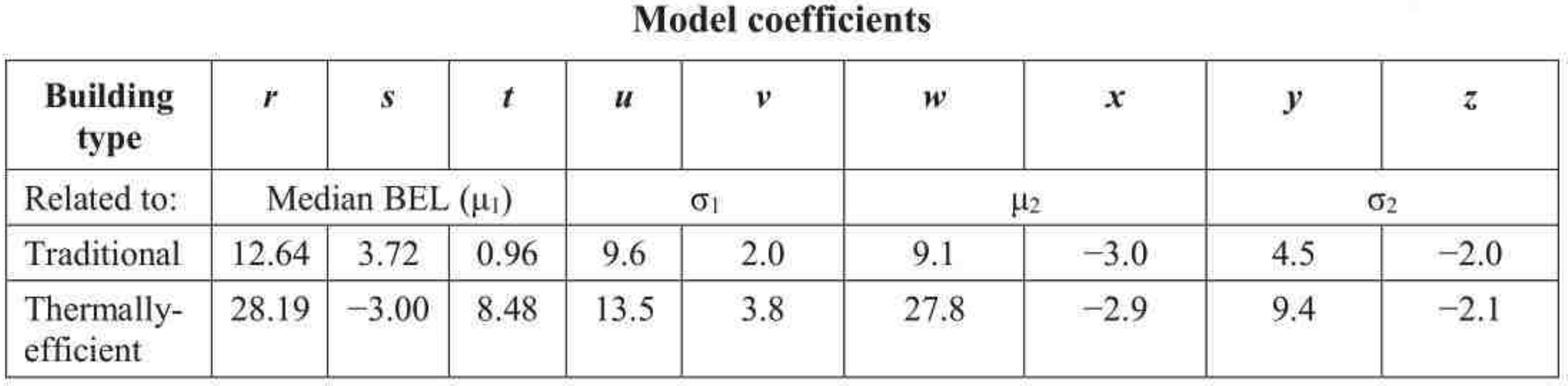
$$\sigma_1 = u + v\log(f)$$

$$\sigma_2 = y + z\log(f)$$

$$L_h = r + s\log(f) + t\,(\log(f))^2$$

$$L_e = 0.212\,|\theta|$$

$$P = Prob(L \le L_{BEL})$$



Model coefficients

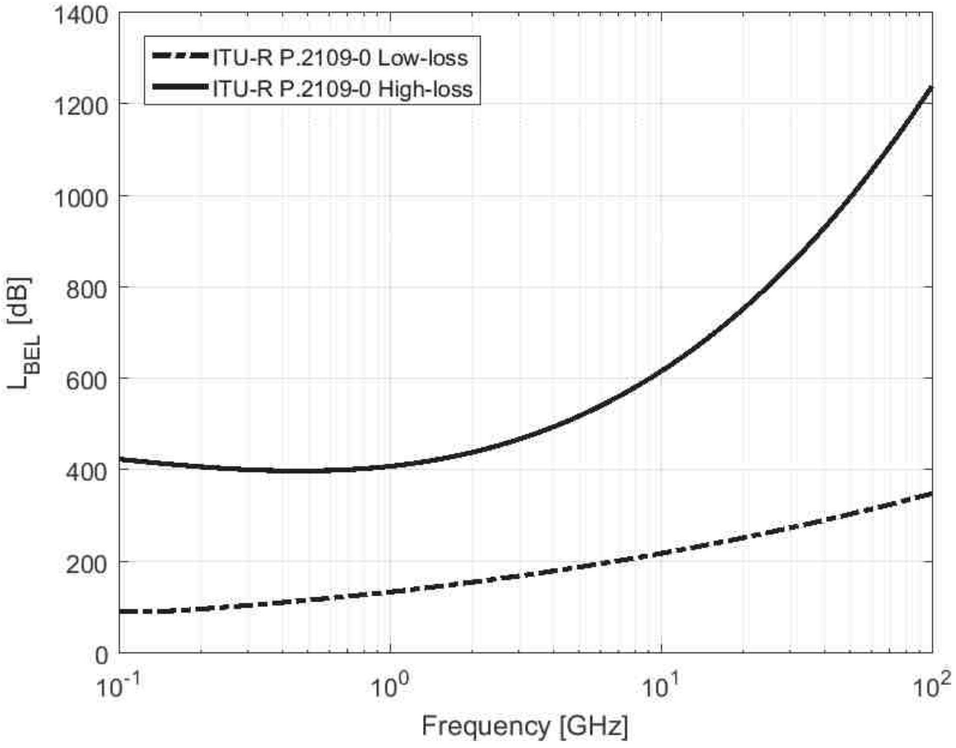
Building type	r	s	t	u	v	w	x	y	z
Related to:	Median BEL (μ_1)			σ_1		μ_2		σ_2	
Traditional	12.64	3.72	0.96	9.6	2.0	9.1	−3.0	4.5	−2.0
Thermally-efficient	28.19	−3.00	8.48	13.5	3.8	27.8	−2.9	9.4	−2.1

Impressão: muitos parâmetros não relacionados a variáveis físicas do link

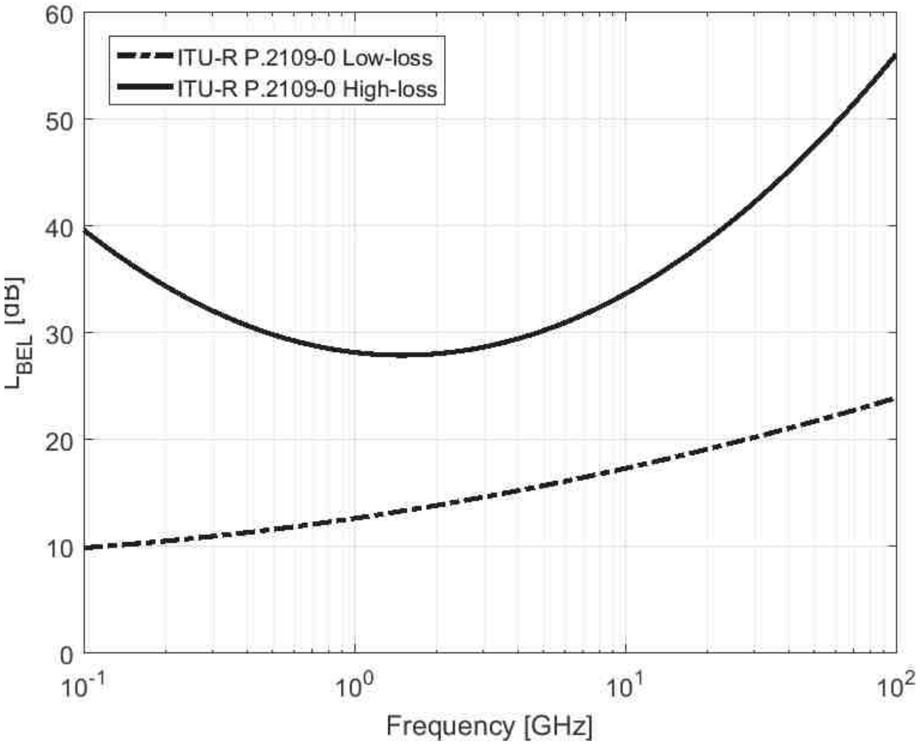
Rec. ITU-R P.2109-0 Prediction of building entry loss

$F^{-1}(P) =$ inverse cumulative normal distribution as a function of probability.

CDF de A e B:
$N(\mu_1,\sigma_1)$ e $N(\mu_2,\sigma_2)$



CDF standard Normal
$N(0,1)$



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Overview of Millimeter Wave Communications for Fifth-Generation (5G) Wireless Networks—With a Focus on Propagation Models

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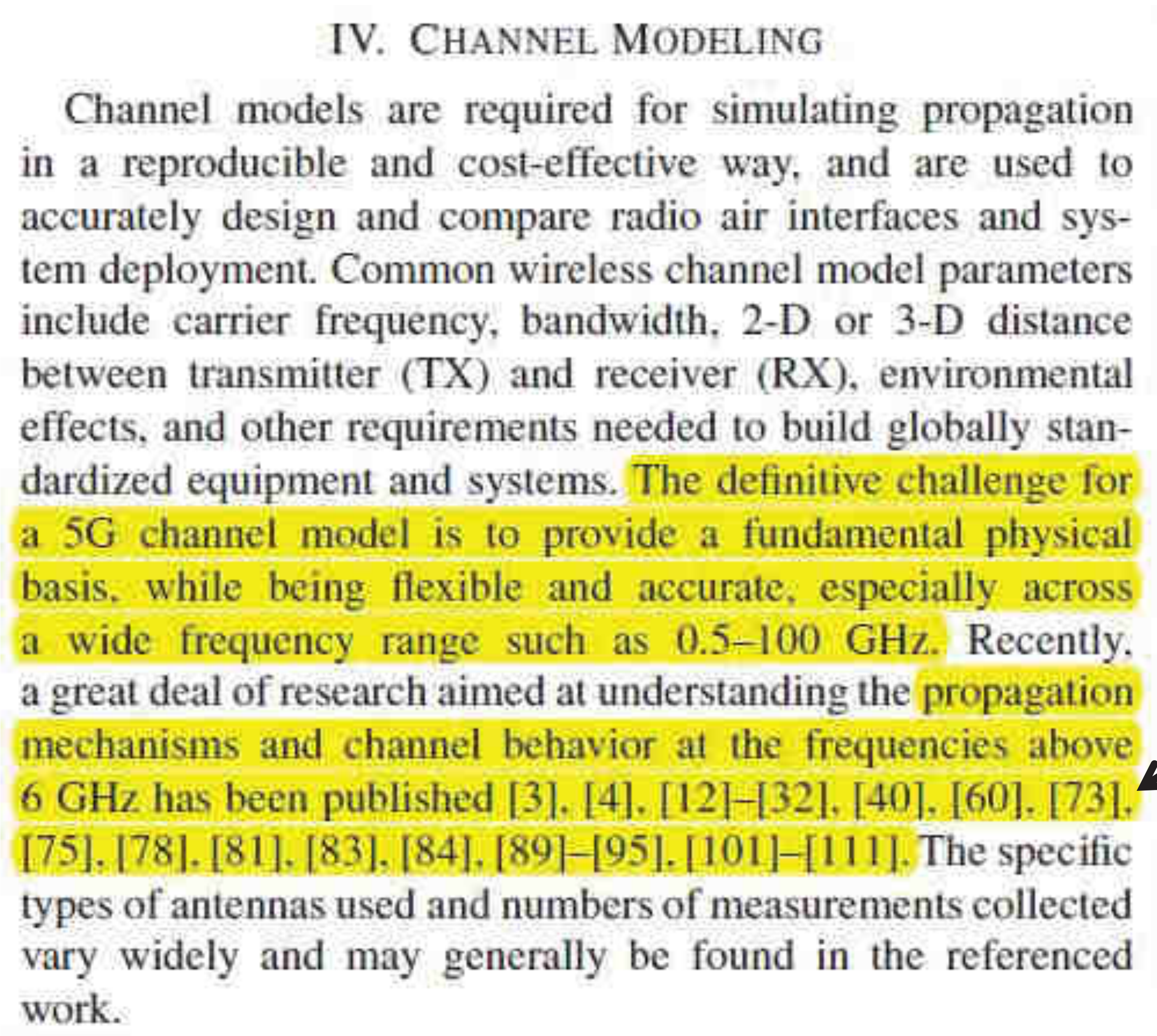
(Invited Paper)

***Abstract*—This paper provides an overview of the features of fifth generation (5G) wireless communication systems now being developed for use in the millimeter wave (mmWave) frequency bands. Early results and key concepts of 5G networks are presented, and the channel modeling efforts of many international groups for both licensed and unlicensed applications are described here. Propagation parameters and channel models for understanding mmWave propagation, such as line-of-sight (LOS) probabilities, large-scale path loss, and building penetration loss, as modeled by various standardization bodies, are compared over the 0.5–100 GHz range.**

***Index Terms*—Cellular network, channel model standards,**

technology that will use millimeter wave (mmWave) frequencies to offer unprecedented spectrum and multi-Gigabit-per-second (Gbps) data rates to a mobile device [3]. Mobile devices, such as cell phones, are typically referred to as user equipment (UE). A simple analysis illustrated that 1 GHz wide channels at 28 or 73 GHz could offer several Gbps of data rate to UE with modest phased array antennas at the mobile handset [4], and early work showed 15 Gbps peak rates are possible with 4 × 4 phased arrays antenna at the UE and 200 m spacing between base stations (BSs) [5], [6].

Promising studies such as these led the U.S. Federal Com-



IV. CHANNEL MODELING

Channel models are required for simulating propagation in a reproducible and cost-effective way, and are used to accurately design and compare radio air interfaces and system deployment. Common wireless channel model parameters include carrier frequency, bandwidth, 2-D or 3-D distance between transmitter (TX) and receiver (RX), environmental effects, and other requirements needed to build globally standardized equipment and systems. The definitive challenge for a 5G channel model is to provide a fundamental physical basis, while being flexible and accurate, especially across a wide frequency range such as 0.5–100 GHz. Recently, a great deal of research aimed at understanding the propagation mechanisms and channel behavior at the frequencies above 6 GHz has been published [3], [4], [12]–[32], [40], [60], [73], [75], [78], [81], [83], [84], [89]–[95], [101]–[111]. The specific types of antennas used and numbers of measurements collected vary widely and may generally be found in the referenced work.

49 papers

For the remainder of this paper, the models for LOS probability, path loss, and building penetration introduced by four major organizations in the past two years are reviewed and compared. These organizations include:

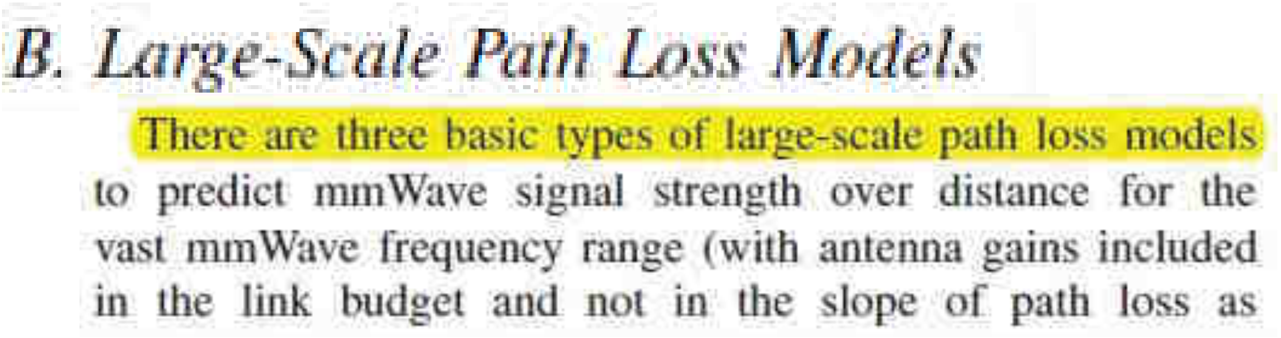
1) The 3rd Generation Partnership Project (3GPP TR 38.901 [101]), which attempts to provide channel models from 0.5–100 GHz based on a modification of 3GPP's extensive effort to develop models from 6 to 100 GHz in TR 38.900 [112]. 3GPP TR documents are a continual work in progress and serve as the international industry standard for 5G cellular.
2) 5G Channel Model (5GCM) [12], an *ad-hoc* group of 15 companies and universities that developed models based on extensive measurement campaigns and helped seed 3GPP understanding for TR 38.900 [112].
3) Mobile and wireless communications Enablers for the Twenty–twenty Information Society (METIS) [102], a large research project sponsored by European Union.

4) Millimeter-Wave Based Mobile Radio Access Network for 5G Integrated Communications (mmMAGIC) [92], another large research project sponsored by the European Union.

A. LOS Probability Model

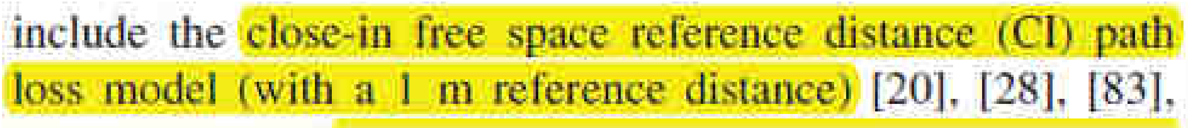
B. Large-Scale Path Loss Models

C. O2I Penetration Loss



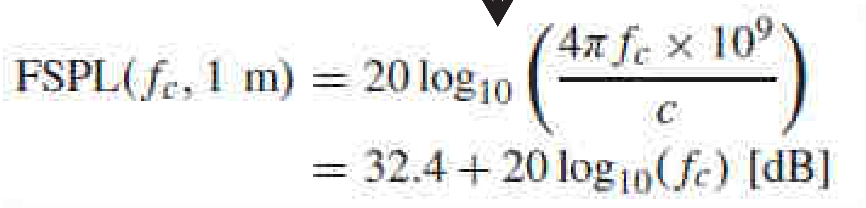
B. Large-Scale Path Loss Models

There are three basic types of large-scale path loss models to predict mmWave signal strength over distance for the vast mmWave frequency range (with antenna gains included in the link budget and not in the slope of path loss as



1) include the close-in free space reference distance (CI) path loss model (with a 1 m reference distance) [20], [28], [83],

$$PL^{\mathrm{CI}}(f_c, d_{\mathrm{3D}})\ [\mathrm{dB}] = \mathrm{FSPL}(f_c, 1\ \mathrm{m}) + 10n \log_{10}(d_{\mathrm{3D}}) + \chi_\sigma^{\mathrm{CI}}$$



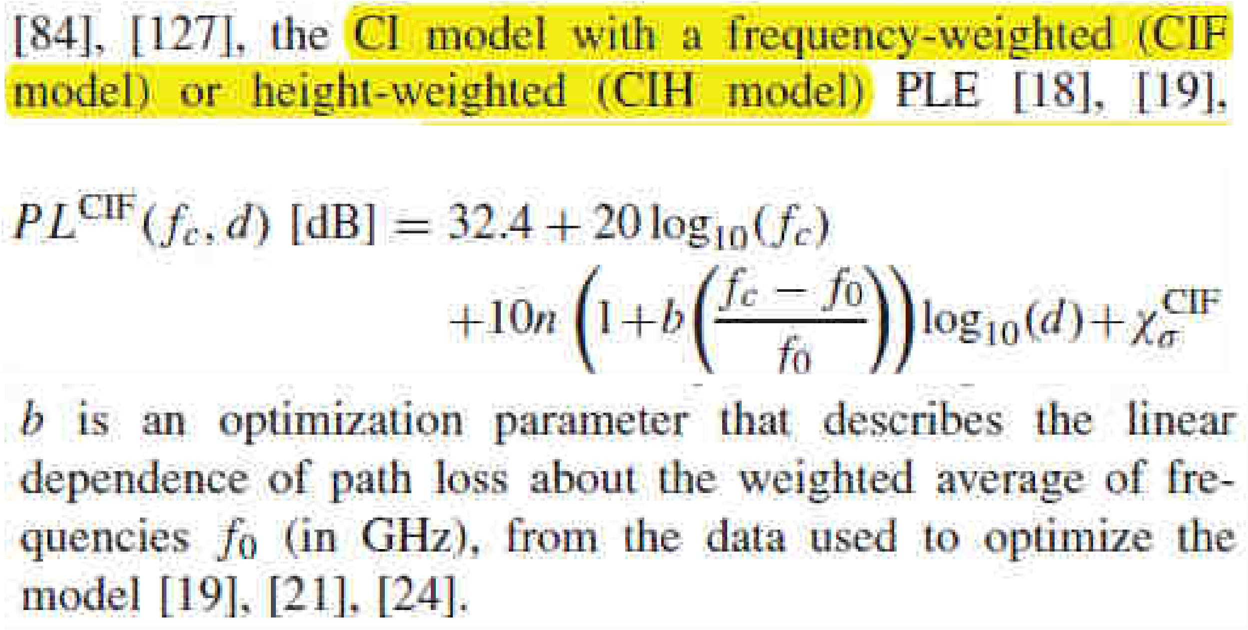
$$\mathrm{FSPL}(f_c, 1\ \mathrm{m}) = 20 \log_{10}\left(\frac{4\pi f_c \times 10^9}{c}\right) = 32.4 + 20 \log_{10}(f_c)\ [\mathrm{dB}]$$

$N(0, \sigma)$
Shadow Fading

$$\boxed{\bar{L}(f_c, d) = 32.4 + 20 \log_{10} f_c + 10n \log_{10} d}$$

f_c: GHz, d: m

2)

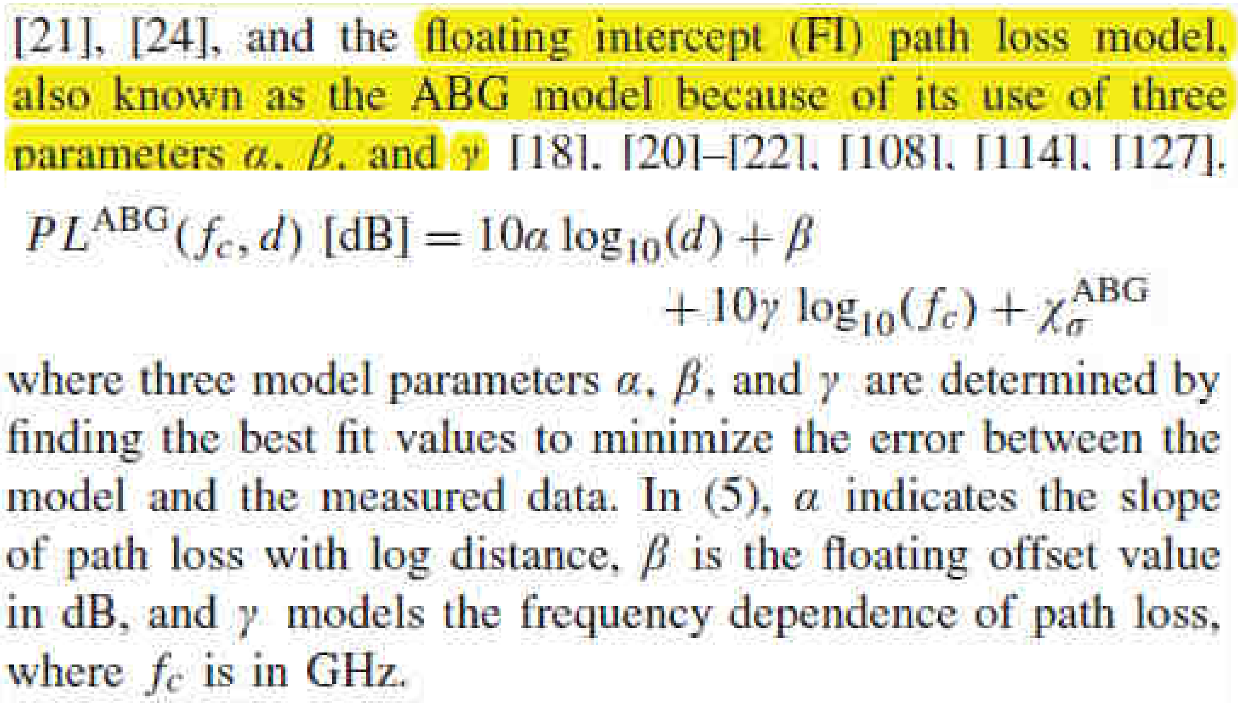


[84], [127], the CI model with a frequency-weighted (CIF model) or height-weighted (CIH model) PLE [18], [19],

$$PL^{\text{CIF}}(f_c, d)\ [\text{dB}] = 32.4 + 20\log_{10}(f_c) + 10n\left(1 + b\left(\frac{f_c - f_0}{f_0}\right)\right)\log_{10}(d) + \chi_\sigma^{\text{CIF}}$$

b is an optimization parameter that describes the linear dependence of path loss about the weighted average of frequencies f_0 (in GHz), from the data used to optimize the model [19], [21], [24].

3)

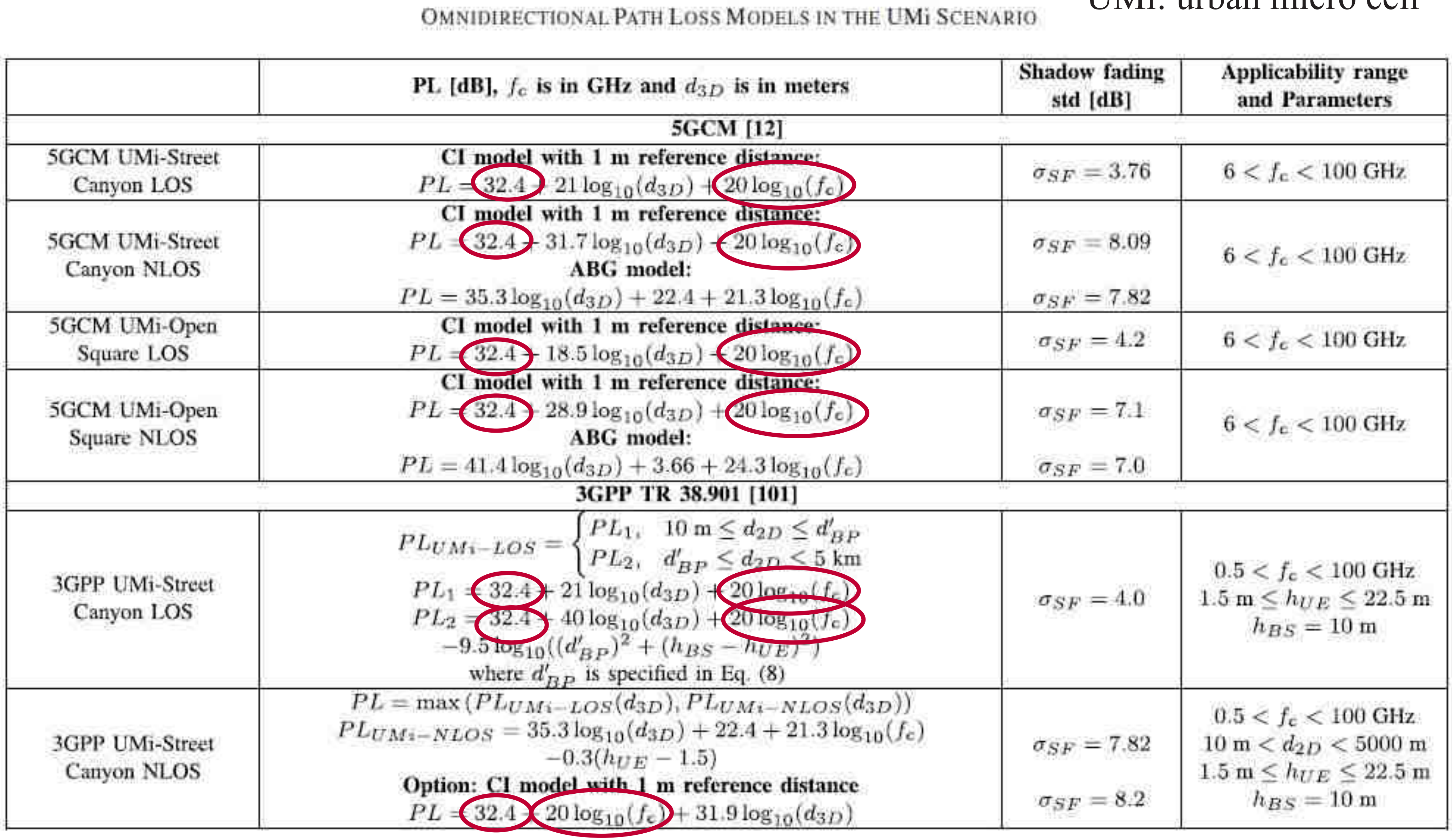


[21], [24], and the floating intercept (FI) path loss model, also known as the ABG model because of its use of three parameters α, β, and γ [18], [20]–[22], [108], [114], [127].

$$PL^{\text{ABG}}(f_c, d)\ [\text{dB}] = 10\alpha\log_{10}(d) + \beta + 10\gamma\log_{10}(f_c) + \chi_\sigma^{\text{ABG}}$$

where three model parameters α, β, and γ are determined by finding the best fit values to minimize the error between the model and the measured data. In (5), α indicates the slope of path loss with log distance, β is the floating offset value in dB, and γ models the frequency dependence of path loss, where f_c is in GHz.

UMi: urban micro cell

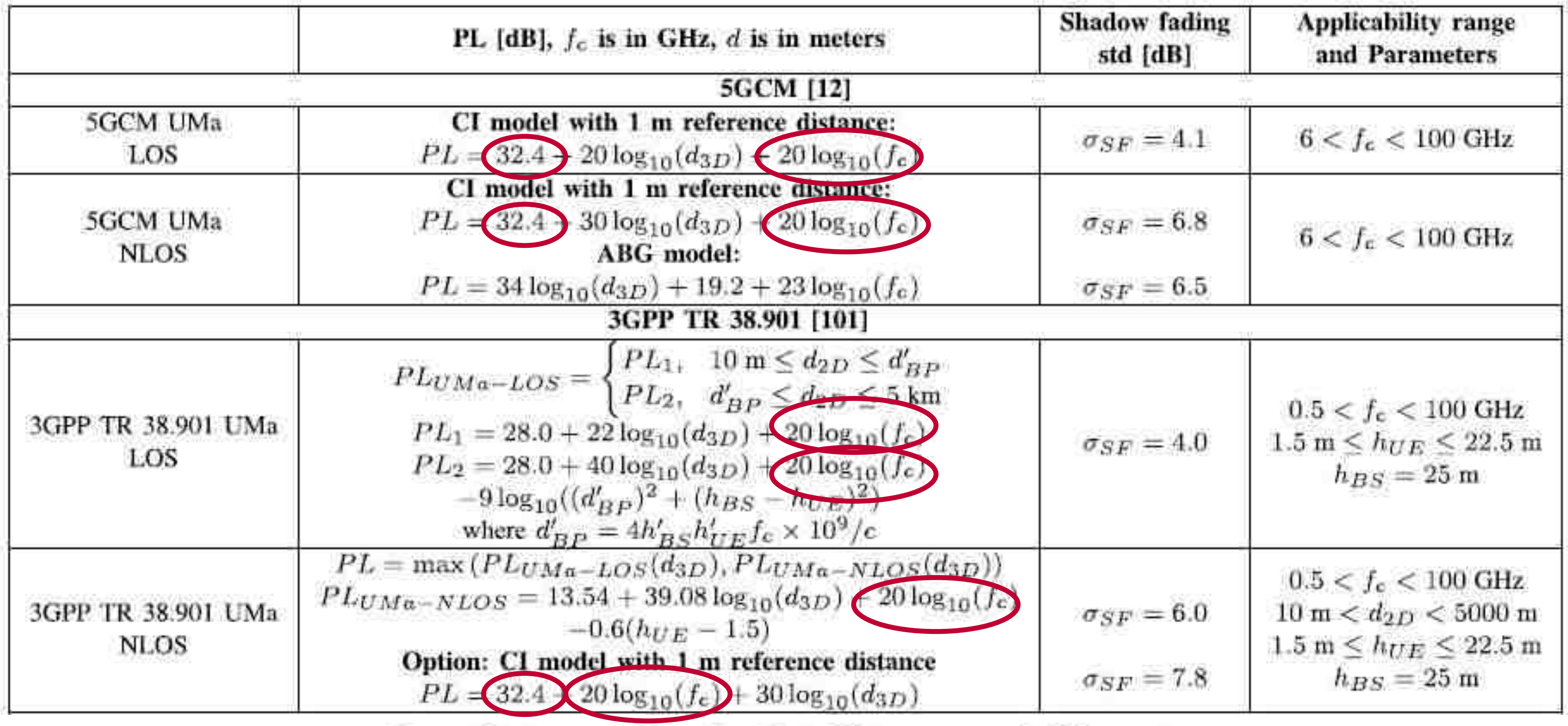


OMNIDIRECTIONAL PATH LOSS MODELS IN THE UMi SCENARIO

	PL [dB], f_c is in GHz and d_{3D} is in meters	Shadow fading std [dB]	Applicability range and Parameters
	5GCM [12]		
5GCM UMi-Street Canyon LOS	**CI model with 1 m reference distance:** $PL = 32.4 + 21\log_{10}(d_{3D}) + 20\log_{10}(f_c)$	$\sigma_{SF} = 3.76$	$6 < f_c < 100$ GHz
5GCM UMi-Street Canyon NLOS	**CI model with 1 m reference distance:** $PL = 32.4 + 31.7\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ **ABG model:** $PL = 35.3\log_{10}(d_{3D}) + 22.4 + 21.3\log_{10}(f_c)$	$\sigma_{SF} = 8.09$ $\sigma_{SF} = 7.82$	$6 < f_c < 100$ GHz
5GCM UMi-Open Square LOS	**CI model with 1 m reference distance:** $PL = 32.4 + 18.5\log_{10}(d_{3D}) + 20\log_{10}(f_c)$	$\sigma_{SF} = 4.2$	$6 < f_c < 100$ GHz
5GCM UMi-Open Square NLOS	**CI model with 1 m reference distance:** $PL = 32.4 + 28.9\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ **ABG model:** $PL = 41.4\log_{10}(d_{3D}) + 3.66 + 24.3\log_{10}(f_c)$	$\sigma_{SF} = 7.1$ $\sigma_{SF} = 7.0$	$6 < f_c < 100$ GHz
	3GPP TR 38.901 [101]		
3GPP UMi-Street Canyon LOS	$PL_{UMi-LOS} = \begin{cases} PL_1, & 10\text{ m} \leq d_{2D} \leq d'_{BP} \\ PL_2, & d'_{BP} \leq d_{2D} \leq 5\text{ km} \end{cases}$ $PL_1 = 32.4 + 21\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $PL_2 = 32.4 + 40\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $-9.5\log_{10}((d'_{BP})^2 + (h_{BS} - h_{UE})^2)$ where d'_{BP} is specified in Eq. (8)	$\sigma_{SF} = 4.0$	$0.5 < f_c < 100$ GHz $1.5\text{ m} \leq h_{UE} \leq 22.5\text{ m}$ $h_{BS} = 10$ m
3GPP UMi-Street Canyon NLOS	$PL = \max(PL_{UMi-LOS}(d_{3D}), PL_{UMi-NLOS}(d_{3D}))$ $PL_{UMi-NLOS} = 35.3\log_{10}(d_{3D}) + 22.4 + 21.3\log_{10}(f_c)$ $-0.3(h_{UE} - 1.5)$ **Option: CI model with 1 m reference distance** $PL = 32.4 + 20\log_{10}(f_c) + 31.9\log_{10}(d_{3D})$	$\sigma_{SF} = 7.82$ $\sigma_{SF} = 8.2$	$0.5 < f_c < 100$ GHz $10\text{ m} < d_{2D} < 5000\text{ m}$ $1.5\text{ m} \leq h_{UE} \leq 22.5\text{ m}$ $h_{BS} = 10$ m

OMNIDIRECTIONAL PATH LOSS MODELS IN THE UMa SCENARIO

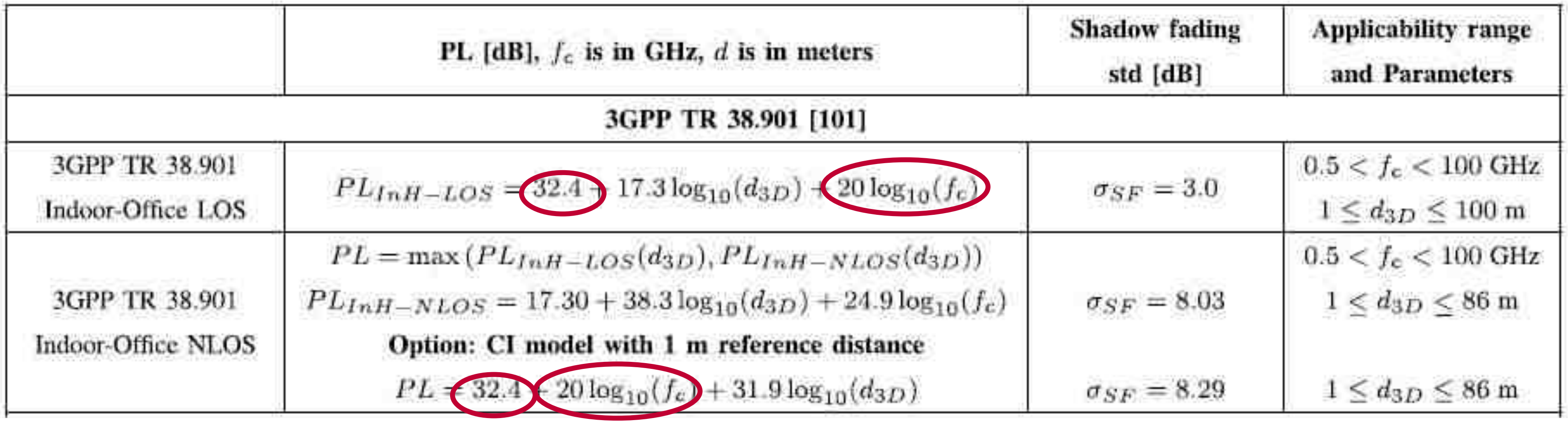
UMa: urban macro cell



	PL [dB], f_c is in GHz, d is in meters	Shadow fading std [dB]	Applicability range and Parameters
	5GCM [12]		
5GCM UMa LOS	**CI model with 1 m reference distance:** $PL = 32.4 + 20\log_{10}(d_{3D}) + 20\log_{10}(f_c)$	$\sigma_{SF} = 4.1$	$6 < f_c < 100$ GHz
5GCM UMa NLOS	**CI model with 1 m reference distance:** $PL = 32.4 + 30\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ **ABG model:** $PL = 34\log_{10}(d_{3D}) + 19.2 + 23\log_{10}(f_c)$	$\sigma_{SF} = 6.8$ $\sigma_{SF} = 6.5$	$6 < f_c < 100$ GHz
	3GPP TR 38.901 [101]		
3GPP TR 38.901 UMa LOS	$PL_{UMa-LOS} = \begin{cases} PL_1, & 10\text{ m} \le d_{2D} \le d'_{BP} \\ PL_2, & d'_{BP} \le d_{2D} \le 5\text{ km} \end{cases}$ $PL_1 = 28.0 + 22\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $PL_2 = 28.0 + 40\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $-9\log_{10}((d'_{BP})^2 + (h_{BS} - h_{UE})^2)$ where $d'_{BP} = 4h'_{BS}h'_{UE}f_c \times 10^9/c$	$\sigma_{SF} = 4.0$	$0.5 < f_c < 100$ GHz $1.5\text{ m} \le h_{UE} \le 22.5\text{ m}$ $h_{BS} = 25$ m
3GPP TR 38.901 UMa NLOS	$PL = \max(PL_{UMa-LOS}(d_{3D}), PL_{UMa-NLOS}(d_{3D}))$ $PL_{UMa-NLOS} = 13.54 + 39.08\log_{10}(d_{3D}) + 20\log_{10}(f_c)$ $-0.6(h_{UE} - 1.5)$ **Option: CI model with 1 m reference distance** $PL = 32.4 + 20\log_{10}(f_c) + 30\log_{10}(d_{3D})$	$\sigma_{SF} = 6.0$ $\sigma_{SF} = 7.8$	$0.5 < f_c < 100$ GHz $10\text{ m} < d_{2D} < 5000\text{ m}$ $1.5\text{ m} \le h_{UE} \le 22.5\text{ m}$ $h_{BS} = 25$ m

OTHER OMNIDIRECTIONAL PATH LOSS MODELS IN THE InH SCENARIO

InH: indoor hotspot

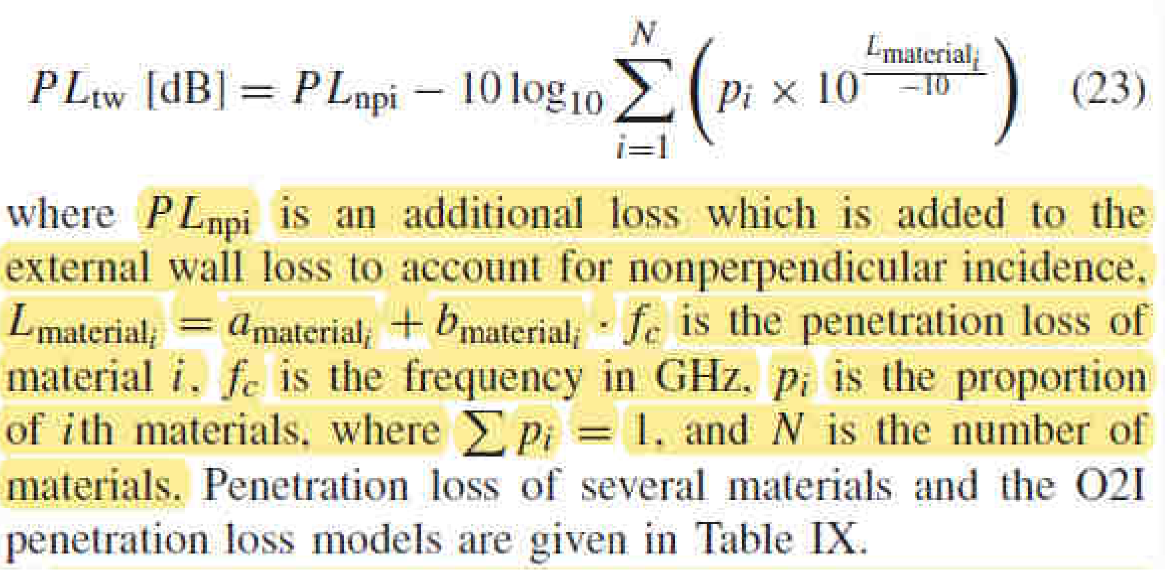


	PL [dB], f_c is in GHz, d is in meters	Shadow fading std [dB]	Applicability range and Parameters
	3GPP TR 38.901 [101]		
3GPP TR 38.901 Indoor-Office LOS	$PL_{InH-LOS} = 32.4 + 17.3\log_{10}(d_{3D}) + 20\log_{10}(f_c)$	$\sigma_{SF} = 3.0$	$0.5 < f_c < 100$ GHz $1 \le d_{3D} \le 100$ m
3GPP TR 38.901 Indoor-Office NLOS	$PL = \max(PL_{InH-LOS}(d_{3D}), PL_{InH-NLOS}(d_{3D}))$ $PL_{InH-NLOS} = 17.30 + 38.3\log_{10}(d_{3D}) + 24.9\log_{10}(f_c)$ **Option: CI model with 1 m reference distance** $PL = 32.4 + 20\log_{10}(f_c) + 31.9\log_{10}(d_{3D})$	$\sigma_{SF} = 8.03$ $\sigma_{SF} = 8.29$	$0.5 < f_c < 100$ GHz $1 \le d_{3D} \le 86$ m $1 \le d_{3D} \le 86$ m

C. O2I Penetration Loss

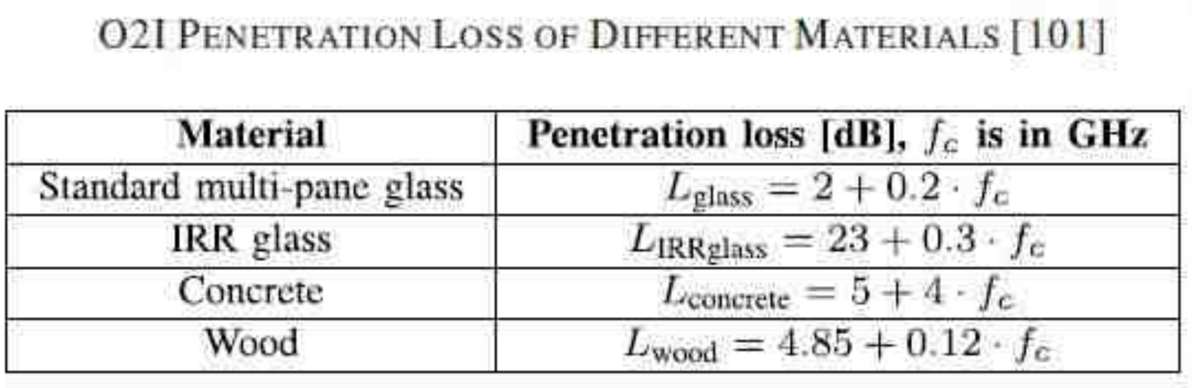
1) 3GPP TR 38.901:

PL_{tw} : building penetration loss (BPL)



$$PL_{\text{tw}}\,[\text{dB}] = PL_{\text{npi}} - 10\log_{10}\sum_{i=1}^{N}\left(p_i \times 10^{\frac{L_{\text{material}_i}}{-10}}\right) \quad (23)$$

where PL_{npi} is an additional loss which is added to the external wall loss to account for nonperpendicular incidence, $L_{\text{material}_i} = a_{\text{material}_i} + b_{\text{material}_i} \cdot f_c$ is the penetration loss of material i, f_c is the frequency in GHz, p_i is the proportion of ith materials, where $\sum p_i = 1$, and N is the number of materials. Penetration loss of several materials and the O2I penetration loss models are given in Table IX.



O2I PENETRATION LOSS OF DIFFERENT MATERIALS [101]

Material	Penetration loss [dB], f_c is in GHz
Standard multi-pane glass	$L_{\text{glass}} = 2 + 0.2 \cdot f_c$
IRR glass	$L_{\text{IRRglass}} = 23 + 0.3 \cdot f_c$
Concrete	$L_{\text{concrete}} = 5 + 4 \cdot f_c$
Wood	$L_{\text{wood}} = 4.85 + 0.12 \cdot f_c$

Impressão: modelo muito detalhado, exige muita informação para o cálculo

1) 3GPP TR 38.901:

Rough models are also provided to estimate the BPL in Table X. Both the low-loss and high-loss models are applicable to UMa and UMi-street canyon, while only the low-loss model is applicable to RMa.

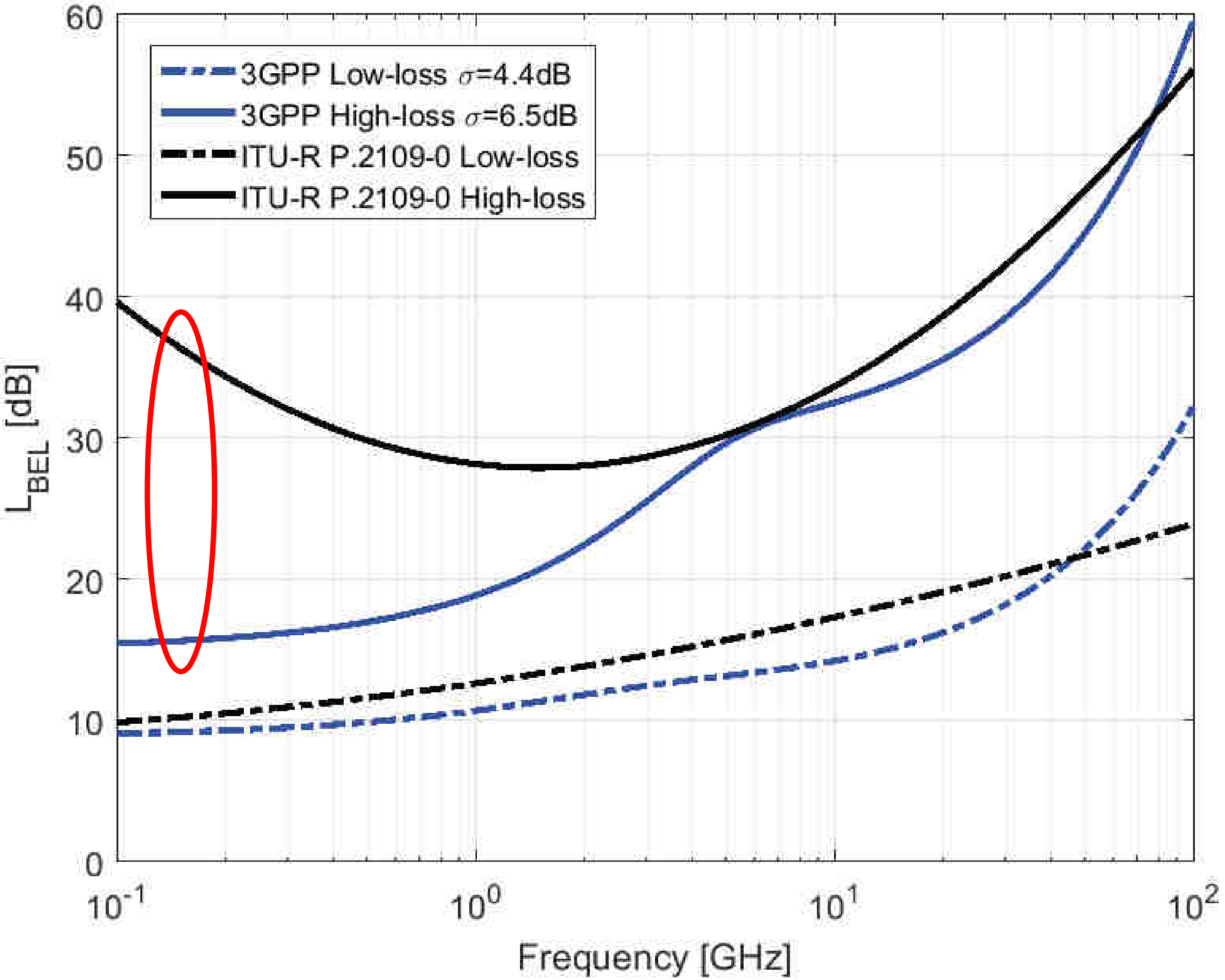
2) 5GCM: The 5GCM adopted the BPL model of 3GPP TR 36.873 which is based on legacy measurements below 6 GHz [96].

$$\text{BPL [dB]} = 10\log_{10}\left(A + B \cdot f_c^2\right)$$

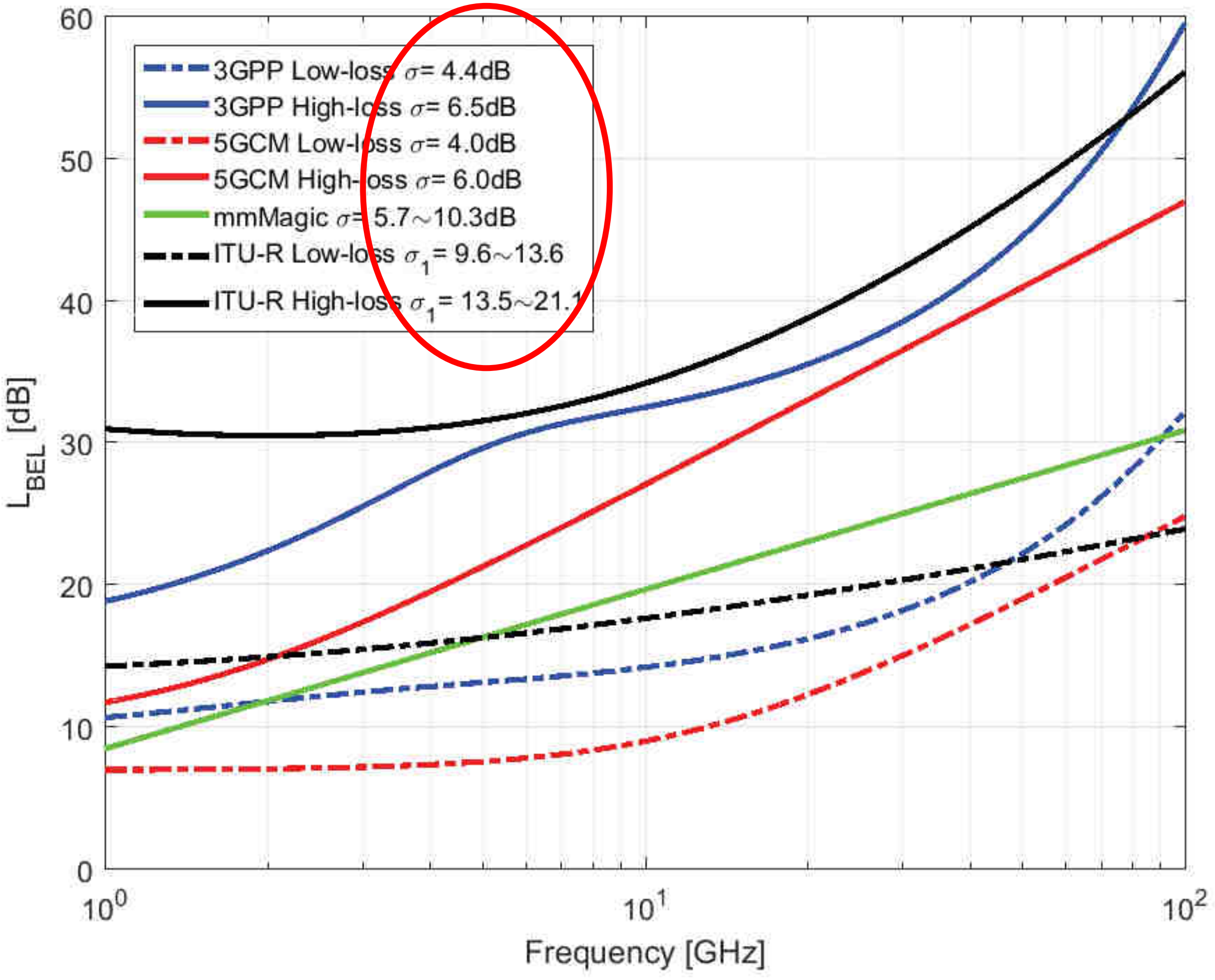
	Path loss through external wall: PL_{tw} **[dB],** f_c **is in GHz**
3GPP TR 38.901 Low-loss model [101]	$5 - 10\log_{10}(0.3 \cdot 10^{-L_{glass}/10} + 0.7 \cdot 10^{-L_{concrete}/10})$
3GPP TR 38.901 High-loss model [101]	$5 - 10\log_{10}(0.7 \cdot 10^{-L_{IRRglass}/10} + 0.3 \cdot 10^{-L_{concrete}/10})$
5GCM Low-loss model [12], [99]	$10\log_{10}(5 + 0.03 \cdot f_c^2)$
5GCM High-loss model [12], [99]	$10\log_{10}(10 + 5 \cdot f_c^2)$

3) mmMAGIC: The O2I penetration loss model in mmMAGIC has the form of

$$\text{O2I [dB]} = B_{\text{O2I}} + C_{\text{O2I}} \cdot \log_{10}(f_c) \approx 8.5 + 11.2 \cdot \log_{10}(f_c).$$



ITU-R P.2109-0 Traditional = Low-loss e Thermally-efficient = High-loss


3GPP Low-loss σ= 4.4dB
3GPP High-loss σ= 6.5dB
5GCM Low-loss σ= 4.0dB
5GCM High-loss σ= 6.0dB
mmMagic σ= 5.7~10.3dB
ITU-R Low-loss σ_1= 9.6~13.6
ITU-R High-loss σ_1= 13.5~21.1
L_{BEL} [dB]
60
50
40
30
20
10
0
10^0
10^1
10^2
Frequency [GHz]

Proposta: Método de Medição do BEL Intra-sistema

As redes móveis existentes podem ser utilizadas para medição do BEL.
A medição pode ser feita através de 2 técnicas de medição e a conversão para a faixa de frequência 5G.

Conversão da perda de propagação da faixa de frequência 4G para 5G:

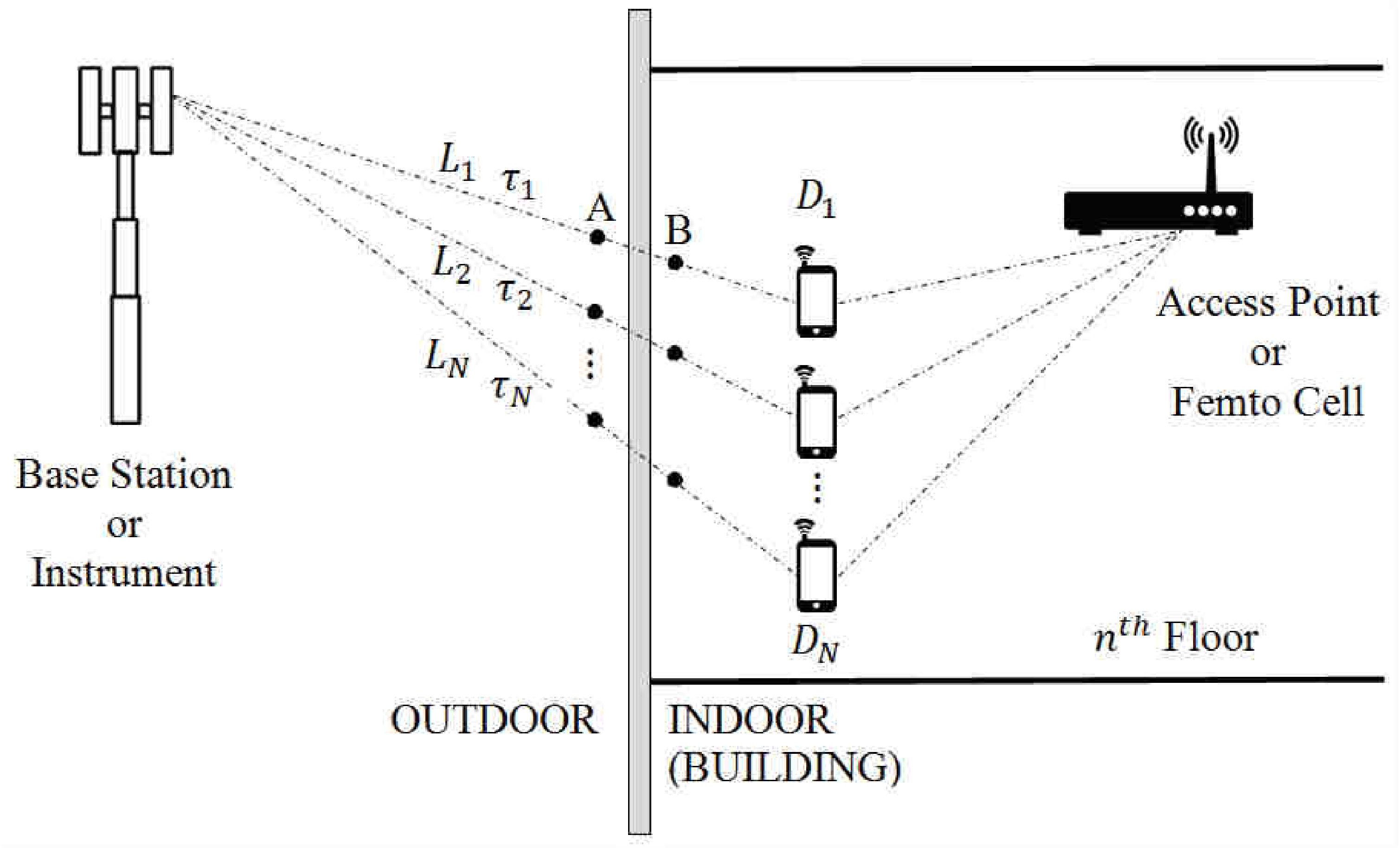
$$L(f_{5G}) = 32.4 + 20\log(f_{5G}) + 10n\log(d)$$
$$L(f_{4G}) = 32.4 + 20\log(f_{4G}) + 10n\log(d)$$

Sendo d e n iguais, subtraindo as duas equações temos

$$L(f_{5G}) = L(f_{4G}) + 20\log(\frac{f_{5G}}{f_{4G}})$$

Obs.: formulação similar a utilizada na Rec. ITU-R P.1546-5 Anexo 5 item 6
(Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz)

Proposta: Método de Medição do BEL Intra-sistema



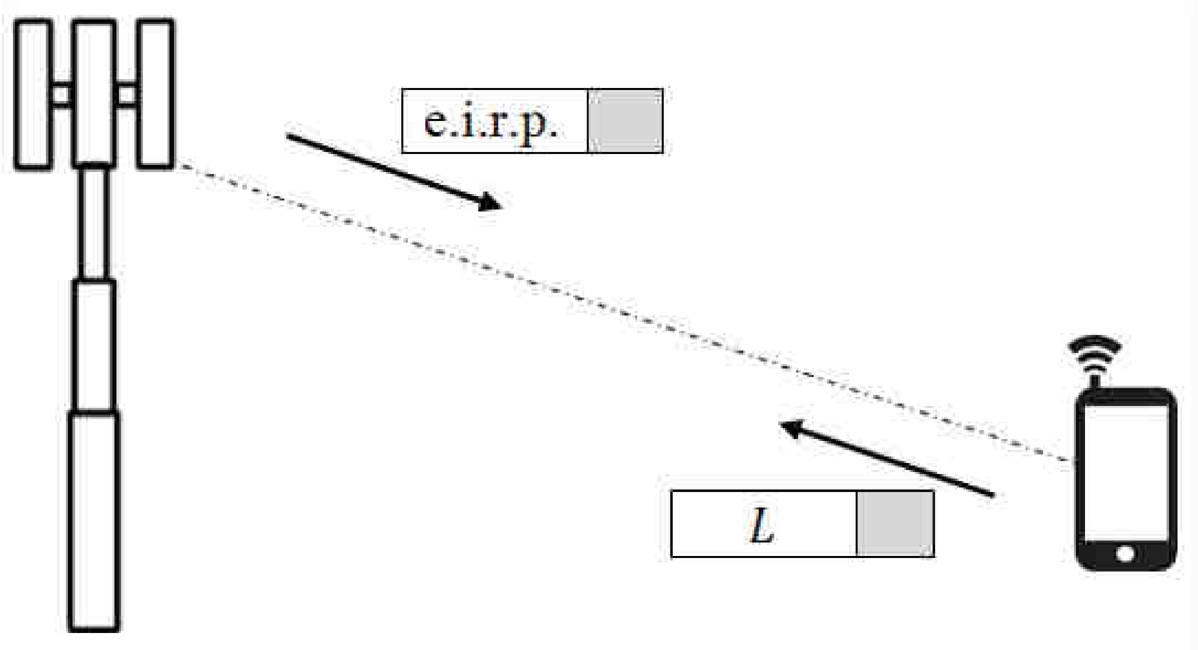
Obs.: AP é para indicar dispositivos no mesmo andar. Não participa da medição.

Variáveis desconhecidas

$$L_k = 32.4 + 20\log f_c + 10n\log(\underbrace{d_k}_{d_k = \tau_k c}) + L_{AB}$$

Proposta: Método de Medição do BEL Intra-sistema

1) Técnica de medição da perda de propagação (L)



Variável desconhecida

$$P_{RX} = \overbrace{P_{TX} + G_{TX}}^{e.i.r.p.} + G_{RX} - L$$

$$L = e.i.r.p. + G_{RX} - P_{RX}$$

D_k com antena de omnidirecional de 0 dBi e desprezando elevação:

$$L = e.i.r.p. - P_{RX}$$

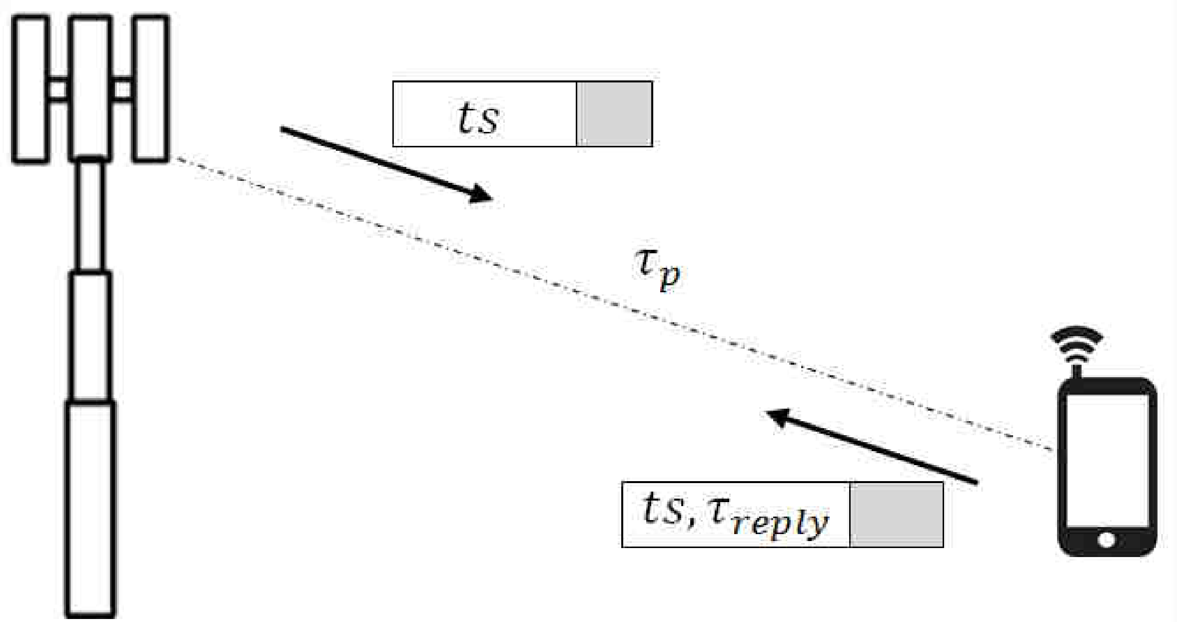
$$\Delta h = 20m$$

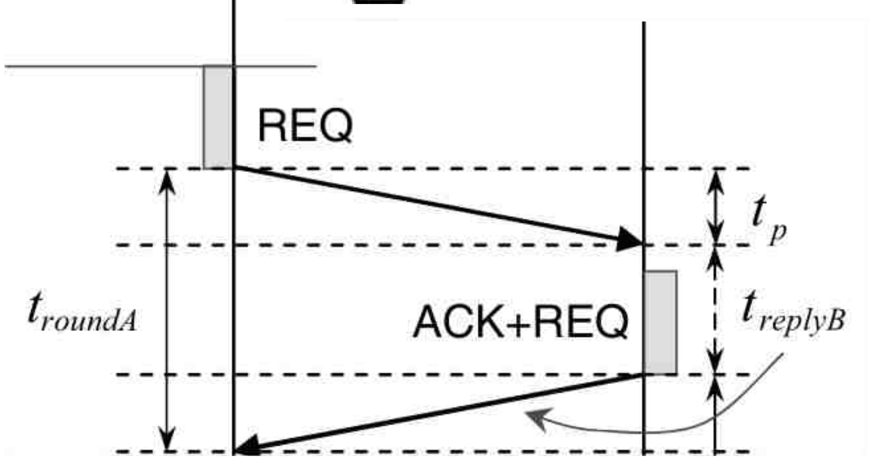
$$\mathrm{d} = 1000m$$

$$\theta = \frac{20}{1000}\frac{180}{\pi} = 1.1^{o}$$

Proposta: Método de Medição do BEL Intra-sistema

2) Técnica de medição tempo de propagação (τ_p): TOA Two-Way Ranging [7] [8]





$$\tau_{roundA} = 2\tau_p + \tau_{replyB}$$

$$\tau_p = \frac{1}{2}(\tau_{roundA} - \tau_{replyB})$$

[7] H. Kim, "Double-sided two-way ranging algorithm to reduce ranging time," IEEE Communications Letters, vol. 13, no. 7, pp. 486-488, 2009.

[8] R. Keating and D. Guo, "Multiuser Simultaneous Two-Way Ranging," IEEE Transactions on Wireless Communications, vol. 17, no. 8, pp. 5107-5119, 2018.

Proposta: Método de Medição do BEL Intra-sistema

$$L_k = 32.4 + 20\log f_c + L_{AB} + 10\, n\log(\tau_k\, c)$$

$$L_k = A + n\, B_k$$

$$A = 32.4 + 20\log f_c + L_{AB}$$

$$B_k = 10\ \log(\tau_k\, c)$$

Considerando todos os dispositivos

$$\underbrace{\begin{pmatrix} 1 & B_1 \\ \vdots & \vdots \\ 1 & B_N \end{pmatrix}}_{\boldsymbol{X}} \underbrace{\begin{pmatrix} A \\ n \end{pmatrix}}_{\boldsymbol{\beta}} = \underbrace{\begin{pmatrix} \bar{L}_1 \\ \vdots \\ \bar{L}_N \end{pmatrix}}_{\boldsymbol{y}}$$

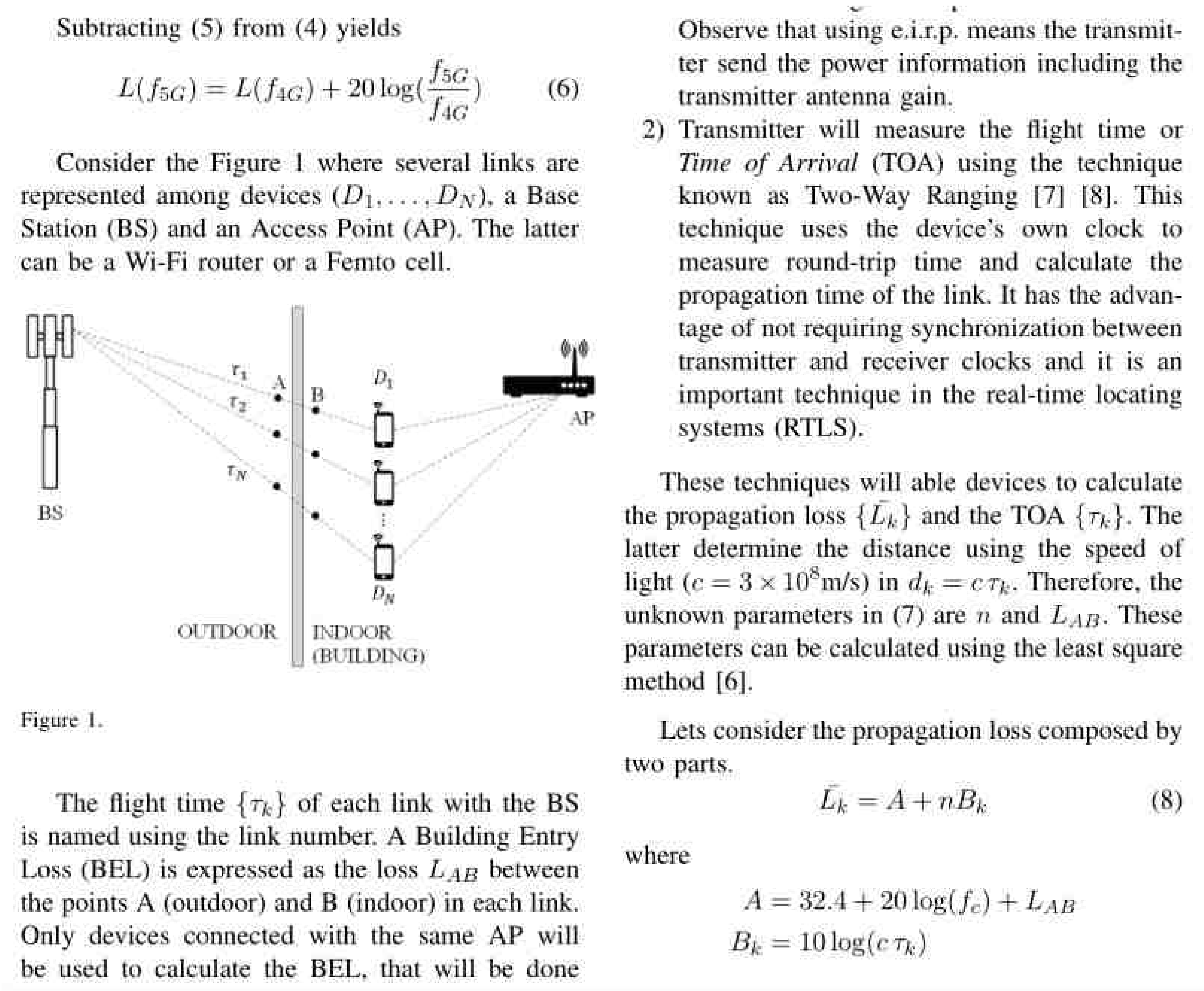
Utilizando Least Square Method [5] [6]

$$\boldsymbol{\beta} = (\boldsymbol{X}'\boldsymbol{X})^{-1}\boldsymbol{X}'\boldsymbol{y} \quad \longrightarrow \quad L_{AB} = A - 32.4 - 20\log f_c$$

[5] A. Zanella, "Best Practice in RSS Measurements and Ranging," in IEEE Communications Surveys & Tutorials, vol. 18, no. 4, pp. 2662-2686, 2016.

[6] John Neter, William Wasserman, Michael H. Kutner, "Applied Linear Regression Models", Richard D. Irwin, 1983.

Proposta: Paper Método de Medição do BEL Intra-sistema



Subtracting (5) from (4) yields

$$L(f_{5G}) = L(f_{4G}) + 20\log(\frac{f_{5G}}{f_{4G}}) \qquad (6)$$

Consider the Figure 1 where several links are represented among devices $(D_1, \ldots, D_N)$, a Base Station (BS) and an Access Point (AP). The latter can be a Wi-Fi router or a Femto cell.

Figure 1.

The flight time $\{\tau_k\}$ of each link with the BS is named using the link number. A Building Entry Loss (BEL) is expressed as the loss L_{AB} between the points A (outdoor) and B (indoor) in each link. Only devices connected with the same AP will be used to calculate the BEL, that will be done

Observe that using e.i.r.p. means the transmitter send the power information including the transmitter antenna gain.

2) Transmitter will measure the flight time or *Time of Arrival* (TOA) using the technique known as Two-Way Ranging [7] [8]. This technique uses the device's own clock to measure round-trip time and calculate the propagation time of the link. It has the advantage of not requiring synchronization between transmitter and receiver clocks and it is an important technique in the real-time locating systems (RTLS).

These techniques will able devices to calculate the propagation loss $\{\bar{L_k}\}$ and the TOA $\{\tau_k\}$. The latter determine the distance using the speed of light ($c = 3 \times 10^8$m/s) in $d_k = c\,\tau_k$. Therefore, the unknown parameters in (7) are n and L_{AB}. These parameters can be calculated using the least square method [6].

Lets consider the propagation loss composed by two parts.

$$\bar{L_k} = A + nB_k \qquad (8)$$

where

$$A = 32.4 + 20\log(f_c) + L_{AB}$$
$$B_k = 10\log(c\,\tau_k)$$