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Estimating Reflection and Transmission Losses for Link-Obstructing Objects at 70 GHz for 5G Wireless Backhauling

U T Virk, K Haneda*, J Putkonen[†]*

**Aalto University, Finland
Department of Electronics and Nanoengineering
email: usman.virk@aalto.fi*

*[†]Nokia Bell Labs, Finland
email: jyri.putkonen@nokia-bell-labs.com*

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Abstract

Wireless backhauling at 70 GHz maybe a viable option for 5G small cells densification. Whether indoors or outdoors, the millimeter-wave (mm-wave) backhaul links in an obstructed-line-of-sight (OLOS) or a non-LOS (NLOS) condition require a thorough investigation on reflection and transmission losses caused by various objects in the environment. In this paper, we evaluate the reflection and transmission loss due to link-obstructing objects at 70 GHz frequency band, ranging from human body to various building materials and vegetation. For this purpose, we employed a free-space wideband mm-wave channel sounding setup in the anechoic chamber and outdoors. The results indicate that building materials, human beings and trees cause significant attenuation of the 70 GHz radio signals, which is on average 45 – 50 dB. On the other hand, building materials such as, windows, and laminated or painted plywood, medium-density fiberboard and plasterboard are good reflectors. This extends an opportunity of establishing stable communication links through reflections from the materials in NLOS conditions using beamforming.

1 Introduction

The fifth-generation (5G) wireless communication is envisaged with applications requiring enormous data rates [1]. To meet this challenging requirement, millimeter-wave (mm-wave) regime of the radio frequency spectrum will be an essential part of 5G technology [2]. 5G wireless network infrastructure will be relying on small cells. However, dense deployment of small cells will render the wired backhauling impractical and costly [3, 4]. A more realistic and scalable solution would be to consider short-range wireless backhauling at low interfering licensed band, such as 70 GHz. Furthermore, a line-of-sight (LOS) mode of communication is always desirable, especially in the case of mm-Wave links. The mm-wave links operating in an obstructed-LOS (OLOS) or a non-LOS (NLOS) condition may suffer from considerable scattering and

transmission losses due to different objects in the given environment. Furthermore, coverage simulations also require accurate properties of built-in materials [5, 6]. All this necessitates a thorough study on the interaction of 70 GHz radio signals with link-obstructing objects. In mm-wave frequency spectrum and especially the V-band (40 – 75 GHz), most of the available research studies in the literature focused at evaluating reflection and transmission characteristics of common building materials at 60 GHz [7–24]. For the same purpose, only a small number of research investigations tapped 70 GHz frequency band [9, 26–31, 33]. [25] reviews the literature for penetration loss and electromagnetic properties of common building materials at mm-Wave frequencies. The International Telecommunication Union (ITU) Recommendation [29] offers models for calculating attenuation due different type of vegetation at mm-wave frequencies. Attenuation from single ficus and conifer trees at 60 GHz is introduced in [34]. Table 1 presents the literature review for reflection and transmission losses of some common materials at 70 GHz frequency band.

In this paper, we investigate reflection and transmission losses for a wide variety of link-obstructing objects at 70 GHz frequency band. The free-space method is employed for measuring different materials in anechoic chamber and outdoors. Our work uniquely supplements the existing literature by estimating the reflection and transmission properties of materials that are not previously measured at 70 GHz frequency band, including: (1) energy efficient office windows typically used in northern Europe, (2) painted and laminated plywood, (3) fabric curtain, (4) plasterboard, (5) commercially available office partition, (6) human body, (7) asphalt and (8) trees.

The remainder of this paper is organized in three sections: Section 2 describes the experimental setup along with the summary of materials under test. Section 3 presents results and discussions on them. Finally, Section 4 concludes the paper.

2 70 GHz Reflection and Transmission Loss Measurements

2.1 Channel sounder

A vector network analyzer (VNA) based channel sounder setup is used for measuring reflection and transmission losses of

Fig. 2: Example of the delay-gating of channel impulse response $h(\tau)$ measured in anechoic chamber.

via inverse fast Fourier transform. Finally, the delay-gating is applied to isolate the main reflection or the transmission path between TX and RX from the unwanted reflections due to antenna mismatch and those originating from the environment, as exemplified in Fig. 2. Even when the measurements are performed in anechoic chamber, we see some reflections in $h(\tau)$ apart from the main reflection or transmission path as shown in Fig. 2, and hence the delay-gating is crucial.

2.3 Material samples and their measurements

A wide range of material specimen are measured. These material samples cover the typical link-obstructing objects indoor and outdoor short-range backhauling and their details are given in Table 3. Energy efficient windows is a common consideration at both commercial and residential buildings especially at high latitude locations. Several types of Pilkington InsulightTM commercially available window samples [35] were acquired for measuring their reflection and transmission properties. These window samples are: (1) fixed and (2) open or operational. Fixed type windows are one time installation windows and are generally used in large buildings, while open type windows are casement windows with hinged sash that swings in or out like a door and are commonly utilized in residential buildings. Each of the measured windows is composed of different components, for instance, glass units, selective surfaces, gas as summarized in Table 4.

Other common construction materials considered for measurements include plywood, plasterboard, medium-density fiberboard (MDF), commercially available office partition, and fabric curtain. As plywood is one of the most common and frequently used construction material in buildings, we measured its four distinct variations with different sizes and surface types. Humans recurrently obstruct radio links due to their frequent movements in the environment, and therefore, we also measured relatively fat and thin human bodies. For outdoor mm-wave links, we measured attenuation due two different trees and reflections from dry asphalt on a road. Item no. 1 to no. 12 in Table 3 were measured inside anechoic chamber and the rest were measured outdoors due to practical limitations.

Fig. 3: Bistatic reflection loss measurement setup.

Fig. 4: Transmission scattering loss measurement setup. $\gamma = 0^\circ$ in our measurements.

For anechoic chamber measurements, the TX and RX antennas heights were fixed at 1 m, the distance of the material specimen from TX and RX antenna was at 0.7 m compared to the far-field distance of the antennas at 70 GHz i.e., 0.42 m, the incidence and reflection angles were $\phi_1 = \phi_2 = 20^\circ, 40^\circ, 60^\circ$, and $\gamma = 0^\circ$ for transmission measurements. The exemplary window measurement in anechoic chamber is shown in Fig. 5. In outdoors, the two trees were measured with their trunks and branches as illustrated through Fig. 6. The link distance in the tree measurements varied between 3 m and 5 m, for which the cross section width of first Fresnel zone at 70 GHz ranges from 5.6 cm to 7.3 cm. In the asphalt measurements, the TX and RX antennas were mounted on tripod stands at a height of 2 m and tilted towards the road at the grazing angles of $33^\circ, 41^\circ$ and 50° . The reflection losses for asphalt are characterized with respect to a metal sheet, which serve as a reference.

3 Results and Discussion

The reflection and transmission losses for various materials measured in anechoic chamber and outdoors are arranged in Table 5 and Table 6, respectively.

It is interesting to observe that all the fixed type windows (F_1 to F_4) offered a very high transmission loss of about 70 dB which can be explained from the presence of two types of specialized glass layers with offline coating, i.e., Optitherm S3 and S1N. Practically, it is not possible to transmit 70 GHz radio signals through these windows. According to the manu-

Table 3: Summary of materials measured in anechoic chamber and outdoors.

Item no.	Material type	ID	Category	Dimensions [W x H x T] cm ³	Measurement
1	Glass windows	O ₁ , O ₂ , O ₃	Open	123 × 148 × 21	Reflection & Transmission
2		F ₁ , F ₂ , F ₃ , F ₄	Fixed	123 × 148 × 17	
3	Plywood	P ₁	Normal	150 × 150 × 0.6	
4		P ₂	Normal	150 × 150 × 01.1	
5		P ₃	Laminated	150 × 150 × 1.6	
6		P ₄	Painted	150 × 150 × 1.1	
7	MDF board	M _b	Normal	150 × 150 × 0.9	
8	Plaster board	P _b	Normal	150 × 150 × 1.1	
9	Office partition	O _p	Commercial	150 × 150 × 2.0	Transmission
10	Fabric curtain	F _c	Commercial	150 × 150 × 2.0	
11	Human body	H _t	Thin	48 × 190 × 30	
12		H _f	Fat	40 × 165 × 25	
13	Tree trunk	T ₁	Mountain ash	40 × 500 × 35	
14		T ₁	Pine	42 × 1000 × 40	
15	Dry asphalt	A	Road	-	Reflection

Table 4: Pelkington Insulight™ windows specifications.

Type	ID	Configuration
Fixed	F1	3K6(S1N)–10(OPF)–16TGI(Ar)4(S3)
	F2	3K6(S1N)–8.4L–16TGI(Ar)4(S3)
	F3	3K8.4L–4(S1N)–16TGI(Ar)6(S3)
	F4	3K4(S1N)–4(S1N)–16TGI(Ar)4(OPF)
Open	O1	[2K8.4L–14TGI(Ar)–4(S1N)]–17(As)–8.4L
	O2	[2K4(S1N)–16TGI(Ar)–6(OPF)]–21(As)–4(OPF)
	O3	[2k4(S3)–16TGI(Ar)–3(OPF)]–21(As)–4(OPF)

- For interpreting e.g. F1: nKx(IGU)–x(IGU)–zTGI(Ar)x(IGU)
- nK: total no. of Insulating Glass Units (IGUs).
- x(IGU): width in mm (IGU).
- Optitherm S1N: optimized and soft-faceted thermal IGU.
- Optitherm S3: traditional energy saving IGU.
- Optifloat OPF: transparent, toughened and heat soaked glass.
- yL: width in mm (Laminated Glass Unit).
- z(TGI): width in mm (Spacer material).
- w(As): width in mm (air space).
- Ar: argon gas.

facturing details [35], these glass layers provide high thermal insulation. Furthermore, the open type windows (O₁ to O₃) allowed the signals to pass through but with high transmission loss of about 40 dB, which is significant. On the contrary, the reflection loss from all widows, whether fixed or open types, is about 8 ~ 10 dB on average and demonstrate that they are good reflector of radio waves at 70 GHz. For the plywood, MDF and plasterboard, the transmission loss is about 6 dB on average. It is compelling to note that if the surface of these materials is covered with lamination or paint, they reflect signif-

Fig. 5: Anechoic chamber window measurements. **Fig. 6:** Outdoor tree attenuation measurements.

icant amount of electromagnetic energy at 70 GHz band. The commercially available office partition and fabric curtain was only tested for transmission loss as they had rough surfaces and caused 5.2 dB and 1.5 dB attenuation, respectively. The width of the measured humans covered the first Fresnel zone of the link and lead to a shadow loss of about 40 dB, similar to what is reported in [32]. This shows that humans can adversely affect a radio link at the measured frequency. The attenuation

Table 5: Estimated reflection and transmission loss for objects measured in anechoic chamber.

Sample	Loss [dB]			
	Reflection (ϕ)			Transmission (γ)
	20°	40°	60°	
Window (F ₁)	11.1	13.8	6.3	60
Window (F ₂)	7.6	4.9	4.3	> 70
Window (F ₃)	14.9	17.1	16.3	> 70
Window (F ₄)	2.0	2.0	1.1	> 70
Window (O ₁)	0.5	2.3	1.6	38.8
Window (O ₂)	1.7	0.9	3.0	37.5
Window (O ₃)	8.1	7.3	8.2	55
Plywood (P ₁)	13.7	15.6	34.6	0.5
Plywood (P ₂)	18.4	10.7	17.9	5.2
Plywood (P ₃)	10.8	5.4	16.9	7.9
Plywood (P ₄)	6.1	6.6	13.8	6.1
MDF (M _b)	2.5	11.7	-	5.3
Plaster (P _b)	10.8	15.8	34.2	4.0
Partition (O _p)	-	-	-	5.2
Curtain (F _c)	-	-	-	1.5
Human (H _f)	-	-	-	48.7
Human (H _t)	-	-	-	38.6

Table 6: Estimated reflection and transmission loss for objects measured outdoors.

Sample	Loss [dB]			
	Reflection (ϕ)			Transmission (γ)
	33°	41°	50°	
Tree (T ₁)	-	-	-	45.2
Tree (T ₂)	-	-	-	17.9
Asphalt (A)	9.8	16.1	10.8	-

through the mountain ash tree (T₁) is 45 dB, which is 27 dB more than the pine tree (T₂). This is probably due to wider and branched trunk of the mountain ash tree. The dry road asphalt also exhibit high reflective properties where the reflection loss is on average 12 dB for different grazing angles. The results are similar to those presented in [27].

In order to quantify the uncertainty in the measured results, the transmission measurement for the plywood sample (P₁) was repeated seven times on different occasions. The standard deviation of error obtained was about 2.2 dB.

4 Conclusion

Transmission and reflection losses due to objects in indoor and outdoor short-range backhaul links are estimated through wideband free-space measurements at 70 GHz. The results demonstrate that windows, plywood, human bodies and trees significantly attenuate radio signals in transmission, but at the same time, are good reflectors and can be used for link establishment in NLOS conditions. It is observed that most modern building windows specialized for heat insulation purposes cause high transmission loss. Some window types offer 3 dB

reflection losses at different incident angles. The human shadowing is about 40 dB on average, which is significant and can result in serious intermittent outages in the link. The other common building materials such as, plasterboard, plywood, MDF, and fabric curtains have transmission losses up to 8 dB. On the other hand, the reflection losses are reduced if the surface is laminated or painted. These results serve as a baseline for the design and deployment of 70 GHz wireless backhaul links.

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References

- [1] “Mobile data growth outlook,” *Mobility report*, (Ericsson AB, June, 2018). Available online: <https://www.ericsson.com/en/mobility-report/reports/june-2018/mobile-data-traffic-growth-outlook>.
- [2] T. S. Rappaport, S. Sun, R. Mayzus, *et al.* “Millimeter wave mobile communications for 5G cellular: It will work!,” *IEEE Access*, **1**, pp. 335–349, (May 2013).
- [3] P. H. Huang and K. Psounis. “Efficient mmWave wireless backhauling for dense small-cell deployments,” In *Proc. Annual Conf. Wireless On-demand Net. Sys. Services (WONS’17)*, Jackson, USA, Feb. 2017, pp. 88–95.
- [4] C. Dehos, J. L. Gonzalez, A. D. Domenico, *et al.* “Millimeter-wave access and backhauling: The solution to the exponential data traffic increase in 5G mobile communications systems?,” *IEEE Communications Magazine*, **52**, (9), pp. 88–95, (Sep. 2014).
- [5] J. Järveläinen, K. Haneda, A. Karttunen. “Indoor propagation channel simulations at 60 GHz using point cloud data,” *IEEE Trans. Antennas Propag.*, **64**, (10), pp. 4457–4467, (Oct. 2016).
- [6] U. T. Virk, S. L. H. Nguyen, K. Haneda *et al.* “On-site permittivity estimation at 60 GHz through reflecting surface identification in the point cloud,” *IEEE Trans. Antennas Propag.*, **66**, (7), pp. 3599–3609, (July 2018).
- [7] L. M. Correia and P. O. Frances. “Estimation of materials characteristics from power measurements at 60 GHz,” In *Proc. IEEE Int. Symp. Personal, Indoor and Mobile Radio Commun.*, The Hague, Netherlands, Sep. 1994, pp. 510–513.
- [8] B. Langen, G. Lober, W. Herzig. “Reflection and transmission behaviour of building materials at 60 GHz,” In *Proc. IEEE Int. Symp. Personal, Indoor and Mobile Radio Commun.*, The Hague, Netherlands, Sep. 1994, pp. 505–509.

- [9] K. Sato, H. Kozima, H. Masuzawa, *et al.* "Measurements of reflection characteristics and refractive indices of interior construction materials in millimeter-wave bands," In Proc. *IEEE Veh. Tech. Conf.*, Chicago, IL, USA, pp. 449–453, July 1997.
- [10] L. M. Correia and P. O. Frances. "Transmission and isolation of signals in buildings at 60 GHz," In Proc. *IEEE Int. Symp. Personal, Indoor and Mobile Radio Commun.*, Toronto, Canada, Sep. 1995, pp. 1031–1034.
- [11] J. Lahteenmaki and T. Karttaavi. "Measurement of dielectric parameters of wall materials at 60 GHz band," *Electronics Letters*, **32**, (16), pp. 1442–1444, (Aug. 1996).
- [12] J. P. Pugliese, A. Hammoudeh, M. Al-Nuaimi. "Estimation of dielectric parameters from reflection and transmission coefficients of building materials at 62 GHz," In Proc. *Int. Conf. Antennas Propag.*, Edinburgh, UK, Apr. 1997.
- [13] K. Sato, T. Manabe, T. Ihara, *et al.* "Measurements of reflection and transmission characteristics of interior structures of office building in the 60-GHz band," *IEEE Trans. Antennas Propag.*, **45**, (12), pp. 1783–1792, (Dec. 1997).
- [14] H. Radi, M. Fiacco, M. A. N. Parks, *et al.* "Simultaneous indoor propagation measurements at 17 and 60 GHz for Wireless Local Area Networks," In Proc. *IEEE Veh. Tech. Conf. (VTC'98)*, Ottawa, Canada, May 1998.
- [15] A. Hammoudeh, J. P. Pugliese, M. G. Sanchez, *et al.* "Comparison of reflection mechanisms from smooth and rough surfaces at 62 GHz," In Proc. *IEE Nat. Conf. Antennas Propag.*, York, UK, Apr. 1999.
- [16] I. Cuinas, J. P. Pugliese, A. Hammoudeh, *et al.* "Comparison of the electromagnetic properties of building materials at 5.8 GHz and 62.4 GHz," In Proc. *Proc. IEEE Veh. Tech. Conf. (VTC'00)*, Boston, MA, USA, pp.780–785, Sept. 2000.
- [17] I. Cuinas, J. P. Pugliese, A. Hammoudeh, *et al.* "Frequency dependence of dielectric constant of construction materials in micro-wave and millimeter-wave bands," *IEEE Antennas Wireless Propag. Lett. Microw. Opt. Lett.*, **30**, (2), pp. 123–124, (June 2001).
- [18] C. R. Anderson and T. S. Rappaport. "In-building wideband partition loss measurements at 2.5 and 60 GHz," *IEEE Trans. Wireless Commun.*, **3**, (3), pp. 922–928, (May 2004).
- [19] A. V. Alejos, M. G. Sanchez, and I. Cuinas. "Measurement and analysis of propagation mechanisms at 40 GHz: Viability of site shielding forced by obstacles," *IEEE Trans. Veh. Tech.*, **57**, (6), pp. 3369–3380, (Nov. 2008).
- [20] J. Ahmadi-Shokouh, S. Noghianian and H. Keshavarz. "Reflection coefficient measurement for North American house flooring at 57–64 GHz," *IEEE Antennas Wireless Propag. Lett.*, **10**, pp. 1321–1324, (Nov. 2011).
- [21] B. Feitor, R. Caldeirinha, T. Fernandes, *et al.* "Estimation of dielectric concrete properties from power measurements at 18.7 and 60 GHz," In Proc. *Loughborough Antennas Propag. Conf. (LAPC'11)*, Loughborough, UK, Nov. 2014.
- [22] J. Lu, D. Steinbach, P. Cabrol, *et al.* "Propagation characterization of an office building in the 60 GHz band," In Proc. *European Conf. Antennas Propag. (EuCAP'14)*, The Hague, Netherlands, Apr. 2014.
- [23] E. Semaan, F. Harrysson, A. Furuskar, *et al.* "Outdoor-to-indoor coverage in high frequency bands," In Proc. *IEEE Globecom Workshops*, Texas, Austin, USA, pp.393–398, Dec. 2014.
- [24] D. Ferreira, I. Cuias, R. F. S. Caldeirinha, *et al.* "A review on the electromagnetic characterisation of building materials at micro- and millimetre wave frequencies," In Proc. *European Conf. Ant. Propag. (EuCAP'14)*, The Hague, Netherlands, pp. 145–149, Apr. 2014.
- [25] S. Salous, V. D. Esposti, F. Fuschini *et al.*, "Millimeter-Wave Propagation: Characterization and modeling toward fifth-generation systems. [Wireless Corner]," *IEEE Antennas and Propagation Magazine*, **58**, (6), pp. 115–127, (Dec. 2016).
- [26] R. Piesiewicz, R. Geise, J. Schoebel, *et al.* "Reflection and transmission properties of building materials in W-band," In Proc. *European Conf. Ant. Propag. (EuCAP'07)*, Edinburgh, UK, Nov. 2007.
- [27] V. Viikari, T. Varpula and M. Kantanen. "Automotive radar technology for detecting road conditions. Backscattering properties of dry, wet, and icy asphalt," In Proc. *European Radar Conference*, Amsterdam, Netherlands, pp. 276–279, Oct. 2008.
- [28] T. S. Rappaport and S. Deng. "73 GHz wideband millimeter-wave foliage and ground reflection measurements and models," In Proc. *IEEE Int. Conf. Commun. Workshop (ICCW'15)*, London, UK, pp. 1238–1243, June 2015.
- [29] International Telecommunication Union (ITU), "Attenuation in vegetation," Rec. ITU-R P.833–8, 2016.
- [30] F. Fuschini, S. Hafner, M. Zoli, *et al.* "Item level characterization of mm-wave indoor propagation," *EURASIP Journal on Wireless Communications and Networking*, **4**, pp. 1–12, (Jan. 2016).
- [31] Y. Du, C. Cao and X. Zou, *et al.* "Measurement and modeling of penetration loss in the range from 2 GHz to 74 GHz," In Proc. *IEEE Globecom Workshops*, Washington DC, USA, Dec. 2016.
- [32] G. R. MacCartney, S. Deng, S. Sun, *et al.* "Millimeter-Wave Human Blockage at 73 GHz with a Simple Double Knife-Edge Diffraction Model and Extension for Directional Antennas," In Proc. *IEEE Veh. Tech. Conf. (VTC'16)*, Montreal, Canada, Mar. 2016.
- [33] J. Ryan, G. R. MacCartney and T. S. Rappaport. "Indoor office wideband penetration loss measurements at 73 GHz," In Proc. *IEEE Int. Conf. Commun. Workshops (ICCW'17)*, Paris, France, pp. 228–233, May 2017.
- [34] R. F. S. Caldeirinha and M. O. Al-Nuaimi. "Cross-polarisation discrimination studies of single trees at 20 and 62.4GHz," *IET Microwaves, Ant. Propag.*, **11**, (5), pp. 695–704, Apr. 2017.
- [35] "Glass window products," Pilkington. Available online: <https://www.pilkington.com/en/global/commercial-applications/glass-applications/windows>