Building-to-Building Propagation Loss Measurements at 3.5 GHz with Application to Micro Operators

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***Abstract*—Recently proposed micro operator concept aims at providing high quality services in specific locations such as hospitals, shopping malls, campuses, or factories, to complement traditional mobile network operators' (MNO) broadband offerings. Micro operators address reliable 5G service delivery with predefined quality guarantees through local small cell deployments especially inside buildings with locally issued spectrum access rights. To properly characterize the resulting interferences in this new 5G deployment scenario with potentially a large number of local indoor networks by different 5G micro operators, accurate propagation loss modeling between the micro operator networks in adjacent buildings is needed. So far there is only one path loss model from indoor small cell to a user equipment (UE) inside a different building proposed by 3GPP, which could be used to model the micro operator scenario. To verify the applicability of this model, we conducted building-to-building propagation loss measurements at University of Oulu campus in Finland in the 3.5 GHz band. Measurement results were compared to the ones obtained from the 3GPP model. Significant differences were found between measurements and model when the default model value for outer wall penetration loss was used. This leads to the conclusion that a single outer wall penetration loss value is insufficient but multiple penetration loss values are needed. Also, for campus scenario with mostly line-of-sight measurement cases, it may be more appropriate to use free space path loss instead of switching to a higher path loss exponent after a breakpoint distance. Finally, the measurements indicate that offset values relatively to the 3GPP-like model are needed for modeling the building-to-building propagation in campus environment, which are proposed in the paper.**

***Index Terms*—building-to-building, path loss, micro operators**

I. Introduction

Future mobile communication networks known as 5G will address reliable provisioning of high-quality services to serve the different needs of the vertical sectors in specific locations such as hospitals, campuses, shopping malls, and factories [1]. While cellular mobile communication networks are traditionally deployed by the mobile network operators (MNO) to provide wide area coverage, future 5G networks will specifically address the serving of high-demand areas and be increasingly deployed inside buildings [2]. New local deployment models for 5G networks are emerging to address the provisioning of local services in indoor environments and introducing more competition to the mobile market currently dominated by the big MNOs.

The concept of micro operators has been recently proposed to allow different stakeholders to establish locally operated 5G small cell networks in various places based on local spectrum availability [3]. Reliable delivery of versatile high-quality services requires different levels of guaranteed wireless connectivity, which is only possible with local spectrum access rights proposed in [4] as micro licenses. For example, a building owner could become a micro operator and deploy a local small cell network or buy it as a service from a local vendor to serve the people in its premises [2].

Spectrum authorization for 5G is an open topic and local licensing models are receiving increasing attention [5]. The introduction of building specific 5G micro operators will result in a novel 5G deployment scenario where different micro operators are issued local spectrum micro licenses in nearby buildings [4]. This calls for accurate modeling of the propagation path losses in order to study the micro operator network performance and potential interference to other micro operators. While micro operators can manage the interference they receive from their own network using standard methods and tools, additional interference is received when two different micro operators operate in adjacent buildings in the same or adjacent frequency channel as initially analyzed in [4]. Therefore, interference modeling and analysis between micro operators in adjacent buildings is important in the development of rules and requirements for operating local 5G networks, which calls for accurate propagation loss modeling. For example, for the local deployment of 5G networks, the maximum allowable transmit power levels near the building walls could depend on the attenuation properties of the building. There could also be deployment specific limitations on the allowed antenna patterns and antenna pointings.

While the topics of outdoor-to-indoor propagation [6]–[10] and indoor-to-outdoor propagation [11]–[13] have been widely studied, the characterization of building-to-building propagation losses has received much less attention. Moreover, there are hardly any measurements conducted to assess the propagation losses in the building-to-building deployment scenario which occurs with the introduction of 5G micro operators [3].

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Most measurements have only considered building penetration losses showing its dependency on the construction material and carrier frequency [14] or the outdoor propagation path losses [15] separately. One of the very few building-to-building propagation models known to the authors comprising the entire path is the 3GPP dual-stripe model described in [16].

In this paper we perform propagation measurements between neighboring buildings in the example case of 3.5 GHz frequency band in University of Oulu campus. The obtained measurement results will then be compared to the ones estimated with the help of the 3GPP dual-stripe model. The 3.5 GHz frequency band is of special interest due to the recent development of the Citizens Broadband Radio Service (CBRS) in the US [17] and the 3.4-3.8 GHz band being the first primary band for 5G in Europe [18]. In fact, the three-tier CBRS spectrum sharing model admits two layers of additional users in local areas in the 3.55-3.7 GHz band in the US while protecting the incumbents in the band. Due to its urgency for 5G use, it is of interest to study the 3.5 GHz band for the micro operator usage. Prior measurements of this band have not addressed the building-to-building propagation loss but focused only either outdoor-to-indoor [10] or indoor-to-outdoor [11], [13] propagation cases.

The rest of this paper is organized as follows. Section II introduces the relevant propagation loss models. Section III presents the measurement setup and locations. Results of the measurements and comparison with the 3GPP propagation loss model is provided in Section IV. Finally, conclusions are drawn in Section V.

II. Building-to-Building Path Loss Model

This section presents the 3GPP path loss model for characterizing the building-to-building propagation scenario. Furthermore, the topic of wall attenuation is discussed.

A. 3GPP Dual-Stripe Model

3GPP has proposed a model in [16] for the path loss between an indoor small cell and a user equipment (UE) located in a different building. The proposed dual-stripe model consists of two multi-floor buildings with apartments of size 10 meters time 10 meters. The two buildings are separated by a distance of 10 meters, as illustrated in Fig. 1.

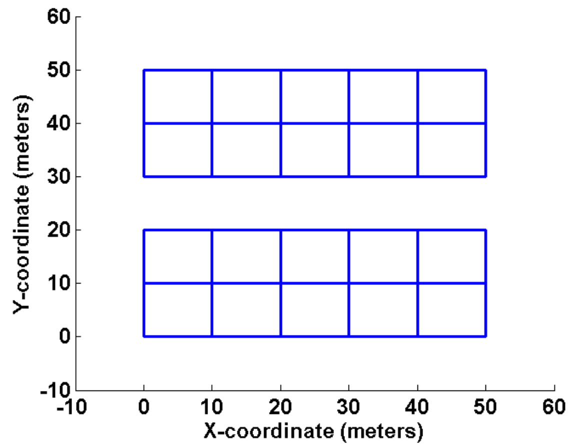

Fig. 1. 3GPP dual-stripe deployment.

The 3GPP model defines the path loss between a UE and a small cell inside different building as [16]

$$PL\,(dB) = \max\left(15.3 + 37.6\log_{10}R,\ 38.46 + 20\log_{10}R\right) + 0.5d_{\text{2D,indoor}} + qL_{iw} + Low_1\,(f_c) + Low_2\,(f_c) + delta\,(f_c) \quad (1)$$

where R is the distance in meters, $d_{\text{2D,indoor}}$ is distance traveled indoors, q is the number of walls (between apartments) crossed, L_{iw} is the loss due inner walls (between apartments), $Low_1\,(f_c)$ and $Low_2\,(f_c)$ are the outer wall losses in the two buildings as a function of the center frequency f_c. The default center frequency f_c is 2 GHz but 3.5 GHz is also supported by this model. In this paper, we assume $f_c = 3.5$ GHz as the example frequency band for micro operator use as used for locally deployed networks in [17]. Therefore, by using the frequency dependency of the free space path loss, $delta\,(f_c) = 20\log_{10}(3.5/2) = 4.8$ dB is needed to convert the path loss model from 2 GHz to 3.5 GHz. The specified value for outer wall penetration losses at 3.5 GHz is 23 dB and the specified value for inner wall loss in the 3.5 GHz band is 5 dB. The path loss term $\max$ has a breakpoint distance equal to 20.7 m. For shorter distances free space path loss is used and for longer distances the path loss exponent is set to 3.76.

B. Wall Material Attenuation and Building-to-Building Attenuation

An important part of the building-to-building propagation model is the penetration loss caused by the outer wall. Previous studies, for example the ones in [8], [14], [19]–[26], have clearly shown that the outer wall loss will depend heavily on both the wall material and the frequency of the transmitted signal. For example, thermally very efficient buildings have higher wall losses than the less efficient buildings. The wall loss, 23 dB, assumed in the 3GPP dual-stripe model is in the upper range of possible values for 3.5 GHz. Furthermore, the 3GPP dual-stripe model specifies only one wall loss value, which limits the usefulness of the model for the micro operator scenarios. However, if the purpose to avoid overestimating the coverage, then the 3GPP dual-stripe model is fully valid. However, since we are considering spectrum sharing as a motivation then interference is just as important, if not more so. These two factors are essentially contradictory.

For measuring attenuation by different wall materials an appropriate approach would be to measure blocks of actual wall materials in an anechoic chamber with sufficiently directional horn antennas on both sides and by using vector network analyzer (VNA) to sweep over considered frequency range. These kind of values have been reported for various building materials at 3.5 GHz in [26, Table 49].

To analyze the path losses in the building-to-building propagation case for the micro operator deployment scenario we are interested in studying the overall propagation losses, instead of the accurate penetration losses of the building walls and windows. For example, even in cases with concrete on both sides signal may have slightly leaked out from some easier propagation paths, which can result in a slightly different wall loss estimates compared to measurements in laboratory conditions. Moreover, for modeling the interference between micro operators it is important to consider the worst-case scenarios in order to see how high the interference can really be. This then motivates to select the measurement locations close to the outer walls.

III. Measurement setup and locations

A. Measurement equipment and approach

Two approaches were used for measuring the propagation losses to increase the reliability of the measurements. First, Elektrobit PropSound wideband channel sounder was utilized in selected locations. This device is suitable for high-quality channel measurements. It utilizes direct sequence spread spectrum technique and Binary Phase Shift Keying (BPSK) modulation with maximum transmit power of 26 dBm and variable bandwidth up to 100 MHz. The measurements used 23 dBm transmit power and 10 MHz bandwidth.

In all measurement locations, we measured the path loss by transmitting signal with IFR 2042 signal generator and by receiving it with Anritsu MS2035B hand-held spectrum analyzer. Multiple measurements were done in each location by slightly moving the receiving antenna to average out fast fading. Both approaches, the use of a channel sounder and the signal generator+spectrum analyzer, led to similar measured propagation losses confirming their validity. The transmitter side used Rohde&Schwarz horn antenna HF906 with 9.8 dB gain at 3.5 GHz and receiver side used dipole antenna (Aerial, AV1433-3550FN1) with 2 dB gain. Antenna height was 1.6 meters. Fig. 2 shows the PropSound transmitter and the used horn antenna.

Fig. 2. PropSound transmitter and HF906 horn antenna.

B. Measurement locations and cases

Building-to-building measurements were conducted in seven different locations at the campus area of University of Oulu including locations with glass walls in both sides and locations with concrete walls on both sides. A location with internal wall in addition to only outer walls was also included. Buildings of different age were considered by measuring new and old parts of the university. Distances were measured with laser range finder when feasible. Otherwise the distances were found based on on-scale maps.

Measurement cases 1, 2 and 7 were performed in the relatively new part of the building. The outer wall material was glass in both ends of the link for cases 1 and 2. In the case 1, measurement distance was 44 meters with big windows in both ends. This case is shown in Fig. 3. In the case 2, the measurement distance was 14 meters with small windows on both sides. In case 7, measurement was instead performed in the first floor of the same building where both outer walls were concrete without windows. Measurement distance was equal to 14 meters as in case 2. All three cases are shown in the satellite image in Fig. 4.

Measurement case 3 has glass as the outer wall material at both ends with a total distance of 44 meters. In case 4, we go further inside the building into a room, in order to measure the effect of internal wall (distance 46 meters). These two measurement cases were in the first floor. Both cases are shown in the satellite image in Fig. 5. Foliage (trees) are in the path.

Measurement case 5 considers a relatively long propagation distance of 66 meters. Both outer walls are concrete without windows. Case 5 is shown in the satellite image in Fig. 6.

Finally, the measurement case 6 considers a short propagation distance of 13 meters. Both outer walls are glass (walls with windows and antennas placed behind the windows). This measurement was done in the first floor. Case 6 is shown in the satellite image in Fig. 7. This place is within the older part of the University of Oulu.

IV. Measurement and modeling results in the 3.5 GHz band

Measurements results of the building-to-building propagation losses in the 3.5 GHz band from the seven different locations in the university campus were compared with the

Fig. 3. Measurement case 1.

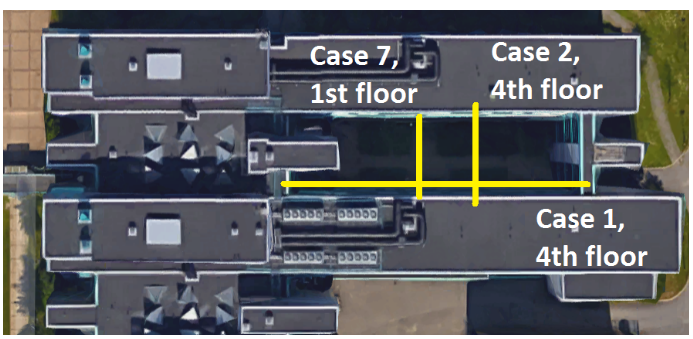

Fig. 4. Measurement cases 1 (window-window, 44 m, 4th floor), 2 (window-window, 14 m, 4th floor), 7 (concrete-concrete, 14 m, 1st floor). Map data (c) Google 2017.

Fig. 5. Measurement case 3 (window-window, 44 m, 1st floor) and 4 (46 m, window-window with internal wall, 1st floor). Map data (c) Google 2017.

Fig. 6. Measurement case 5 (concrete-concrete, 66 m, 2nd floor). Map data (c) Google 2017.

Fig. 7. Measurement case 6 (window-window, 13 m, 1st floor). Map data (c) Google 2017.

3GPP path loss model. Moreover, offset values to 3GPP-like model were defined in order to fit with the measurement results. These are explained in more detail in the following.

A. Comparison of Measurement Results with 3GPP Model Results

Fig. 8 shows measured average path losses from all cases compared to results from the 3GPP model using the specified parameters (e.g. 23 dB wall attenuation). The results indicate that the 3GPP dual-stripe model results in much higher path losses than what was actually observed with measurements. In measurement case 1 differences of around 50 dB are observed. There are several reasons for these differences. For example, in the case 1 free space path loss is the appropriate model to use but the 3GPP model has switched to much higher path loss exponent since breakpoint distance is exceeded. Generally speaking, the obtained results suggest that the 3GPP model is not really suited or meant for situations where free space path loss dominates. Also, the assumed outer wall attenuation of 23 dB is only valid for special cases, such as thermally very efficient windows or thick concrete walls.

B. Path Loss Model for University of Oulu Campus

We have seen that the 3GPP dual-stripe model results in poor fit with the actual measurement results from University of Oulu campus. Considering different options, taking into account that free space path loss seems more appropriate for our measurement cases, and taking into account that observed excess loss (compared to pure free space path loss) varied greatly between different measurements cases (it was either very low or around 15 dB per wall/window), we suggest two models for University of Oulu campus. This can be viewed as proposing values for the offset for 3GPP-like model for campus environment, where it is expected that more measurements in different environments will give us a better idea about the range to be used for this offset. The suggested path loss model is as follows:

$$PL\,(dB) = \begin{cases} 38.46 \;+\; 20\log_{10} R + 0.5 d_{\text{2D,indoor}} & \\ +qL_{iw} + delta\,(f_c) & \text{Model 1} \\ 38.46 \;+\; 20\log_{10} R + 0.5 d_{\text{2D,indoor}} & \\ +qL_{iw} + delta\,(f_c) + 30 & \text{Model 2} \end{cases}$$

where (same as with the 3GPP model) $L_{iw} = 5$ dB, $delta\,(f_c) = 4.8$ dB. Both suggested models use always free space loss. In the model 1, we do not include any extra loss due to the outer walls. Therefore, model 1 represents the worst-case for interference. Model 2 is the same as model 1 but it does include 30 dB extra loss in order to model propagation through two walls/windows.

Figure 9 shows the results from the suggested offset values with the 3GPP-like model vs the actual measurement results. We can see for measurement cases 1 and 2 that the proposed model 1 leads to a very good fit. This suggests that the windows in those measurement locations cause only small attenuation. For cases 3–7, we can see that the proposed model 2 leads to good fit. This is remarkable since measurement cases 3–7 include both old and new parts of the university and both windows and concrete as wall materials.

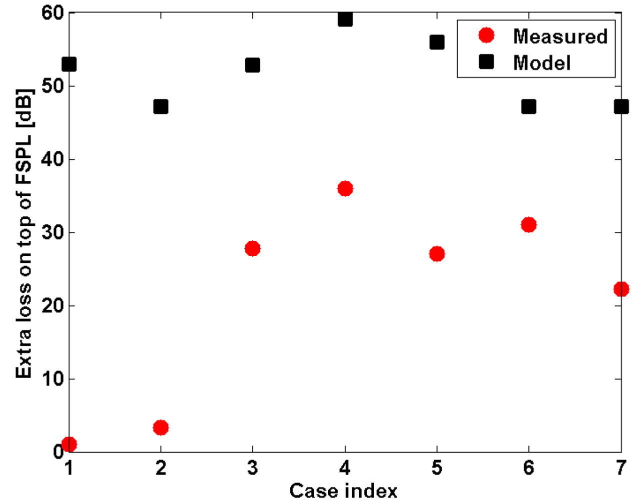

Fig. 8. 3GPP model with standard parameters (e.g. 23 dB wall attenuation) and measured results in University of Oulu campus. Losses relative to the free space path loss (FSPL).

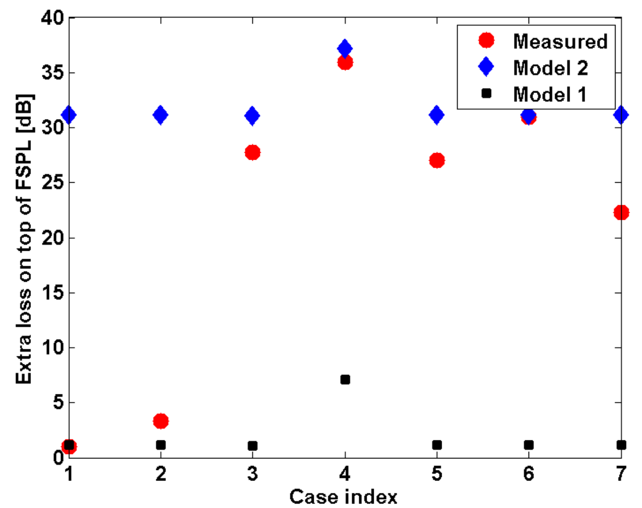

Fig. 9. Suggested path loss models (1 and 2) and measured results in University of Oulu campus. Losses relative to the FSPL.

V. Conclusions

Building-to-building propagation losses were evaluated by conducting multiple measurements in University of Oulu campus. The measured propagation losses were then compared to the state of the art 3GPP dual-stripe model for modeling of path loss between a small cell and a user equipment located inside different buildings. We found out that for the specific cases measured in the University campus, the use of a higher path loss exponent after some break point distance is not appropriate. This is because our measurements were mostly line-of-sight and the 3GPP model is not well suited for this case. It is therefore suggested to modify 3GPP model to only use path loss exponent 2 (free space). It is important to note that in other locations non-line-of-sight (NLOS) may need to be covered. For measurement case 1–2 only a minimal outer wall attenuation was observed. For the other cases (3–7) an outer wall attenuation equal to 15 dB gave a reasonably good fit between the 3GPP-like model and measurements.

The use of path loss models in studying the new micro operator concept is important in the evaluation of the micro operator network capacity and coverage as well as in analyzing the potential interference between different micro operators and towards potential incumbent spectrum users in the band. For interference analysis it is better to use low path losses to see the worst-case interference situations. Based on our measurements, there are cases where the path loss between different buildings can be only slightly above free space path loss. Moreover, the large variations in the wall attenuation between different building types and materials indicate that the potential future spectrum micro licenses issued to the micro operators could include building specific conditions such as node placement based on the thermal efficiency of the building. In fact, even being thermally efficient may not be sufficient condition to consider since "signal window" concept where windows are on purpose built to let wireless signals in and out is being developed. For buildings with minimal wall attenuation, there could be limitations in antenna placement, antenna orientation, and transmit power levels in order to avoid interference to other deployments. In the worst-case, micro operators in adjacent buildings should use different frequency bands. In the future, it would be important to prepare tools and approaches for effectively managing the interference among different micro operators and their users. In future work, it would also be valuable to measure locations well inside the buildings and to consider an appropriate building-to-building model for this case as well as to consider higher carrier frequencies above 3.5 GHz.

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