An *In Situ* Characterization of 1.7 GHz Building Entry Loss

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***Abstract*—In this manuscript, we assess the suitability of the ITU Recommendation P.2109 building entry loss models through continuous-wave and broadband measurements conducted in two distinct buildings: a historical structure and a recently constructed modern building. The findings reveal that both the construction material type and the density of materials significantly influence the entry loss. Moreover, our results indicate that the P.2109 categories of "traditional" and "thermally efficient" might not adequately describe the intricacies of building construction, leading to challenges in accurately inferring propagation loss values.**

I. INTRODUCTION

Wireless users are increasingly operating in indoor environments with the expectation of seamless and uninterrupted coverage when moving from an outdoor to indoor environment. Understanding the excess propagation loss imparted by the attenuation of an exterior building wall (building entry loss, or BEL) is therefore a vital component of mobile network operators' coverage planning. For outdoor towers, properly accounting for BEL ensures adequate signal penetration and acceptable indoor coverage. For scenarios relying on indoor distributed antenna systems, properly modeling BEL ensures that external wireless systems operating in similar frequency bands do not experience harmful interference.

Over the years, a plethora of BEL measurements have been performed (e.g., [1]–[3]), covering a wide variety of frequencies and scenarios, culminating in the International Telecommunication Union P.2109 BEL model [4]. Our objective in this study was to experimentally evaluate the applicability of the P.2109 model to two types of buildings: a modern energy-efficient construction involving mostly glass, and a traditional brick and concrete building. The frequency of 1.75 GHz was selected to characterize the new AWS-3 cellular band that had been recently authorized in the U.S.

II. MEASUREMENT SYSTEMS AND LOCATIONS

BEL measurements were performed using two systems[1]: (i) a continuous-wave (CW) system consisting of an Anritsu E4432B signal generator, Ophir 5162 Power Amplifier, and Tektronix SA2500 spectrum analyzer, and (ii) an Infovista TEMS™ measurement system [5] installed on a consumer-grade mobile phone (UE). The CW measurement system transmitted a single tone at a frequency of 1755 MHz; the received signal level was recorded via an omnidirectional antenna using the spectrum analyzer in zero-span mode with a 10 kHz resolution bandwidth. The TEMS UE was locked to LTE Band 3 (1710-–1785 MHz uplink / 1805–1880 MHz downlink) and recorded RSRP measurements. Detailed specifications for UE measurement of RSRP are provided in [6]; we also note that the accuracy for relative RSRP measurements (such as the ones used in this campaign) is given as ±2.0 dB [7]. Prior to the measurement campaign, both systems were calibrated to ensure that amplifier gains, cable and connector losses, and component losses were accounted for in the CW system and to validate the noise floor of the TEMS system.

Measurements were performed in two buildings on the campus of the United States Naval Academy: Hopper and Carter Hall. Hopper Hall was finished in 2020 and was constructed using modern energy-efficient techniques. The building envelope is primarily concrete and glass, mostly classroom and office space, and includes an outdoor observation deck on the top (5^{th}) floor. Carter hall was finished in 1907; the building envelope is primarily brick and cinderblock. The building was refurbished in 2000. Refurbishment included replacement of windows, but did not involve structural changes or upgrades. Measurements were performed on the 1^{st} and 5^{th} floor of Hopper and the 1^{st} floor of Carter.

III. MEASUREMENT SETUP AND DATA COLLECTION

BEL measurements are defined in [4] as the dB difference between the spatial median signal level immediately outside the building and immediately inside the building as measured at identical heights above the ground, via:

$$BEL(x) = |RSS_{out}(x) - RSS_{in}(x)| - EPL(x) \quad \text{dB}, \quad (1)$$

where x is the measurement index, RSS_{out} is the received signal strength measured outside the building, RSS_{in} is the received signal strength measured inside the building, and EPL is the excess free space path loss due to the nonzero euclidean distance between the outdoor and indoor measurements. Measurements were recorded at a $1.5\,\mathrm{m}$ height above ground and at a distance of $1.5\,\mathrm{m}$ from the building wall, in order to minimize near field reflective effects. For the CW measurements, the transmitter was placed as close to the center of the building as possible, resulting in relatively short link distances ($10-30\,\mathrm{m}$), generating EPLs ranging from 0.8 to $5.3\,\mathrm{dB}$. The TEMS measurements utilized a cell tower that was approximately $2.5\,\mathrm{km}$ away from the measurement sites, resulting in an essentially negligible EPL.

All measurements were collected with the receiver continuously traversing either the inside or outside of the building envelope at a walking pace ($\approx 4.0\,\mathrm{kph}$). To mitigate the effects of small-scale fading, RSS data was block-averaged in one second increments. For the CW measurements, position

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[1] Certain commercial equipment and materials are identified in this report to specify adequately the technical aspects of the reported results. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the material or equipment identified is the best available for this purpose.

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locations for each block average were manually logged; TEMS data was GPS tagged using the phone's GPS receiver.

IV. MEASUREMENT RESULTS

Fig. 1 and Table I provide the BEL CDFs and mean values for the measured data as well as the P.2109 model prediction. We observe that the TEMS measurements always have a lower BEL than the CW measurements, where the offset exceeds the published ±2.0 dB uncertainty of RSRP measurements. A methodology for calculating RSRP is not prescribed by 3GPP, thus it is not unlikely that RSRP measurements would be optimistic, leading to the lower loss [8].

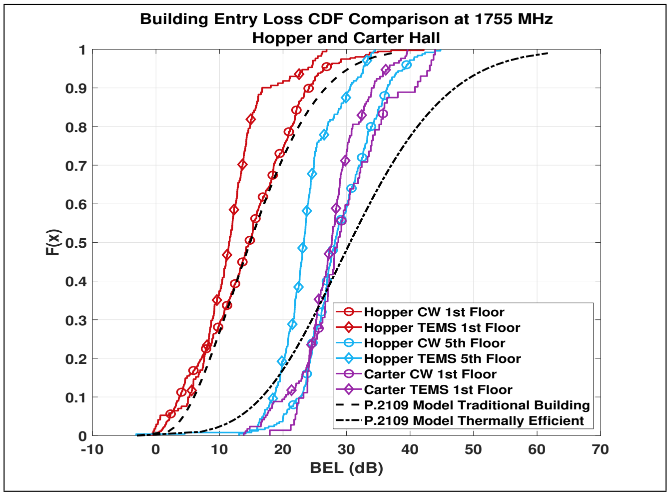

Fig. 1. Measured Building Entry Loss CDFs for Hopper and Carter Hall.

TABLE I
BUILDING ENTRY LOSS VALUES

Measurement/Model	Mean Loss (dB)	Std. Dev. (dB)
Hopper CW 1st Floor	14.5	7.7
Hopper TEMS 1st Floor	11.5	5.6
Hopper CW 5th Floor	28.8	6.1
Hopper TEMS 5th Floor	23.7	4.4
Carter CW 1st Floor	29.9	6.2
Carter TEMS 1st Floor	27.5	5.2
P.2109 Traditional	14.8	8.8
P.2109 Thermally Efficient	30.6	20

Additionally, we observe similar BEL for the 5th floor of Hopper and 1st floor of Carter, but dramatic differences between these two and the 1st floor of Hopper. Examining the building structures more closely, the 5th floor of Hopper utilized low-emissivity metallized glass for much of the observation deck, which is known to significantly attenuate RF signals. The 1st floor of Hopper, however, was a combination of concrete cinderblock with ballistic glass windows. These windows were ≈6 cm thick, but did not contain the metalized coating for thermal efficiency. Carter Hall, as discussed previously, had extremely thick concrete and cinderblock walls and did not utilize energy efficient windows.

Considering the BEL attenuations in the context of the building materials, we first note that P.2109 defines "Thermally Efficient" as *..metallised glass windows, insulated cavity walls, thick reinforced concrete and metal foil back cladding...* [4] (no definition is provided for "Traditional" building construction). Based on that definition, we postulate that the ITU descriptors of "Traditional" and "Thermally Efficient" are insufficient to characterize the impact of building structure and materials on propagation losses. Even though Hopper Hall was constructed as a modern energy-efficient building, BEL losses on the 1st floor more closely track the Traditional CDF than the Thermally Efficient CDF. Even on the 5th floor of Hopper, the BEL falls below that predicted by the Thermally Efficient model. The 1st floor of Carter Hall–with the highest wall density–has the highest BEL, although the mean value is less than the Thermally Efficient model prediction. Our conjecture, therefore, is that the building wall density and material composition has a significant impact on the propagation loss and that these variables are inadequately captured in a two-category BEL model. We note that our inability to sample the entire perimeter of both buildings may also contribute to the differences between measured and modeled CDFs.

V. CONCLUSION

In this manuscript, we performed an *in-situ* measurement of building entry loss using narrowband and broadband measurement techniques. Broadband measurements exhibited lower loss than the CW measurements. Measured BEL was compared to predictions from the ITU P.2109 model; the "Thermally Efficient" model prediction was found to overestimate BEL even for modern energy-efficient building construction. Our initial conclusion is that two categories for building construction is insufficient to fully capture the variety of construction materials, techniques, and nuances for both modern and historic buildings.

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