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PROPAGATION PATH LOSS MODELING AND COVERAGE MEASUREMENTS IN URBAN MICROCELL IN MILLIMETER WAVE FREQUENCY BANDS

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ABSTRACT

The global bandwidth deficiency facing wireless carriers has motivated the exploration of the underutilized millimeter wave (mm-wave) frequency spectrum for future broadband cellular communication networks, and mm Wave band is one of the promising candidates due to wide spectrum. This paper presents propagation path loss and outdoor coverage and link budget measurements for frequencies above 6 GHz (mm-wave bands) using directional horn antennas at the transmitter and omnidirectional antennas at the receiver. This work presents measurements showing the propagation time delay spread and path loss as a function of separation distance for different frequencies and antenna pointing angles for many types of real-world environments. The data presented here show that at 28 GHz, 38 GHz and 60 GHz, unobstructed Line of Site (LOS) channels obey free space propagation path loss while non-LOS (NLOS) channels have large multipath delay spreads and can utilize many different pointing angles to provide propagation links. At 60 GHz, there is more path loss and smaller delay spreads. Power delay profiles PDPs were measured at every individual pointing angle for each TX and RX location, and integrating each of the PDPs to obtain received power as a function of pointing angle. The result shows that the mean RMS delay spread varies between 7.2 ns and 74.4 ns for 60 GHz and 28 GHz respectively in NLOS scenario.

Keywords: mm-wave, RMS delay spread, propagation path loss, PDPs, UMi.

1. INTRODUCTION

Wireless communications technology has been developed fast and frequently to provide the requirements for the modern techniques in different applications. However, the high data rate and fast communication demand increases more and more [1]. In the year 2020, wireless data traffic is expected to increase by 1000 fold and may increase by 10,000 fold by 2025 [2]. For cellular communication, the cellular capacity must be increased to face the growing traffic demand.

Today there are a lot of multimedia services arises with the evolution of the mobile devices industry and rapid development in the mobile communication sector and the using of mobile communication at these days does not depend on voice communication only, it includes also broadband and multimedia services that the mobile communication infrastructure can support, but on the first place is always a user demand for high mobility, high data rate and high availability [3]. All these user requirements make the mobile communication industry searching for a new technology and new frequency spectrum to support their infrastructure to meet the user requirements [4]. The experiences of current mobile and wireless communications networks have shown that data traffic, especially, is growing more than anticipated. This development is providing a significant challenge to the development of future mobile and wireless communication networks. It is envisioned that future IMT systems, in addition to other features, will need to support very high throughput data links to cope with the growth of the data traffic [5]. International mobile telecommunications (IMT)-advanced specifications of fourth generation (4G) terrestrial mobile telecommunication were approved by the international telecommunication union radio standards sector (ITU-R) in January 2012. Meanwhile, the dramatic growth of mobile data services driven by wireless Internet and smart devices has triggered the investigation of 5G for the next generation of terrestrial mobile telecommunications [6].

5G wireless networks are expected to be a mixture of network tiers of different sizes, transmit powers, backhaul connections, different radio access technologies (RATs) that are accessed by an unprecedented numbers of smart and heterogeneous wireless devices. This architectural enhancement along with the advanced physical communications technology such as high-order spatial multiplexing multiple-input multiple-output (MIMO) communications will provide higher aggregate capacity for more simultaneous users, or higher level spectral efficiency, when compared to the 4G networks [7].

2. RADIO PROPAGATION MODEL

A radio propagation model is an empirical mathematical formulation for the characterization of radio wave propagation as a function of frequency, distance and other characteristics. A single model is usually developed to predict the behavior of propagation for every similar link under similar constraints. The essential aim of signal propagation is to formalize how the signal can propagate from one point to another. Only in such situation can a typical model predict the path loss effect on an area covered by a single or multi transmitter (s) [8]. In wireless communications, radio propagation between base station

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and terminals is affected by such mechanisms as scattering, diffraction and reflection.

The radio coverage is determined by radio signal path loss, which increases with increasing frequency. The RF power of radio signals would be reduced when radio signals have travelled over a considerable distance. Therefore, in most cases, the systems with higher frequencies will not operate reliably over the distances required for the coverage areas with varied terrain characteristics [9]. For clear line of sight (LOS) propagation, the range between the transmitter and receiver is determined by the free space path loss equation, given by:

$$Pathloss = 20\,\log_{10}\left[\frac{4\,\pi\,d}{\lambda}\right]\text{ dB} \qquad (1)$$

Where d and λ are the range and wavelength in meters, respectively.

In Non-Line-of-Sight (NLOS) cases, the performance of higher frequencies is worse with reliable distances dropping even faster. Most paths are obstructed by objects and buildings. When penetrating obstacles, radio waves are decrease in amplitude. As the radio frequency increases, the rate of attenuation increases. Figure 1 illustrates the effect of higher frequencies having higher attenuation on penetrating obstacles [1].

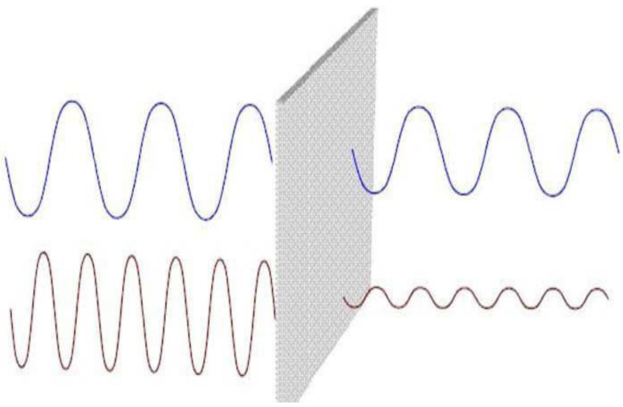

Figure-1. Higher frequencies have higher attenuation on penetrating obstacles.

A radio beam can diffract when it hits the edge of an object. The angle of diffraction is higher as the frequency decreases. When a radio signal is reflected, some of the RF power is absorbed by the obstacle, attenuating the strength of the reflected signal. Figure-2 show that higher frequencies lose more signal strength on reflection [4].

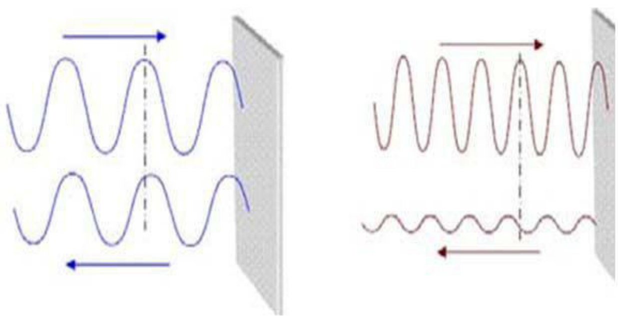

Figure-2. Frequency dependence of signal strength on reflection.

In free space propagation, clear and unobstructed line-of-sight (LOS) path is available and the first Fresnel zone is maintained between base station and terminal. Free space path loss can be obtained by using the logarithmic value of the ratio between the receiving and transmitting power.

Equation 2 indicates that free space path loss is frequency dependent and it increases with distance. The increase of distance and frequency produce similar effect on the path loss.

$$PLdB = 92.44 + 20\ \log10\ f\ GHz + 20\ \log\ d\ Km \qquad (2)$$

Where f is frequency, d is distance respectively.

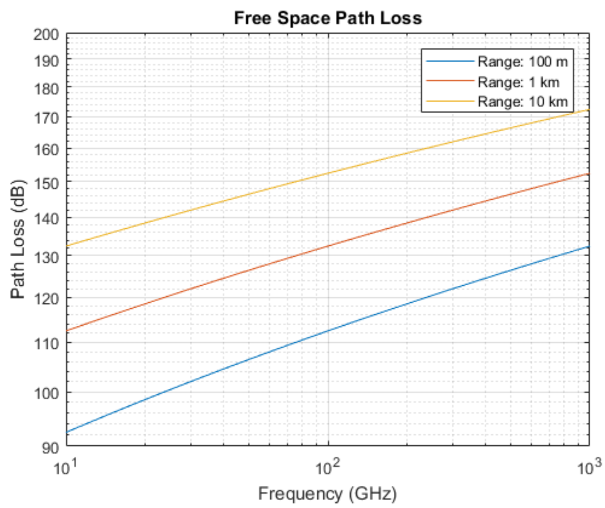

Figure-3. Free space path loss at frequencies above 6 GHz for different ranges [12].

3. PROPAGATION PATH LOSS MEASUREMENTS

One of the challenges of mobile communications in the higher bands for outdoor access will be to overcome the expected difficulties in propagation conditions. The most obvious obstacle will be the higher path loss of the bands above 6 GHz relative to traditional cellular bands [10].

Using a free-space reference of 3 meters, experiments in urban micro cell outdoor-to-outdoor scenarios, with transmitter and receiver antenna heights below rooftop, measured path loss exponents for 10 GHz,

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28 GHz, 38 GHz, and 60 GHz in both LOS and NLOS environments in distance 200 m, which are summarized in Table-1 below.

Table-1. Path loss exponents measured in several frequencies.

Frequency	10 GHz	28 GHz	38 GHz	60 GHz
NLOS	3.27	3.36	3.41	3.46
LOS	1.76	1.87	1.9	1.95

For comparison, Table-2 compares the measured LOS with the NLOS path loss derived from the 10 GHz and 28 GHz path loss exponents in the urban micro cell outdoor-to-outdoor experiments as well as 38 GHz and 60 GHz. The values are computed for various small cell applicable distances.

The free-space path loss (FSPL) model is considered, FSPL reference distance model, provides a path loss exponent which has physical relevance since the path loss is tied to the FSPL at a specific close-in reference distance (1 m is convenient and practical at millimetric wave frequencies).

Figure-4 shows that the measured omnidirectional LOS path loss is very close to the free-space path loss with an exponent of 2 in both the backhaul and access cases for 60 GHz.

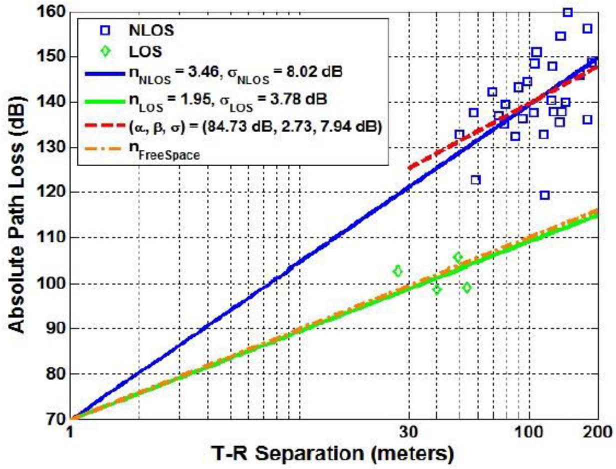

Figure-4. Measured omnidirectional antenna path loss computed relative to 1m free-space path loss for 60 GHz.

The omnidirectional path loss models were developed by considering the measured power delay profiles PDPs at every individual pointing angle for each TX and RX location, and integrating each of the PDPs to obtain received power as a function of pointing angle, and then subtracting the TX and RX antenna gains from every individual power measurement. At each incremental step along the sweep in the azimuth plane, a PDP was recorded at the receiver. Figures 5 and 6 shows the measurements in different frequencies.

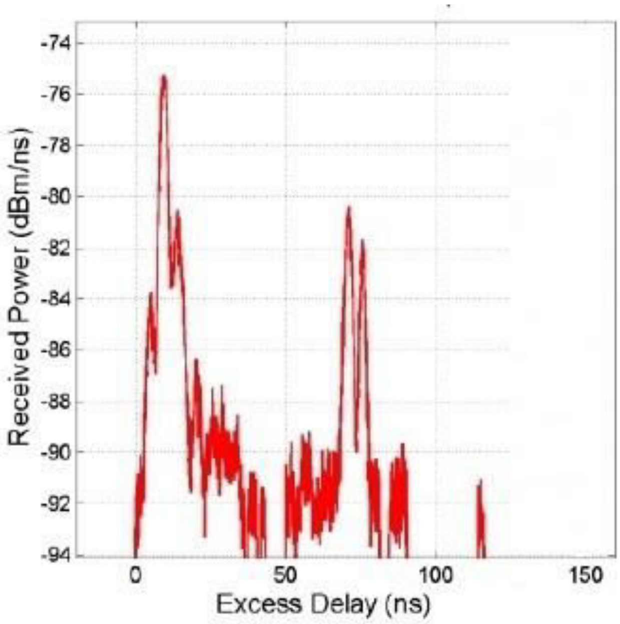

Figure-5. PDPs Measured at 28 GHz

Table-2. Path loss comparison for LOS and NLOS scenarios in different frequencies.

Frequency		**10 GHz**			**28 GHz**			**38 GHz**			**60 GHz**		
Distance	**Meters**	20	100	200	20	100	200	20	100	200	20	100	200
NLOS Path Loss	dB	91.3	113.5	124	95.6	121.7	132.3	103.9	131.1	142.1	107.6	135.8	147.4
LOS Path Loss	dB	79.4	91.8	97.9	84.2	96.3	104.7	91	104.2	109.8	97.3	112.7	119.3

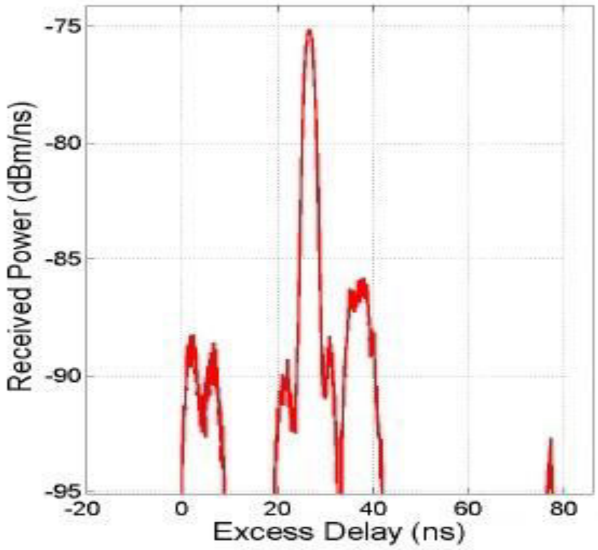

Figure-6. PDPs measured at 60 GHz.

4. RMS DELAY SPREAD MEASUREMENTS

Root-Mean-Square (RMS) delay spread is increased for lower gain antennas which employ wider beams, as the wider profile collects signals from more directions with similar or equal gain to the boresight angle. This particularly applies to user equipment UE whose size and power requirements do not support large arrays and have a more omni-directional pattern as exemplified in Figure-7.

Conversely, RMS delay spread is decreased for higher gain antennas and the associated narrower beamwidth. The transmit beamwidth from the base station limits the direction of the generated energy and thus the opportunities to scatter. Likewise, in spite of the higher gain, scattered energy of the multipath link may not be picked up by the spatial range of the receive antenna boresight.

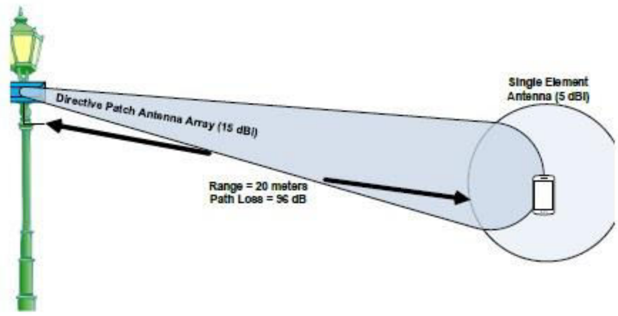

Figure-7. link budget scenario.

A transmitter beamwidth of 6 degrees and the transmitter distance of 100 meters, the UE receiver will be illuminated by the primary transmitter energy and its reflections over an arc length of about 10 meters the reflections will thus be primarily bounded by delays around 31 ns.

Meanwhile, higher-order rays (i.e., rays with more reflections) have larger angles of incidence, therefore, more likely to fall outside of the receiver antenna beamwidth. Theoretically, for a typical geometry of lampposts several meters above the ground and several hundred meters separate, second order systems are often deemed sufficient approximations.

Thus, for a given environment and use cases with different transmitter and receiver antenna radiation patterns, one may observe different scattering effects as illustrated, in a rather ideal sense for ease of conceptualization, in Figure-8. The primary point is that delay spread is mitigated by the beamforming paradigm.

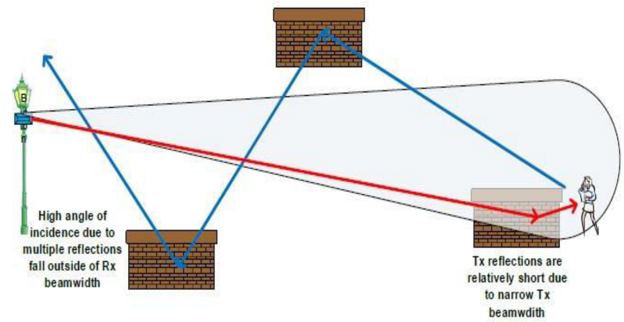

Figure-8. Scattering effects

The experiment conducted at millimetric wave frequencies in outdoor environments. This experiment involved NLOS scenario over a variety of several frequencies. The findings are summarized in Table-3.

Table-3. Summary of channel RMS delay spread for NLOS experiments.

	28 GHz	38 GHz	60 GHz
Mean RMS delay spread	74.4 ns	22.8 ns	7.2 ns
Max RMS delay spread	455.3 ns	184.1 ns	37.7 ns

5. OUTDOOR-TO-OUTDOOR COVERAGE AND LINK BUDGET

The first consideration for link budget analysis is the signal power attenuation due to propagation loss over the air. Free space path loss FSPL also increases in proportion to the square of the distance between the transmitter and receiver. As such, a 28 GHz signal transmitted over a distance of 20 meters loses 84.2 dB of power just covering this relatively short distance between transmitter and receiver. At 100 meters, the loss is increased to 96.3 dB. Coverage can be analyzed from the link budget perspective. Since the typical outdoor urban environments will include NLOS paths, the analysis should include the NLOS cases.

For the given system parameters of Table-4, the maximum distances that can support 1 Gbps data rate in various environments can be found in this section.

Table-4. System parameters for link budget analysis.

Carrier Frequency (GHz)	**28**	**38**	**60**
Tx EIRP + Rx Gain (dBm)	66	68	69
Bandwidth (GHz)	1	0.5	2
Rx Noise Figure (dB)	6	9	9
Other losses (dB)	10	10	10
Target SNR (dB)	0	N/A	N/A
Target Data Rate (Gbps)	1	1	1

In the analysis presented in Table-5, the 28 GHz frequency band is considered for the center frequency of systems with 1 GHz bandwidth. Tx EIRP and Rx gain are assumed to be 66 dBm, which can be realized by low-power base stations. 30 dBm Tx power with 26 dBi Tx antenna gain and 10 dBi Rx antenna gain have been used for the systems.

Table-5. link budget analysis for various environments at 28 GHz.

Environments	Open Space	Campus	Dense Urban
LoS / NLoS	LoS	NLoS	NLoS
Path loss model	PL(d) = 61.4 + 20*log10(d)	PL(d) = 47.2 + 29.8*log10(d)	PL(d) = 61.4 + 34.1*log10(d)
Max. distance for 1 Gbps	976 meter	305 meter	58 meter

As shown in the Table-5, the low-power base station can give 1 Gbps using 1 GHz bandwidth for the outdoor coverage with from tens to hundreds meter cell radius depending on cell environments.

6. CONCLUSIONS

A propagation path loss, RMS delay spread, and outdoor-to-outdoor coverage measurements at a range of frequencies above 6 GHz (up to 60 GHz) in LOS and NLOS scenarios have been analyzed. The specific frequencies used in the measurements (10 GHz, 28 GHz, 38 GHz, and 60 GHz) are arbitrarily selected and intended to illustrate the general trends of how coverage varies across the frequency range.

Outdoor studies conducted at different frequencies showed that consistent coverage can be achieved by having base stations with a cell-radius of 200 meters. Path loss was in NLOS and higher frequencies larger than in LOS and lower frequencies. Multipath delay spread is found to be much larger in lower frequencies (28 GHz) due to small coherence bandwidth. The key trends include near free-space path loss and low RMS delay spread for all LOS links, while NLOS links have higher RMS delay spread, as much as 455.3 ns (for the 28 GHz) and 37.7 ns (for the 60 GHz). In general, NLOS links offer increasing RMS delay spread as the azimuth pointing angles are increased away from boresight at either or both the transmitter and receiver. By picking the best combination of transmitter and receiver antenna pointing angles at any location, path loss and RMS delay spread can be reduced substantially.

Some short-range communication technologies, like millimeter -wave communication technology, can be seen as promising candidates to provide high-quality, bandwidth required for mobile broadband applications and high-data-rate services to outdoor and indoor users. And we have analyzed the suitability of different millimeter-wave frequencies for mobile communication.

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