

A Geometrical approach for multipath characteristics study with 28GHz measurements

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Abstract—In this paper, a geometrical approach is presented to estimate locations of the last hop of multipath based on measurement data. Statistic characteristics of last hops can be used to generate spatially consistent channels which are required for 5G channel modelling. The measurement was conducted with a 28GHz wideband channel sounder in urban street environments. Results show that most last hops are distributed either on the walls of buildings or in the crossroad area.

Keywords— mmWave, 5G, propagation, channel modelling

I. INTRODUCTION

Due to the extensive development of wireless broadband communication, especially personal mobile communication, the utilization of currently used frequency bands is almost saturated. Millimetre-wave systems, which allow much higher frequency bands, will be operated in the fifth generation mobile networks to meet the huge demands of bandwidth resources [1] [2]. For the fifth generation channel model, a spatially consistent channel model is necessary to guarantee the density of links and support mobility of users [3].

The currently used channel models, e.g., WINNER II [4], IMT-Advanced [5], are dependent on multipath parameters such as delay, direction of arrival, direction of departure, polarized amplitude, etc., but not on scatterers. In these models, even users close to each other can see absolute different scatterers. In order to generate a spatially consistent model, it is necessary to know locations of the first and the last hop of every multipath [3]. According to [6], the distance from RX to the last hop and the distance from TX to the first hop are considered as two new parameters for the cluster-based channel model with the spherical wavefront assumption by using the massive MIMO antenna array.

Besides that the last hop characteristics can be used to create a spatially consistent channel model, which is mentioned in the last paragraph, they have many other usages. Last hop information can be utilized to generate channel realizations in ray tracing methods. In a moving environment, if there is a path always bouncing at the same scatterer, Doppler frequency of that path can be estimated. If a path bounces with a certain scatterer that continually appears and disappears, a birth-death model of this path (same concept of the visibility region of users) can be presumed [7].

In this paper, the analysis of the last hop characteristics is based on the 28GHz measurement data in Seoul. We used

multipath parameters (Azimuth of Arrival (AoA), delay and multipath amplitude) in a geometrical method to estimate the position of the last hop and the Distance from RX to the Last Hop (LHD). In Section II, the 28GHz wideband channel sounder and measurement environment are introduced. The estimation algorithm is illustrated in Section III. In Section IV the distribution of the last hops are shown on the map, and the channel characteristic —LHD spread (LHDS) is provided.

II. MEASUREMENT EQUIPMENT AND CAMPAIGNS

A. 28GHz Wideband Channel Sounder and Antenna

A millimetre-wave Band Exploration and Channel Sounder (mBECS) was developed by the Electronics and Telecommunications Research Institute (ETRI), Korea. The detail parameters of mBECS are listed in Table 1.

TABLE 1. CONFIGURATIONS OF MBECS

Characteristics	Configurations
Center Frequency	28 GHz
Bandwidth	500 MHz
PN Code Length	4095 chips
Sliding factor	12500
Receiver chip rate	499.96 MHz
TX Output Power (max.)	29 dBm
Multipath Resolution	2ns (0.6m)
Antenna type	Horn (TX:30° , RX:10°)

B. Measurement Campaign

The measurement was conducted in a high-rise (50-120m) area of Korea. Figure 1 shows the map of the measurement sites: the red circle is TX; blue circles are RX's in LoS case (6 spots); yellow circles are RX's in NLoS case (11 spots). The number beside RX index is the direct distance from TX to that RX.

At the TX side, a horn antenna with 30° Half Power Beam Width (HPBW) was equipped and the direction of the antenna was fixed (translucent yellow area in Figure 1). At the RX side, an antenna with 10° HPBW was rotated with a 10° increment in azimuth domain (in horizontal level), and therefore, 36 subchannels' impulse responses were obtained at one measurement point. Since RX was rotated only in horizontal level, we assume a 2D propagation in this paper.

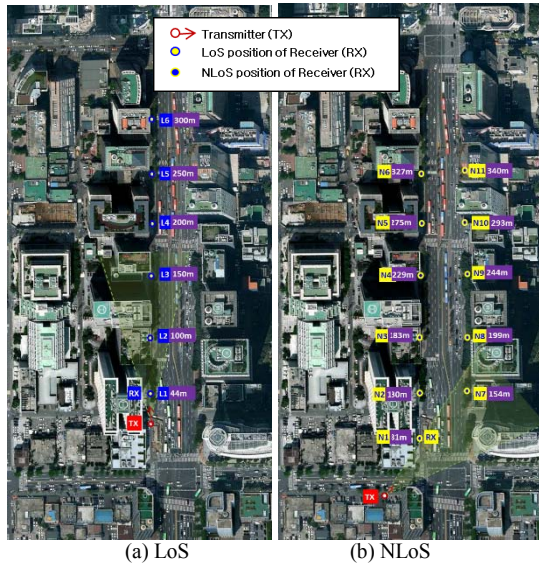


Figure 1. Measurement spots and scenarios. (a) LoS case: L1~L6, (b) NLoS case: N1~N11.

III. ESTIMATION ALGORITHMS

A. Definition of Distance to the Last Hop (LHD)

LHD is the distance between RX and the last hop. Figure 2 is an example to illustrate an LHD. LHD of multipath components (marked with dashed lines in the figure) are denoted by d_1 , d_2 and d_3 , and the last hop of them is depicted by s_1 , s_2 and s_3 (marked with small circles). Angle ϕ_1 is the AoA of the first multipath (ϕ_2 and ϕ_3 is not marked in Figure 2).

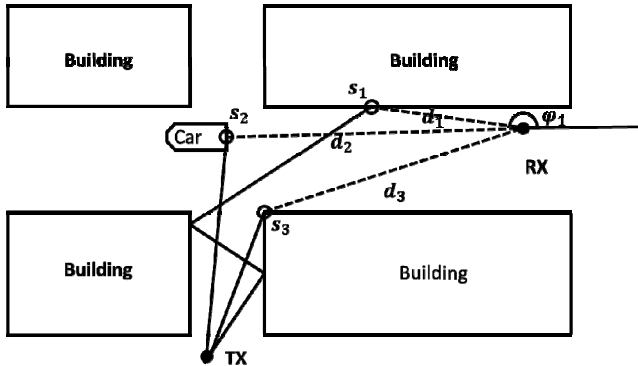


Figure 2. An example of LHD in a 2D environment

B. LHD Estimation

LHD can be estimated with a geometry way based on the digital maps and channel characteristics such as AoA's and delays. The digital map includes the environmental structure such as buildings (But not the cars. The car in Figure 2 is just an example to show that the last hops can be cars.). AoA's and delays can be calculated from measurement data in Bartlett Beam Forming method [8]. Figure 3 shows the LHD estimation algorithm flowchart.

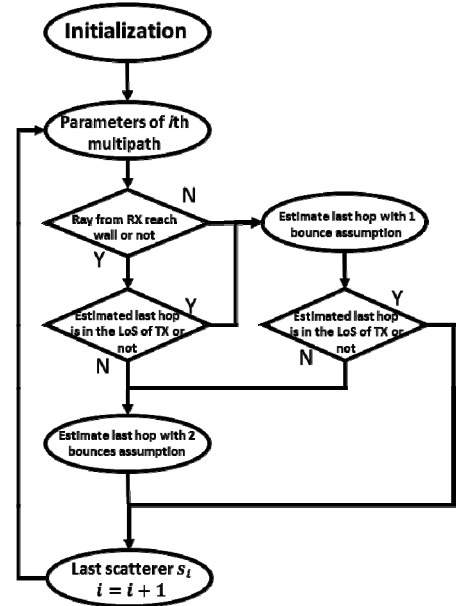


Figure 3. How to find the last scatterer

Details of every step of the algorithm are listed as follows:

- “Initialization”
Our channel sounder measured multipath sequentially with a 10° increments in the azimuth domain, i.e., 36 subchannels were not measured simultaneously. We use the shortest multipath distance from TX to RX to offset the delay of the first arrival multipath:
$$\tau_{\text{offset}} = d_{\min}/0.3 - \tau_{\text{first}} \quad (1)$$

In Eq.1, $d_{\min}$ is the shortest distance (e.g., in Figure 2, multipath #3 is the shortest one); τ_{first} is the measured delay of the first arrival multipath; 0.3 is the speed of light (0.3m/ns).
- “Parameters of i th multipath”
In the i th multipath, channel characteristics delay and AoA are τ_i and ϕ_i (calculated in Bartlett Beam Forming method) respectively.
- “Ray from RX reach wall or not”
If the extended ray from RX in the direction ϕ_i reaches a wall, e.g., in Figure 2, extended ray d_1 from RX in the angle of ϕ_1 reaches the building at s_1 , we define the output as “Y”. If the ray of i th path does not reach any wall, d_i will be temporarily set as $d'_i = \tau_i \times 0.3(\text{m/ns})$, of which the predetermined last hop is s'_i , and the output is “N”.
- “Estimated last hop is in the LoS of TX or not”
After the position of last hop s'_i being defined, whether s'_i is in the LoS of TX should be known. E.g., in Figure 2, there is a LoS between s_3 and TX, but no LoS between s_1 and TX.
- “Estimate last hop with 1 bounce assumption”
This step is to check whether the last hop s'_i is realistic or not when the i th multipath bounces only once. If $r_1 + r_2 > d'_i$ (in Figure 4 (a)), which means the estimated distance of the i th path is larger than the distance corresponding to the multipath delay. In this

case, s'_i cannot be the last hop in one bounce multipath. The last hop s_i should be on the RX- s'_i line. We can calculate the location of s_i which meets the condition: $r_3 + r_4 = d'_i$.

- "Estimate last hop with 2 bounces assumption"

If the estimated last hop s'_i is not in the LoS of TX, the current multipath must experience more than one time bounce. E.g., there's a building blocking the LoS of TX- s'_i in Figure 4 (b), which means the path TX- s'_i -RX cannot exist. Instead of TX- s'_i -RX, the possible path is TX- c_0 - s_i -RX. We manually find a corner c_0 , which is in the LoS of all the scatterers on the line RX- s'_i , as the first scatterer. The position of last scatterer s_i , which meets the condition that $r_3 + r_4 + r_5 = d'_i$, can be calculated. In this algorithm, considering the complexity, multipath of one or two bounces is considered.

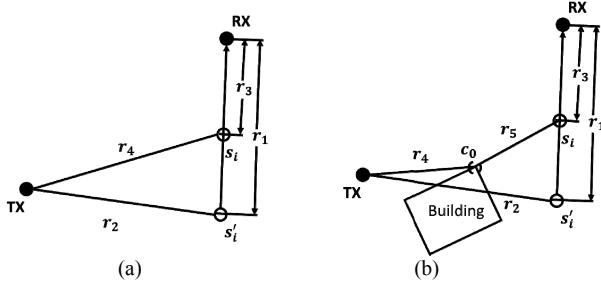


Figure 4. Illustration of (a) "One bounce assumption", (b) "Two bounce assumption"

C. LHD Spread

In the concept of delay spread, we define a variability of delays of multipath. Similarly, so-called LHD Spread (LHDS) is the standard deviation of the LHD of multipath and weighted proportional to the amplitude of the multipath. LHDS can be calculated as:

$$\sigma_{LHD} = \sqrt{\sum d_i^2 \frac{P_i}{\sum P_i} - \left(\sum d_i \frac{P_i}{\sum P_i}\right)^2} \quad (2)$$

, where σ_{LHD} is LHDS, d_i and P_i are LHD and amplitude of multipath #i respectively. LHDS can be used to generate statistically distributed LHD, which is a parameter of the spatial consistency channel model [6].

IV. RESULTS

In this section, we analyzed the location of the last hops, LHD and LHDS, based on the measurement data.

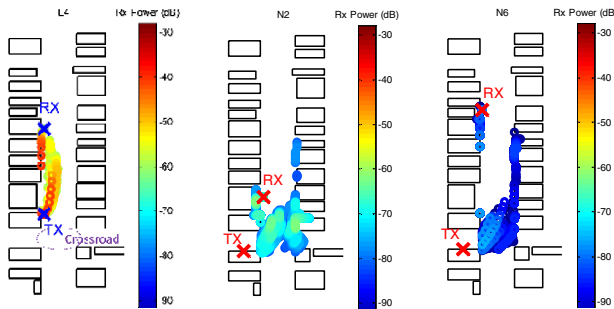


Figure 5. Estimated last hops and the received power of each multipath.

Given the estimated s_i , the last hops can be plotted on the digital map. Figure 5 shows the distributions of the last hops (circles in different colors, e.g., with more RX power if the color is red) along with building layouts and positions of TX and RX. The RX power is calculated by the amplitude of multipath compensated with system Automatic Gain Control (AGC) level. We can see that many scatterers are separated in crossroad area of NLoS case (N2, N6, N8, N11), although there is no building in this region. The scatterers in the crossroad area were mobile vehicles. Since the mobiles such as cars, people, etc., are not included in the digital map, this algorithm can be used to estimate these scatterers' locations.

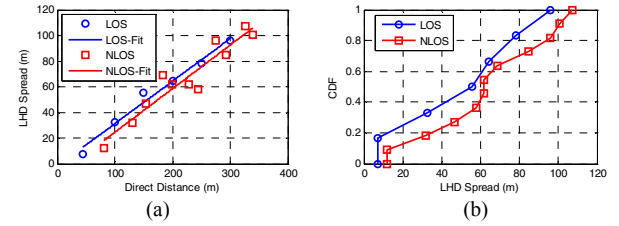


Figure 6. LHDS (a) and its CDF (b).

Figure 6 shows the LHDS vs direct distance curve and its CDF. LHDS is proportional with direct distance of TX-RX and the linear fitting curves are:

$$\text{LoS: } \sigma_{LHD} = 0.33 \times d - 1.99, \sigma_{std} = 4.52$$

$$\text{NLoS: } \sigma_{LHD} = 0.34 \times d - 9.53, \sigma_{std} = 9.23$$

TABLE 2. MEASUREMENT RESULTS OF LHD SPREAD

Scenario	LHD spread (m)		
	10%	50%	95%
LoS	7.3	55.6	90.6
NLoS	14.0	61.8	103.7

V. CONCLUSIONS

The geometrical approach proposed in this paper can estimate the position of the last hops of multipath. Estimated hops are not only scatterers on the walls of buildings, but also the mobiles such as cars, people, etc. The estimation results show that many scatterers are separated in the crossroad. LHD spread is linearly proportional with the distance of RX-TX.

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