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# Empirical Characterisation of Indoor Broadband Propagation Channel

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*Abstract*—**This paper describes measurement campaign conducted in different scenarios of indoor office environment. An ULA antenna array and virtual antenna array were used at receiver and transmitter respectively. The measurement aims to characterize indoor radio propagation characteristics. Results of measurement at 5.2 GHz frequency and 120 MHz bandwidth are discussed that include propagation path loss, time delay spread, angular spread, and spatial correlation.**

***Keywords-component; propagation path loss; delay spread; angular spread; spatial correlation***

## I. Introduction

Indoor propagation channel is equally important as outdoor propagation channel and various kinds of broadband systems are currently being considered to support indoor applications.

Transmission of high-speed signal over radio channel is subject to impairment due to inter-symbol interference (ISI). This is because of time delay spread of transmitted signal as a result of multipath propagation phenomena. Indoor environment in general poses relatively low channel time delay spread as compared to outdoor propagation scenarios. Effect of delay spread can be reduced by using directional antenna [1].

The use of directional antenna on the other hand tends to increase spatial correlation between antenna elements as compared to omni-directional antennas. System equipped with multiple antennas at both transmitter and receiver is a frequently discussed topic to increase channel capacity for next generation broadband mobile communications systems. The achievable MIMO capacity relies on the scattering richness of propagation channel in order to achieve uncorrelated parallel sub-channel between transmitter and receiver [2].

Thus, radio propagation characteristic is playing an important role in future broadband mobile communications systems. Detailed radio propagation characteristics information for each specific propagation environment and scenarios is necessary in order to further explore the limit of radio propagation channel.

The widely used method to characterize radio propagation channel is to measure channel impulse response. It could provide accurate insight of radio propagation characteristics in a specific propagation scenarios. This paper intends to describe measurement campaign conducted in office environment and discuss immediate results from the analysis. Results will cover statistical analysis on propagation path loss, time delay spread, angular spread, and spatial correlation analysis for each propagation scenarios, i.e. corridor-corridor, room-to-corridor, room-to-room, and in-room scenarios. Effect of each propagation scenarios on radio propagation characteristics are discussed. Results will contribute to the development of channel model for future mobile communication systems.

## II. Measurement System Setup

RUSK ATM MIMO channel sounder was used in measurement. Table 1 provides details of measurement system set up. Frequency at 5.2 GHz is used since it is one of the promising candidate frequencies for future mobile communication systems. 120 MHz bandwidth is used to achieve channel impulse response with up to 1.5 ns time resolution.

X-Y virtual antenna array used at transmitter is shown in Figure 1. The merits of using X-Y virtual antenna array include no coupling effect between antenna elements, allows flexible and small antenna spacing. However, it is suitable for measurement in static environment. To avoid confusion, in this paper measurement position means measurement location with separation in the order of meters, and antenna position means antenna position of X-Y virtual antenna array with antenna spacing in the order of 0.1 $\lambda$.

Time duration for each 1x8 SIMO snapshot between X-Y virtual antenna array and ULA array is about 12.8 μs, with 1.6 μs maximum time delay.

TABLE I. MEASUREMENT SYSTEM SETUP

| | |
|---|---|
| Measurement frequency | 5.2 GHz |
| Frequency bandwidth | 120 MHz |
| Transmit power | 0.5 and 2 watt |
| Receiving antenna (Rx) | 8 elements ULA antenna |
| Antenna spacing ($\lambda$) | 0.5 |
| Antenna height | 1.3, 1.5 m |
| Transmitting antenna (Tx) | X-Y virtual array (Omni-direction) |
| Antenna spacing ($\lambda$) | 0.1 (5.76mm) |
| Grid length ($\lambda$) | X-axis = 14 |
| | Y-axis = 14 |
| Antenna height | 1.3, 1.5 m |
| Number of 1x8 SIMO snapshot | 200 per each Tx antenna position |

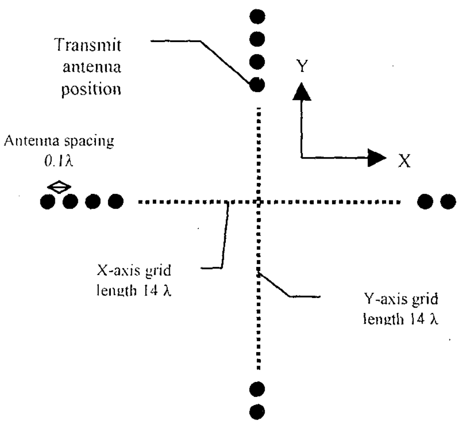



Figure 1. X-Y virtual transmit antenna array.

## III. MEASUREMENT

Measurement campaign was conducted in office building. Building floor is about 50 meters width and 50 meters length with an open ground at the centre as shown in Figure 2. The outer wall comprises of glass windows with metal frame separated by narrow concrete structure in about 3:1 ratio. Metal sun-blinds are installed outside glass windows. During measurement campaign, all metal sun-blinds were wound up. The office floors are divided into a number of office rooms with different sizes along corridor by thin wall. Ceiling along corridor is made from metal. Each room has wooden door with metal door frame.

During measurement campaign, all rooms where measurement has been conducted were empty. However, for in-room measurement scenario, measurement was repeated with two room conditions; empty and furnished room such as in Room F and Room G. During measurement static environment is maintained. Measurement has been conducted in four different scenarios such as corridor-corridor, room-to-corridor, room-to-room, and in-room scenarios.

200 set of 1x8 single-input multiple output (SIMO) snapshots are measured at each antenna position. Antenna movement is controlled by means of mechanical antenna positioner. Measurement starts from X-axis and continued by Y-axis. X-axis of virtual antenna array is always aligned in parallel with the receiving ULA antenna array except for room-to-room scenario. For each axis, there are 140 antenna positions that start from the left most antenna position across centre point and stop at the right most antenna position. For each measurement position, there is a total of 2x140x200 set of 1x8 SIMO snapshots. Synchronization between receiver and transmitter is achieved by means of wired approach.

### *A. Corridor-corridor Scenario (LOS+NLOS)*

In corridor-corridor measurement scenario, receiving ULA antenna array was permanently placed at located indicated as Rx in corridor 1 with ULA array facing to the direction of Corridor 1. Receiving ULA antenna array was mounted on a tripod at 1.5 m height relative to floor level.

Transmitter was moving along Corridor 1 from one measurement position to next position. The separation distance between transmitter (with reference to the centre position of antenna positioner) and receiver (with reference to the position of ULA antenna array) increases in two meters step. The first measurement position is two meters away from the receiver. The omni-directional transmitting antenna was fixed on wooden rod at 1.5 m height relative to floor level.

There are 20 measurement positions along corridor 1 (LOS) and 5 measurement positions along Corridor 3 (NLOS). During measurement, static channel condition is maintained and all doors along Corridor 1 and 3 are closed.

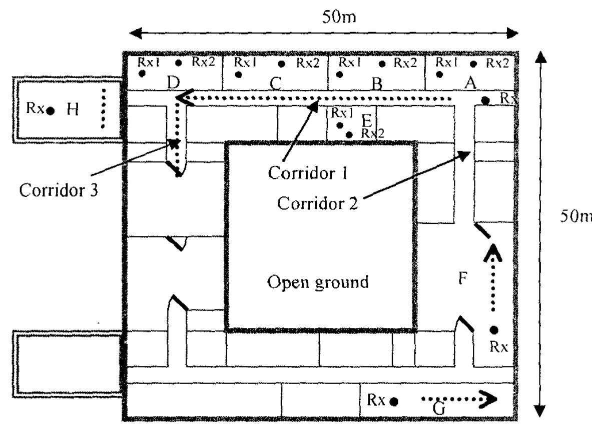



Figure 2. Building floor plan.

### *B. Room-to-corridor Scenario (NLOS)*

For room-to-corridor scenario, the receiving ULA antenna was placed permanently at the same location and at the same antenna height as for corridor-to-corridor scenario. This measurement covered room A, B, C, D, and E. In each room, the transmitter was placed at the centre of room with X-axis of virtual transmit antenna array in parallel with the receiving ULA antenna array. There are two transmitting antenna heights, 1.3 m and 1.5 m. During the measurement all rooms were empty and measurement area are maintained in static condition. Complete measurement was repeated for two room conditions; with door opened and closed respectively.

### *C. Room-to-room Scenario (NLOS)*

For room-to-room measurement, transmitter was permanently placed at the centre of room A while receiver was placed in room B, C, D, and E. In each room, snapshots were recorded with receiving ULA array placed at two different locations indicated as Rx1 and Rx2 in Fig. 2. Measurement was repeated for two door conditions; close and open, two measurement positions; Rx1 and Rx2, and two receiving antenna heights; 1.3 m and 1.5 m.

### D. In-room Scenario (LOS)

This measurement was conducted in room F, G, and H. In this measurement, both transmitter and receiver were placed within the same room.

In room F and G, there are five measurement positions in a straight line separated by 3 m apart. The first measurement position is 3 m away from the receiving ULA antenna array. Meanwhile in room H, there are 3 measurement positions in parallel with the ULA antenna array. Each measurement position is separated 2 m apart.

About the antenna height setting, in this measurement the height of transmitting and receiving antennas were maintained at same level, that is 1.3 m and 1.5 m respectively to reflect peer-to-peer communications scenario. This is slightly different than corridor-to-corridor and room-to-room measurement scenarios where the transmitting antenna was fixed at 1.5 m height through out the complete measurement. In room F and G, measurement was repeated for two room conditions; with and without furniture. In room H, measurement was only conducted in empty room.

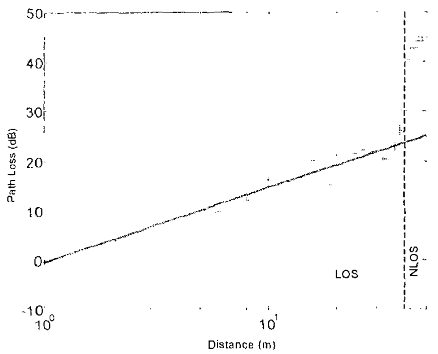



Figure 3. Path loss obtained in corridor-corridor scenario.

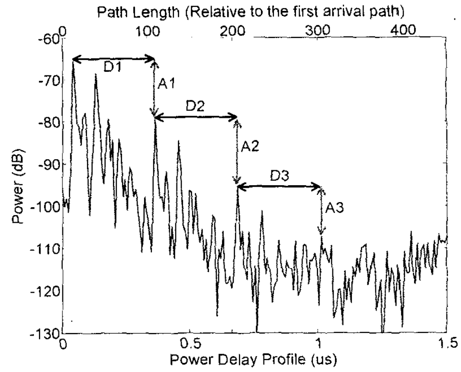
## IV. EMPIRICAL CHARACTERISATION

### A. Path Loss

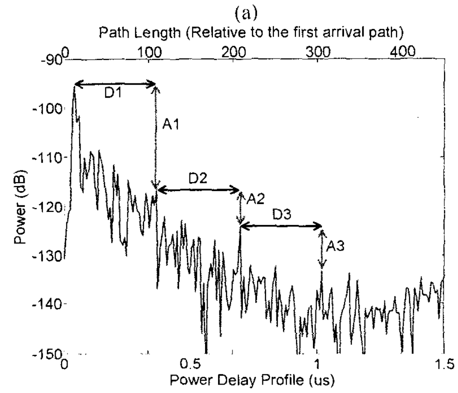
Simple power-law decay model with an empirical path loss exponent ($n$) and a log-normally distributed variable ($X_\sigma$) as shown in equation (1) is widely used. $PL_0(D_0)$ is reference path loss one meter apart from receiver. In more detailed model, attenuation loss of walls and floors is considered separately.

$$PL(D) = PL_0(D_0) + 10n\log\left(\frac{D}{D_0}\right) + X_\sigma \qquad (1)$$

In free space propagation, $n$ is equal to 2. It can be as high as 4 when the first Fresnel zone is highly obstructed [3]. Results of corridor-corridor measurement reveal that signal strength decay slower than in free space as shown in Figure 3. In this measurement campaign, the measured path loss exponent is found to be 1.5. Result also indicates that signal strength drop between 15 to 20 dB for transition from LOS to NLOS corridors. For room-to-corridor scenario along Corridor 1, results indicate additional loss of 10-15 dB as compared to LOS corridor-corridor scenario due to additional wall attenuation loss. The required signal strength information is obtained from broadband measurement data by averaging signal strength of frequency lines at each measurement position.




(a)




(b)

Figure 4. (a) Power delay profile for corridor-corridor scenario (LOS), and (b) room-to-corridor scenario (NLOS).

### B. Time Delay Spread

In frequency selective fading channel, replicas of the transmitted signal will arrive at receiver with different time delays, amplitudes, and phases. In a time discrete impulse response, each distinct path is vectorial sum of a number of sub-paths. RMS delay spread is often used to indicate channel time dispersiveness and is useful parameter for rough estimation of maximum data rate that can be transmitted through radio channel.

In corridor-corridor scenario, measurement results are evaluated for LOS and NLOS path. In LOS corridor measurement, the measured average power delay profile consists of several clusters [4]. In Figure 4a, tt is found that cluster length (except D1) is approximately two times the length of corridor that is about 95 meter (take into account position of receiver). D1 is slightly shorter than D2 and D3 due to distance between transmitter and receiver. The resulting clusters are due to multiple reflection of dominant path by reflector at the both end of corridor. The second peak in each cluster is due to reflection from Corridor 2.

In this way almost similar cluster shape is repeated within a power delay profile with reducing signal strength. The power difference between clusters A1, A2, and A2 is around 15 dB. This value is closed to path loss value per decade obtained in the last section that is 15 dB. In NLOS corridor, clusters in each power delay profile are not so clear. In NLOS room-to-corridor scenario, power delay profile tends to decay exponentially as shown in Figure 4b. TABLE II summaries delay spread obtained in all propagation scenarios. In room-to-corridor scenario, value of delay spread in Room A is lower than the rest of rooms because receiver was located at Corridor 1 just outside the room.

Results show that doors either open or close do not have significant effect on delay spread. This suggests that propagation through wall is important mode of propagation in NLOS scenarios. Results of in-room measurement also indicates the effect of furniture on delay spread is negligible. This finding implies that room metal structure like window and doorframes are major reflector inside room as compared to furniture used in this measurement that are mainly made from wood. In general, changes in height of receiver and transmitter obviously do not influence delay spread even in moderately furnished rooms. This is because in this measurement all antenna heights are above or equal to furniture heights available inside room.

TABLE II. POWER AZIMUTH SPREAD FOR ALL SCENARIOS

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Room-to-corridor | | | | | | | | |
| | Power Azimuth Spread (degree) | | | | | | | |
| | Rx=1.5 m, Tx=1.3 m | | | | Rx=1.5 m, Tx=1.5 m | | | |
| | Door close | | Door open | | Door close | | Door open | |
| Room A | 33.17 | | 28.25 | | 34.71 | | 28.08 | |
| Room B | 25.14 | | 24.10 | | 23.26 | | 22.54 | |
| Room C | 20.03 | | 19.63 | | 21.34 | | 20.95 | |
| Room E | - | | - | | 24.98 | | 24.68 | |
| Room-to-room | | | | | | | | |
| | Rx=1.3 m, Tx=1.3 m | | | | Rx=1.5 m, Tx=1.5 m | | | |
| | Door close | | Door open | | Door close | | Door open | |
| | Rx1 | Rx2 | Rx1 | Rx2 | Rx1 | Rx2 | Rx1 | Rx2 |
| Room B | 17.91 | 34.14 | 17.93 | 32.52 | 20.50 | 34.17 | 20.68 | 33.65 |
| Room C | 16.71 | 31.62 | 18.90 | 29.46 | 19.66 | 31.12 | 20.54 | 29.35 |
| Room D | 20.79 | 28.40 | 22.65 | 28.04 | 22.21 | 29.66 | 22.69 | 33.42 |
| Room E | 19.90 | 33.83 | 20.22 | 32.55 | 21.79 | 35.09 | 23.53 | 32.82 |
| In-room | | | | | | | | |
| | Rx=1.3 m, Tx=1.3 m | | | | Rx=1.5 m, Tx=1.5 m | | | |
| | Furniture | | W. Furniture | | Furniture | | W. Furniture | |
| Room F | 15.65 | | 17.76 | | 15.56 | | 16.32 | |
| Room G | 19.21 | | 19.44 | | 19.26 | | 18.53 | |
| Room H | - | | 17.66 | | - | | 25.62 | |

### C. *Angular Spread*

In indoor environment, the direction of arrival is not obvious especially in NLOS propagation channel since signal could be coupled from the corridor with mechanisms such as propagation through walls, through doors, guided waves combined with diffraction, and diffuse scattering from the non-homogenous structures [5] as shown in Figure 5. However, information on power azimuth spread is important as to some extend it could provide information on richness of scattering in an propagation environment.

Power azimuth spread of angle of arrival analysis has been done using unitary Esprit super-resolution technique [6]. Figure 6 below shows power azimuth spread measured in LOS corridor scenario along Corridor 1. The azimuth spread at receiving ULA seems to decrease with distance from slightly above 20 degree to lower than 10 degree azimuth spread. The antenna view is about 120 degree facing Corridor 1. Decrease in azimuth spread can be seen as increasing influence of wave guiding effect with distance along Corridor 1.

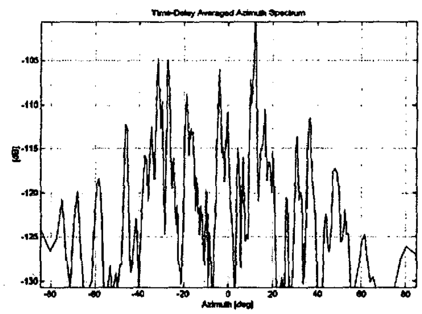



Figure 5. NLOS angular spectrum.

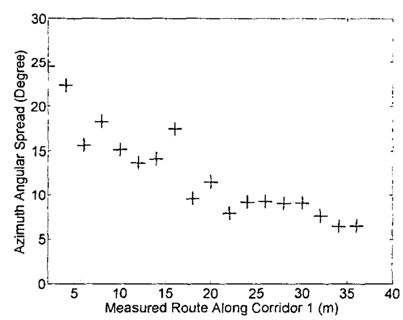



Figure 6. Power azimuth spread in corridor-corridor scenario (LOS).

TABLE II contains summary of power azimuth spread for all propagation scenarios. Results indicate strong influence of room size and antenna position of receiving ULA on power azimuth spread. In room-to-room measurement scenario, power azimuth spread at position Rx1 and and Rx2 is almost proportional to room dimension. For instance in room B, power azimuth spread is 17.91 degree at position Rx1 that is facing the width of room, about 5.5 meter, while 34.14 degree at position Rx2 that is facing the length of room, about 11 meter. For positions of Rx1 and Rx2 are shown in Figure 2. Similar to delay spread, effect of door either open or close on power azimuth spread is negligible. For in-room scenario, the effect of furniture on power azimuth spread is not obvious. In general, effect of changes in height of receiver and transmitter on power azimuth spread is mixed and not obvious.

### D. Spatial Correlation

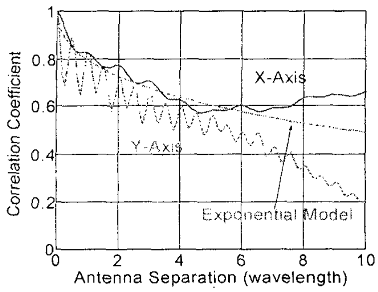



Figure 7. Spatial correlation in corridor-corridor scenario (LOS).

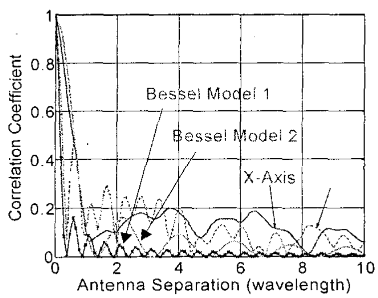



Figure 8. Spatial correlation in room-tocorridor scenario (NLOS).

Spatial correlation for receiving ULA is analyzed and is found that all spatial correlation coefficient in LOS case such as LOS corridor-corridor scenario and in-room scenario is high and above 0.6 regardless of axis of virtual antenna array at transmitter. In NLOS case such as NLOS corridor-corridor scenario, room-to-corridor scenario, and room-to-room scenario, spatial correlation coefficient becomes lower than 0.5 for ULA antenna spacing greater than half wavelength.

More detailed narrowband correlation coefficient information at transmitter can be obtained since the use of virtual antenna array allowed measurement at antenna spacing as small as 0.1 wavelength by means of stepping motor. Figure 3 shows spatial correlation results at transmitter observed in corridor-corridor scenario, room-to-corridor scenario, room-to-room scenario, and in-room scenario. In LOS corridor-corridor scenario Figure 7, spatial correlation coefficient is above 0.5 for all antenna spacing [5]. It is found exponential model $\exp\left(-\sqrt{d(\theta/\pi)}\right)$can be used to approximate spatial correlation in LOS case, where $d$ is antenna spacing in a fraction of wavelength, $\theta$ is angular spread. While in NLOS corridor-corridor scenario Figure 8 signal received at antennas tend to decorrelate for antenna spacing greater than 0.5 wavelength. It can be also observed that spatial correlation coefficient for Y-axis is oscillating with peak value repeating at about every 0.5 wavelength. Bessel model 1, $I_o(2\pi d)$ consider only antenna spacing where $I_o$ is Bessel function, while Bessel model 2, $I_o\left(2\pi d\sqrt{\theta/\pi}\right)$ consider antenna spacing and angular spread. It seems that Bessel model 1 fits well spatial correlation along X-axis and Bessel model 2 fits well spatial correlation along Y-axis especially for the first few wavelength of antenna spacing [7]. Result obtained in room-to-corridor scenario is quite similar to NLOS corridor-corridor scenario while spatial correlation for in-room scenario is closed to LOS corridor-corridor scenario. Therefore, all these scenarios can be commonly categorized based on the existence of LOS or NLOS path. For all scenarios except for room-to-room scenario explained in next paragraph, the ULA antenna array is always placed in direction perpendicular to Y-axis of virtual antenna array of transmitter.

## V. CONCLUSIONS

In path loss analysis, results show that signal strength decay slower than free space with path loss exponent 1.5 due to wave guiding effect and strong reflection from metal structures available along Corridor 1. This is shown in the obtained power delay profile along Corridor 1 where clusters with strong reflected paths are observed. Beside that, power delay profile in NLOS scenarios including room-to-corridor and room-to-room scenario tends to decay exponentially. Power azimuth spread analysis in all scenarios shows strong influence of room size on azimuth spread at receiving ULA antenna. Value of azimuth spread is proportional to room length and width. Delay spread and power azimuth spread analysis in general indicates negligible influence of door condition either open or close, furniture (for moderately furnished rooms), and antenna heights in both LOS and NLOS condition. Results of spatial correlation reveal the effect of antenna array position. When receiving ULA array and X-axis of virtual transmitting antenna array is in parallel position, smooth spatial correlation coefficient curve can be observed in most cases. While receiving ULA antenna and Y-axis of virtual transmitting antenna array is in perpendicular position, spatial correlation coefficient curve is fluctuating in an order of approximately half wavelength.

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