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Stochastic Analysis of In-door MIMO Channel Measurements

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1. Introduction

Modelling the radio channel accurately is essential for system design and performance evaluation through extensive measurement campaigns. With the multiple-input and multiple-output (MIMO) antenna structure it is quite cumbersome and difficult to perform channel measurements over a time-varying multipath fading environment. In this paper, we extends our previous work [1] to a non-line-of-sight (NLOS) MIMO channel measurement based on multiple-input and single-output (MISO) antenna configurations associated with dynamic measurements. The measurement is considered in a time-stationary elliptical scattering in-door propagation scenario, where a special case of the *"Kronecker"* MIMO channel model is derived and the channel reciprocity for the uplink and downlink is assumed. The cumulative distribution functions (CDF's) of the delay spread and fading envelope, as well as the maximum-to-minimum eigenvalue ratio (MMEVR) are investigated and compared with respect to different antenna spacing and angular spread, respectively. Since analysis results meet most real MIMO channel statistical property scenarios, a wider arrival angle shows that it is not necessary to increase the un-correlated inter-subchannels, especially for a larger angular spread case.

2. In-door MIMO Channel Model with Elliptical Scattreing Scenario

With a time-stationary elliptical scattering propagation environment for indoor MIMO channels, these features and attributes include:

1. Accessible constant delay paths onto each spatially separated antenna.
2. Scatters are uniformly distributed inside the ellipse with foci between TX/RX.
3. Well-defined mean direction-of-arrival (DOA) to average overall angular spread associated with dynamic measurement.
4. Grossly reciprocal between TX/RX transmission channels in time-stationary condition.
5. Based on (1)-(4), dynamic measurements using the MISO antenna configuration are approached under independently and identically distributed (i.i.d.) multipath channel

For a narrow-band MIMO channel with M_T transmit elements and N_R receive elements, the channel matrix can be expressed as [2, 3]

$$H_{N_R M_T x N_R M_T} = [U_n]_{N_R \times N_R} \otimes [U_m]_{M_T \times M_T} \tag{1}$$

where $H_{N_R M_t x N_R M_T}$ is the channel covariance matrix, $[U_m]_{M_T \times M_T}$ and $[U_n]_{N_R \times N_R}$ are the covariance matrices at the transmitter and receiver sides respectively. $\otimes$ denotes the "*Kronecker* product". By assuming that these features are true, the channel covariance can be further simplified as

$$\begin{aligned} H_{N_R M_T} &= [I]_{N_R x N_R} \otimes [U_m]_{M_T \times M_T} \\ &= diag\left[\ U_m(1), U_m(2), \cdot \quad \cdot \quad \cdot \ , U_m(N_R)\right]_{N_R} \\ &= diag[U_m, U_m, \cdot \quad \cdot, U_m]_{N_R} W(\phi_0) \end{aligned} \tag{2}$$

where $[I]$ is a unity matrix. From the receiver prospective, the overall received antennas have the same channel characteristics, multiplied by an arrival angular vector *W(ϕ)*, in the covariance matrices. The MIMO received signal vector at the mobile side is given by [4]

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$$y(t) = W(\phi_0)\int_{t_0}^{t_d} H(\tau)S(t-\tau)d\tau \tag{3}$$

where $H(\tau) = \sum_{l=1}^{L} H_{N_R M_T, l}\,\sigma(\tau - \tau_l)$

$W(\phi_0) = diag\lfloor \omega_1, \omega_2, \cdot\cdot, \omega_{N_R} \rfloor$ is the steering diagonal matrix and ω_{N_R} is the average phase shift relative to the antenna number with spacing d and mean DOA of the impinging field ϕ_0. $\omega_{N_R} = \Omega_{N_R}(\phi_0)\exp\left[-j(N_R - 1)\frac{d}{\lambda}2\pi\sin(\phi_0)\right]$ where $\Omega(\phi_0)$ is the antenna radiation pattern with angle ϕ_0 w.r.t. DOA. $[t_0, t_d]$ represents the available time period , and $H_{N_R M_T, l}$ is the channel impulse response at the delay path *l*. As a consequence, a simplified channel analysis is derived using MISO antenna configuration associated with a dynamic measurement, instead of the traditional *Kronecker* matrix in the MIMO channel model. Thus, an non-singular square matrix $[U_m]_{M_T x M_T}$ is applicable to approach MIMO channel covariance.

3. Measurements

Extensive measurement campaigns were undertaken within the University gym of National Taiwan Ocean University. This indoor environment provides a simulated elliptical scattering propagation environment [1], which has LOS and NLOS paths and time-stationary measurement scenarios, as depicted in Fig.1. Two specified routes (S→A and S→B), so called routes A and B, were measured using carrier frequency 1.89GHz. Various antenna spacing (i.e. d=λ/4, λ/2, λ, 3λ/2, 2λ, 5λ, and 10λ) are investigated. The measurements were, therefore, made free from people moving around in time-stationary LOS and NLOS environments. A ground sensor was installed for rigid alignment at the start and end-points of the measurement route. A vertically polarized omni-antenna was used in TX and a λ/2 dipole antenna was used in the mobile receiver for CW measurements. For delay spread measurements, the channel sounding system is applied where16 individual power delay profiles were recorded in both routes A and B. Dynamic measurements were carried out by slowly moving the mobile receiver along the specified routes.

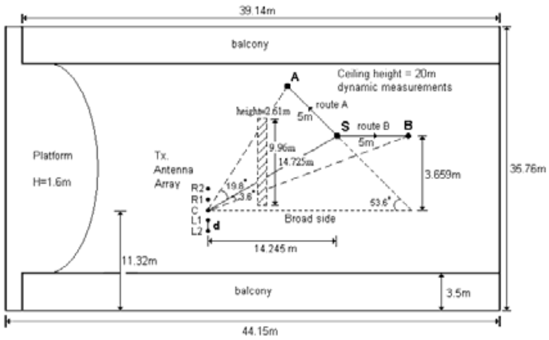
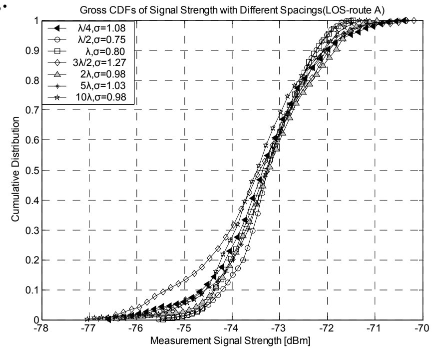


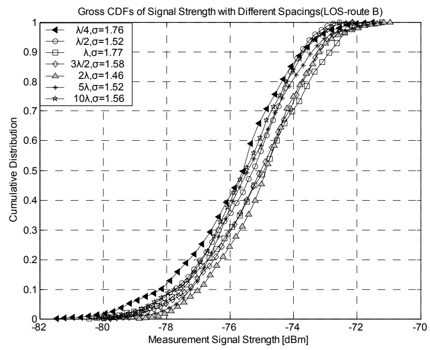
Fig.1 Sketched plan for in-door elliptical scattering measurements within NTOU Gym-station. The shade area is allocated when NLOS measurements are performed.

4. Analysis Results

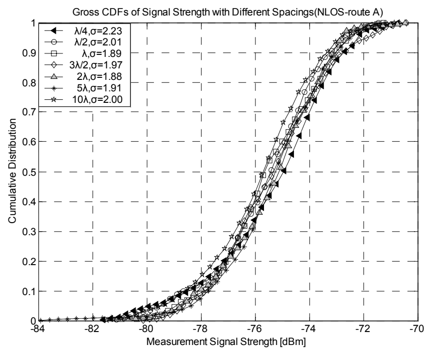
For fading envelope characteristics, the CDF shows a Rician distribution with large value of the Rician factor, *K*, at individual antenna for LOS. However, route-A (wider arrival angle) has larger K values than those of the route-B. It shows a Gaussian distribution with lower value for the standard deviation (σ=0.7~1.3 dB) in LOS route-A, and a higher value (σ=1.8~1.5dB) in route-B after summing these signals together, as depicted in Fig. 2. This is consistent to the Central limit theorem of statistics. For NLOS, route-B has much smaller *K* factor (2.5~-5 dB) that tends to be in large angular spread than route-A (K=1.2~4.5 dB). As a consequence, for LOS paths, it is realized that a wider angle of arrival (route-A) results in a lower standard deviation value in a Gaussian distribution with aggregate received signals. While, the narrower angle of arrival (route-B) reduces more dominant signals (i.e. LOS components); suffering more multipath components, results in larger standard deviation. In contrast, for NLOS paths, it shows that large angular spread (route-B) results in a small standard deviation (σ=1.95~1.2 dB), while small angular spread (route-A) has a large standard deviation (σ =2.25~1.9 dB). The largest MMEVR's = 6.041 and 12.058 are presented when the antenna space is d=λ/4 for LOS route-A and route-B respectively. Similarly, it shows the largest MMEVR's =7.587 and 8.45 with d=λ/4 for NLOS route-A and route-B respectively. Thus, they provide great noise enhancement in a typical channel, but with strong correlated channel paths. With regard to the MMEVR value, it is shown that the LOS has a larger value than that for the NLOS, where the correlated path increases. In other words, the number of orthogonal channels increases with an increase in the angular spread. In all cases, it reveals that the value of MMEVR and its standard deviation of eigenvalue (σ_e) decrease with an increase in antenna spacing.



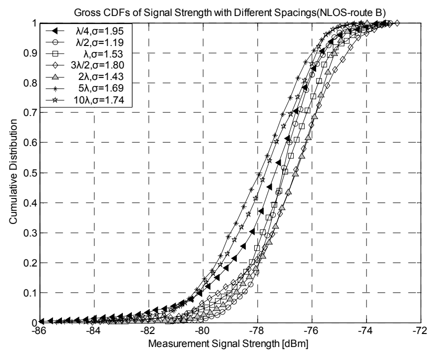
(LOS route-A)



(LOS route-B)



(NLOS route-A)



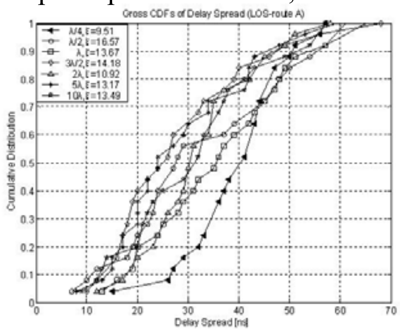
(NLOS route-B)

Fig.2 CDF's of aggregate signals received vs. antenna spacing in LOS and NLOS routes

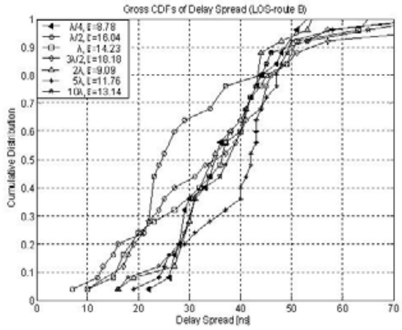
Fig. 3 shows the empirical CDF of the delay spread measured. in the specific routes. It was observed that CDF's have the best fitting curve to the Gaussian distribution characterized by the standard deviation of the delay spread, ξ. During our analyses, the Gaussian curve was found preferable, although log-normal distribution was presented in [5].

The mean delay spread and MMEVR values, obtained from the LOS and NLOS measurements, are compared in Fig. 4, with respect to different antenna spacings. However, there is no indication that shows any dependency between the time delay spread and the angular spread. The channel covariance matrices indicate that the two extreme eigenvalues of the largest and smallest values tends to exist at antenna spacing $d \le \lambda/2$. This indicates that the transmitted signals are approximately correlated, but have distinct signal paths with a higher S/N value. With wide arrival angle in rout-A, NLOS with large angular spread (i.e. small value of K factor) affects insignificantly on the channel correlation, while LOS has more concentrated signal strength with small value of σ . Conversely, with narrow arrival angle, the angular spread apparently affects the channel correlation that makes NLOS route-B has both small MMEVR and its σ_e values than that of the LOS route-B;

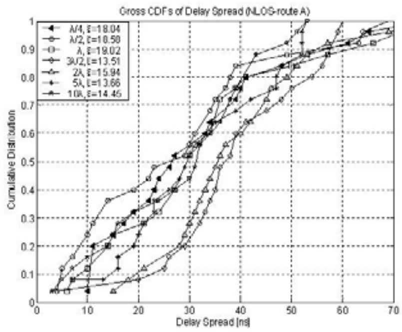
as the multpath spread increases, the channel correlation between antenna elements will decrease.



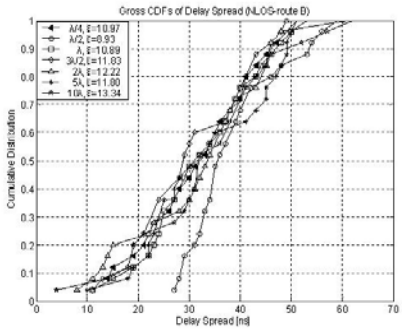
(LOS route-A)



(LOS route-B)



(NLOS route-A)



(NLOS route-B)

Fig.3 Empirical CDF's of time-delay spread vs. antenna spacing in LOS and NLOS route-A and route-B respectively

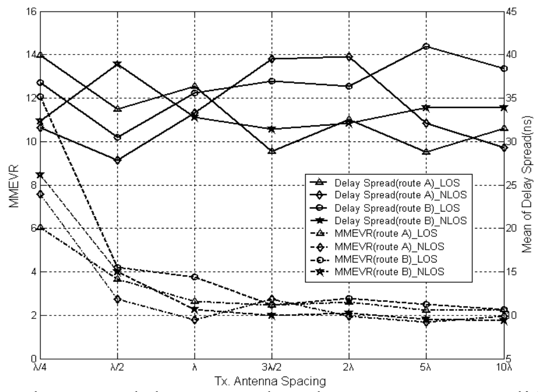


Fig.4 Comparisons for both mean delay spread and MMEVR w.r.t different antenna spacing

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