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Analysis of kurtosis-based LOS/NLOS Identification based on indoor MIMO Channel Measurements

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Abstract—**The location of the mobile station (MS) can be estimated from the distance measures between MS and several base stations (BS). However, the distance measure accuracy is degraded due to the complicated indoor environment, particularly non line-of-sight (NLOS) propagation. In order to improve the accuracy of wireless localization, the knowledge of whether the BS - MS path is line-of-sight (LOS) or NLOS may be of significant importance. Several papers have proposed to use kurtosis for the NLOS identification in ultra wide band systems. In this paper, we investigate the kurtosis of the channel impulse response (CIR) and explore the potential of kurtosis for LOS/NLOS identification with different system parameters in terms of both simulations and measurements. The statistical analysis is based on an extensive set MIMO channel measurement data collected at Aalto University. Both simulation and measurement results indicate that kurtosis by using decibel of CIR amplitude provides consistent information about the LOS/NLOS condition regardless of system parameters.**

Index Terms— **identification, kurtosis, LOS, MIMO measurement, NLOS**

I. INTRODUCTION

Over the last few years, localization and navigation services in wireless mobile networks have gradually entered into the daily life of the people all over the world, in most of the cases through applications such as route guidance. This trend will continue in the future and more people will become direct or indirect users of such services. Basically, the mobile station (MS) location may be determined based on the distance measures between MS and several base stations (BS). The distance measures can be estimated based on, for example, a logarithm-distance path-loss model [1]-[3] as shown in (1):

$$\text{PL [dB]} = PL_0 + n10\log_{10}\frac{d}{d_0} + X_g \qquad (1)$$

where PL is total path loss measured in decibel (dB); PL_0 is the path loss in dB at the reference distance d_0; d is the length of the path; d_0 is the reference distance; n is the path loss exponent, X_g is a Gaussian random variable with zero mean. In this path-loss model, PL and PL_0 are usually obtained by the measurement. Therefore, the distance d between MS and BS can be estimated if n and X_g are known. However, the accuracy of n and X_g estimation depends on the wireless propagation channel. If the path between MS and BS is in the line-of-sight (LOS), accurate n and X_g estimation yields high quality distance d estimates, and thus enables MS localization. However, Non Line-Of-Sight (NLOS) conditions in MS-BS path often occur indoors due to complex building structures, which block the direct radio link. The precision of path-loss parameters estimation is degraded, which result in poor estimation of MS location. It is therefore critical to identify NLOS conditions so that the accuracy of path-loss model could be improved.

Several papers have proposed different techniques based on kurtosis for NLOS identification [4] - [6], however, these identification techniques based on kurtosis proposed are mainly used in Ultra Wide band (UWB) system, which has >500MHz bandwidth. The distribution of CIR, hence the kurtosis in other systems might be very different from those in UWB systems. The kurtosis-based NLOS identification may not be valid with different system configurations. This research investigates kurtosis with different system parameters and potential of kurtosis on the LOS/NLOS identification in terms of both simulations and measurements. The statistical analysis is based on an extensive set MIMO channel measurement data were collected at Aalto University [8]. The contribution of this paper is the analysis and validation of kurtosis with different system parameters in terms of both simulations and measurement for NLOS identification purpose.

The remainder of this paper is organized as follows: Section II describes the channel measurement environment; Section III presents the definition of kurtosis; Section IV and V show the statistical results and discussion in terms of simulation and measurement, respectively; finally, conclusions are drawn in Section VI.

II. Measurement Description

Radio channel measurements were carried out at Aalto University, Computer Science Building. The building has typical office or library structure: it is a three-storey building with a large hall in the middle. The hall occupies the whole height of the building and is surrounded by the classrooms and offices. The measurements use a MIMO channel sounder [7] with 5.3 GHz center frequency, 120 MHz signal bandwidth and two separate receiver units. Four measurement routes considered in this article are shown in Fig. 1. The location of RX1 and RX2 are fixed and the transmitter is moving along the route in the direction of the arrow. These routes cover both of LOS and NLOS conditions. As can be seen from the map in Fig. 1, the TX-RX2 link at the beginning of route 21 and the end of route 20 are LOS, as well as TX-RX1 link at the end of route 24. Each route has a large number of snapshots (instantaneous MIMO channel realization, spaced 39.32 ms apart). With two receivers, we have CIR of TX-RX1 and TX-RX2 links with

MIMO matrix size of 30 × 30 and 30 × 32, respectively. More details about the antenna structure and measurement configurations can be found in [8].

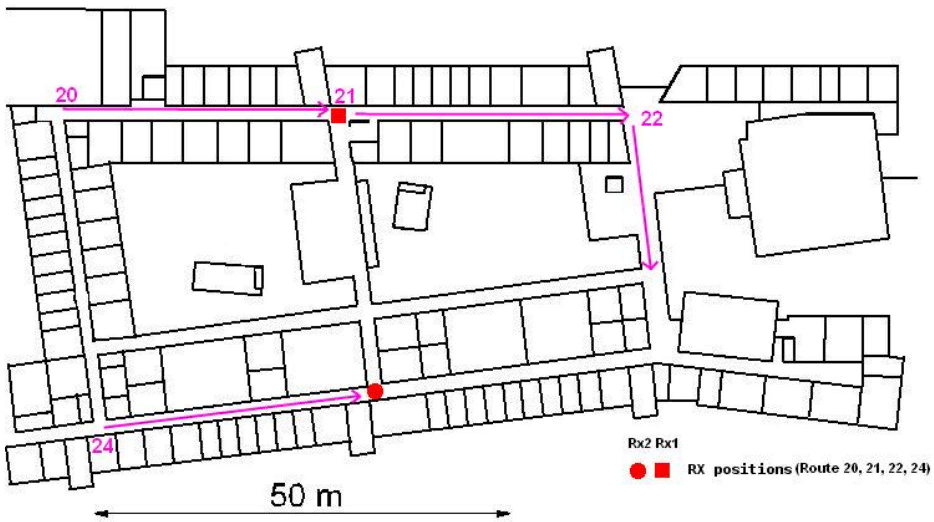

Fig. 1: The map of routes.

III. Parameter Definition and Statistical Analysis

Kurtosis defined here as the ratio of the fourth-order moment of the data to the square of the second-order moment. It characterizes the peakedness of the data samples. The kurtosis can be expressed as in (2),

$$\kappa = \frac{E\left[\left(X-\mu_X\right)^4\right]}{E\left[\left(X-\mu_X\right)^2\right]^2} = \frac{E\left[\left(X-\mu_X\right)^4\right]}{\sigma_X^4} \qquad (2)$$

where X is the random variable under evaluation, μ_X and σ_X are the mean and standard deviation of X, respectively. We assume the kurtosis to have a high value in LOS and a low value for NLOS (ideally 3 for a pure Gaussian random variable). For this reason, the decision can be taken for NLOS when κ is smaller than a certain threshold. In [4]-[6], the authors have taken the CIR amplitude, X=|h(t)| as the data samples for kurtosis calculation in UWB system. However, the properties of the CIR and hence the kurtosis might be different depending on the system parameters. Moreover, the kurtosis calculation by using the |h(t)| may not be the best option for NLOS identification, since the linear scale amplitude is positive and thus always different from Gaussian. In this paper, we evaluate the kurtosis of the logarithm of the CIR amplitude in dB, i.e., $X=20\log_{10}(|h(t)|)$, which is supported by the often assumed log-normal of the CIR amplitude fading. Moreover, we use the different MIMO channels to average over the kurtosis estimates computed from each individual CIR.

IV. SIMULATION RESULTS

In order to evaluate the dependence of kurtosis value on system parameters, the computer simulations have been carried out using the calibrated model of the same antenna arrays that used in the measurements. In the simulation, the transmitter location is fixed. The receiver is randomly placed within +/- 25m away from the transmitter and the scatters are randomly placed +/- 50 meters away from the transmitter. There are 30 scatters in NLOS condition and one direct path with five scatters in LOS condition. The simulation generates CIR vectors for two different system parameters: 1) 120 MHz bandwidth and 192 frequency taps (CIR length = 192/120 MHz = 1.6 micro seconds (μs)), which corresponds to the data from the sounder in the measurement, and 2) 20 MHz bandwidth and 64 frequency taps (CIR length = 64/20 MHz = 3.2 μs), which corresponds to 802.11 Wireless Local Area Network (WLAN) Orthogonal Frequency Division Multiplexing (OFDM) standards. For each set of parameters, 30×32 CIR vectors are generated and the kurtosis is calculated as the average of all the kurtosis values of each CIR vector. The variable X is by taken CIR h(t) samples with two different methods: 1) the amplitude of CIR, X=|h(t)|; 2) logarithm of CIR amplitude, $X=20\log_{10}(|h(t)|)$.

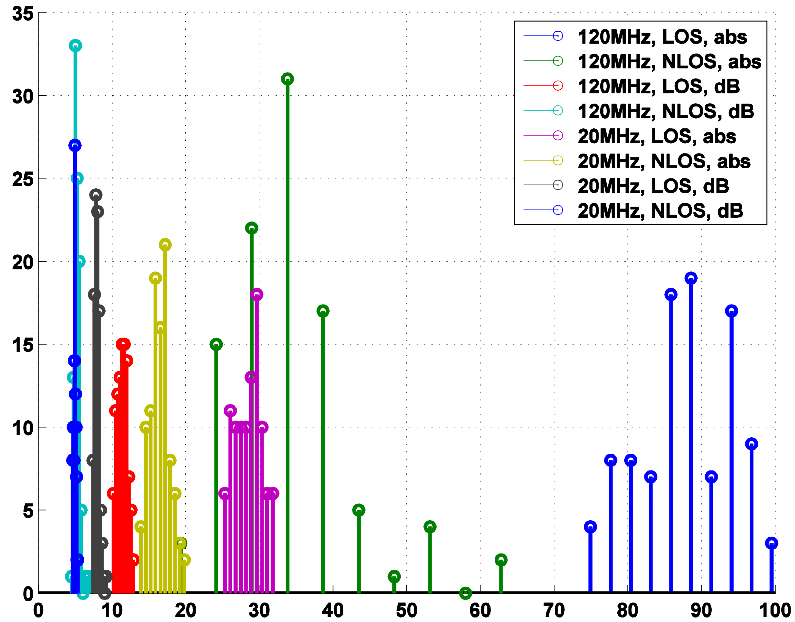

Fig. 2: Kurtosis with simulated channel impulse response. The dB based kurtosis yields reasonable threshold selection for both system parameters sets, whereas absolute value based is more sensitive on the system settings.

The histograms of the kurtosis in LOS and NLOS conditions with different system parameters are shown in Figure 2. The distribution of kurtosis by using CIR amplitude has significant dependence on the system parameters. A general threshold for NLOS identification is hard to select due to the high variance between system parameters. On the other hand, the kurtosis by using dB of CIR amplitude is less sensitive to the system parameters. The kurtosis of the dB of CIR amplitude in NLOS is quite similar with different system parameters and the value is close to 3, which indicates that the probability density function of dB of CIR amplitude is close to Gaussian distribution. From the NLOS identification point of view, the kurtosis by using dB of CIR amplitude shows good consistence and separation between LOS and NLOS, regardless the system parameters. Therefore, a threshold can be easily selected for NLOS identification.

V. MEASUREMENT RESULTS

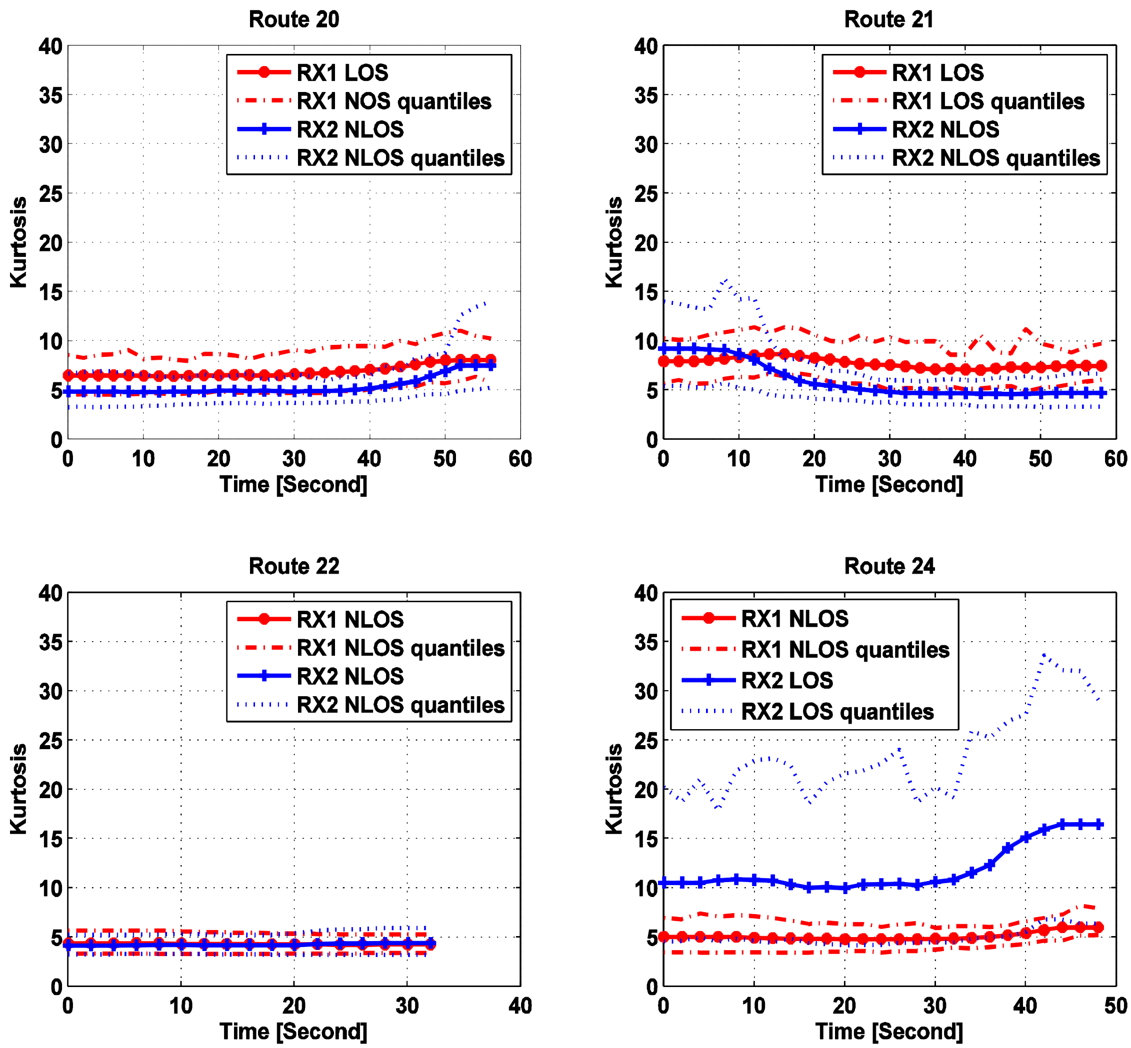

Fig. 3: Average kurtosis (solid lined) at each snapshot in different routes. The dashed lines denote the 10% and 90% quantiles. The average kurtosis curves in each subplot show a clear difference for LOS and NLOS conditions.

The kurtosis was also evaluated with measurement data. In the measurement, we obtain 30×32 CIR vectors for TX-RX1 link and 30×30 CIR vectors for TX-RX2 link at each snapshot. Figure 3 shows the average kurtosis of CIR amplitude in the logarithmic scale at different routes. The kurtosis at each snapshot is calculated as the average of 30×32 kurtosis values for TX-RX1 link and 30×30 kurtosis values for TX-RX2 link. As can be seen from the figure, the average kurtosis curves show a clear difference for LOS and NLOS conditions regardless of the routes. In each subplot, it also shows the 90% quantiles and 10% quantiles of kurtosis values (960 kurtosis for TX-RX1 Link and 900 kurtosis for TX-RX2 link) at each snapshot in the route. It shows the kurtosis in best/worst cases of all the Single Input Single Output (SISO) channels, depending on the antenna orientations. Comparing with the kurtosis in SISO channels, the average kurtosis gives a better indication of the LOS/NLOS conditions.

VI. Conclusion

This paper has presented the statistical analysis based on the MIMO channel measurements in an office building at Aalto University. The kurtosis of CIR in LOS and NLOS channels has been studied with different system parameters in terms of both simulation and measurement. Both the simulation and measurement results revealed the kurtosis by using CIR amplitude had significant dependence on the system parameters. The values of kurtosis of CIR amplitude varied over a wide range with different system parameters in LOS and NLOS conditions. A general threshold is hard to select for NLOS identification. On the other hand, the CIR amplitude in logarithmic scale is less sensitive to the system parameters. The kurtosis by using dB of CIR amplitude is more consistent and has clearer separation for NLOS and LOS conditions regardless of system parameters. Therefore, a general threshold can be selected based on the kurtosis of dB of CIR amplitude and it would also work even if the system parameters would change based on the finding from simulations. The measurement results also showed that if multiple antennas are available, the average kurtosis, which is averaged over all the kurtosis values and a period of time, should give better indication of the LOS/NLOS conditions.

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Reference

[1] S. Mazuelas, A. Bahillo, R.M. Lorenzo, P. Fernandez, F.A. Lago, E. Garcia, J. Blas, E.J. Abril, "Robust Indoor Positioning Provided by Real-Time RSSI Values in Unmodified WLAN Networks," Selected Topics in Signal Processing, IEEE Journal of , vol.3, no.5, pp.821-831, Oct. 2009

[2] E. Laitinen, J. Talvitie and E.-S. Lohan, "Comparison of Positioning accuracy of Grid and Path Loss-based Mobile Positioning Methods using Received Signal Strength", Proc. Of SPAMEC 2011, Cluj-Napoca, Romania.

[3] Sukhoon Jung; Choon-oh Lee; Dongsoo Han; , "Wi-Fi fingerprint-based approaches following log-distance path loss model for indoor positioning," *Intelligent Radio for Future Personal Terminals (IMWS-IRFPT), 2011 IEEE MTT-S International Microwave Workshop Series on* , vol., no., pp.1-2, 24-25 Aug. 2011

[4] I. Guvenc, C.-C. Chong and F. Watanabe, "NLOS identification and mitigation for UWB localization systems," in Proc. of the IEEE Wireless Communications and Networking Conference, pp: 1571–1576, 2007.

[5] I. Guvenc, C.-C. Chong, F. Watanabe and H. Inamura, "NLOS identification and weighted least-squares localization for UWB systems using multipath channel statistics," EURASIP Journal on Advances in Signal Processing, 2008.

[6] L. Mucchi and P. Marcocci, "A new parameter for channel identification in UWB indoor environments," *Computer Communications and Networks, 2007. ICCCN 2007. Proceedings of 16th International Conference on* , vol., no., pp.419-423, 13-16 Aug. 2007

[7] V.-M. Kolmonen, J. Kivinen, L. Vuokko, and P. Vainikainen, “5.3-GHz MIMO radio channel sounder," IEEE Transactions on Instrumentation and Measurement, vol. 55, no. 4, pp. 1263-1269, Aug. 2006.

[8] V.-M. Kolmonen, P. Almers, J. Salmi, J. Koivunen, K. Haneda, A. Richter, F. Tufvesson, A.F. Molisch and P. Vainikainen , “A Dynamic Dual-Link Wideband MIMO Channel Sounder for 5.3 GHz,” Instrumentation and Measurement, IEEE Transactions on , vol.59, no.4, pp.873-883, April 2010

[9] D. Dardari, M. Luise and E. Falletti, “Satellite and Terrestrial Radio Positioning Techniques”, Acedemic Press, Oct. 2011

[10] A. Hong, G. Sommerkorn, R. Thomä and W. Zirwas, “Considerations on the relationship between path loss and spatial characteristics based on MIMO measurements,” in Proc. of *WSA 2006 / International ITG/IEEE Workshop on Smart Antennas*, Reisenburg : Mar. 2006