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Distance and Bandwidth Estimation for MIMO Channel

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Introduction

We have considered MIMO-OFDM system as multiple antennas which are used for data streams sent out and receive in the same way. We have denoted each antenna by spatial multiplexing, and this method are known as to provide higher spectral efficiency, compared to single-input-single-output (SISO) systems [1].

In Rayleigh fading environment multiple antenna systems provide significant increase of data transmission capacity compared to single antenna systems [1], [8]. It has been shown theoretically that the capacity of the MIMO channel scales linearly with the number of transmitting/receiving elements in the case of uncorrelated channel gains [1], [6]. Consequently, the MIMO systems are recommended for high data rate wireless communication. [7], [8]. The MIMO channel can be decomposed into LOS and NLOS matrix component, ratio characterized by Ricean K-factor. As soon as the K-factor decreases with distance, users closer to the access-point (AP) have the MIMO channel that have had dominant LOS matrix component and may exibit a poor eigenvalue distribution. Consequently, such users might not experience the spatial-multiplexing effect despite having a high SNR [7].

It is possible to reduce the level of correlation between the antenna elements by providing sufficient inter-element spacing. However, for the practical application of MIMO-OFDM systems in indor WLAN, the spacing between adjacent antenna elements cannot be too large [5].

A coherent dual 3x3 MIMO channel wireless-local-area-network (WLAN) system spanning a bandwidth of 20MHz and 40MHz was setup for measurements in typical office environment. Measurements were taken for broadband short range environment sistematicaly with lineary varying distance indoor environment. The data was then analyzed in temporal, frequency and spatial domain.

The channel properties have been characterized by parameters such as Ricean K-factor, MIMO spatial domain distance and bandwith estimation [7].

The purpose of this paper is to present the distance and banwidth estimation of MIMO channel over SISO channel, that was measured in a fixed typical indoor environment with a real-life narrowband MIMO-OFDM system. The main difference with previous measurements [2-6] are that probability for fixed real-life commercial MIMO-OFDM AP system will be mounted on wall or ceil [7], not in geometrical center of the actual location in the room.

System model and analysis

We consider a narrowband MIMO single user communication link in which the transmitter and receiver are equipped with n_T transmit (Tx) and n_R receive (Rx) antennas in lineary equidistant linear array, operating in a static indoor environment. The discrete-time received signal in such a system can be written in matrix form as [1-7]:

$$r = \sqrt{P_s}\,[H]s + n \tag{1}$$

where r – received signal vector, $\sqrt{P_s}$ - average SNR of the indepent transmitted signal on each input, H – channel transfer matrix representing complex subchannel gain, s – received signal vector, n- receiver noise vector.

The channel matrix H can be decomposed into fixed H_F and Rayleigh variable H_V matrix [6]:

$$[H] = \sqrt{k/k+1} * [H_F] + \sqrt{1/k+1} * [H_V]. \tag{2}$$

The Rx and Tx spatial correlation matrix, which show the correlation among the various array antenna elements and LOS elements are calculated as [7]:

$$\begin{cases} [H_F] = [L_{Rx}][H_U][L_{Tx}] \\ [H_V] = \sqrt{[C_{Rx}]}[H_{ID}]\sqrt{[C_{Tx}]} \end{cases} \tag{3}$$

where C_{Rx} - Rx and C_{Tx} - Tx NLOS condition correlation matrix, H_{ID} - independent zero-mean and unit-variance complex Gaussan random variables; L_{Rx} - Rx and L_{Tx} - Tx LOS condition matrix, H_U - complex value matrix that takes into account the polarisation angles θ betwen Rx and Tx antenna. For 3x3 MIMO channel we can express complex correlation coefficients ρ between ith and jth Rx and Tx antennas with diogonal matrix [7]:

$$\begin{cases} L_{Rx} = \left[e^{-j2\pi\lambda \sin\theta_{Rx}} ij \right],\ L_{Tx} = \left[e^{-j2\pi\lambda \sin\theta_{Tx}} ij \right] \\ C_{Rx} = \left[\rho_{Rxij} \right],\ C_{Tx} = \left[\rho_{Txij} \right] \\ H_U = \left[e^{j\pi\theta} ij \right]. \end{cases} \quad (4)$$

The general trend suggests that increase of spacing between the elements have caused to the decorrelation of the subchannels. For n_T Tx and n_R Rx antennas, the generalized Shannon formula for the channel capacity *C* can be expressed as [1-7]:

$$C = \log_2 \left(\det \left[I + P_S / \sigma^2 * HH^T \right] \right) \quad bps/Hz \quad (5)$$

where *I* – identity element matrix $n_T \times n_R$, H^T - transpose conjugate for *H* matrix. It does not matter what type of antenna polarisation we use (in case that signal is still detectable), we define eigenvalues for HH^T to be $\lambda_1, \lambda_2, ..., \lambda_\beta$, where $\beta = \min(n_T, n_R)$, we can rewrite (5) as following [7]:

$$C = \sum_{i=1}^{\beta} \log_2 \left(1 + \left(P_S / \sigma^2 \right) \lambda_\beta \right). \quad (6)$$

From (6) we can estimate that the capacity increases lineary with the number of dominant eigenmodes. Here we can assume that antennas with small inter-element spacing will better Rx than Tx data.

The path gain consists of fixed component plus zero-mean fluctuating component. Often this fluctuation is complex Gaussan. Then the time-varying envelope of the composite gain has a Ricean distribution. The ratio of the fixed and fluctuating power components is defined as the K-factor [2]:

$$k = |m|^2 / \left(2\sigma^2 \right), \quad (7)$$

where *m* – is the power of the fixed and *σ* – the power of the random component. Normalization can be expressed as $|m|^2 + 2\sigma^2 = 1$. Note that Rician distributin reduces to the Rayleigh distribution when $k = 0$ [5].

Measurement setup

A measurement campaign in ISM band (2.4-2.5 GHz) was conducted in an enclosed indoor environment in the Riga Technical University (RTU) Faculty of Electronics and Telecommunications (ETF) (Fig. 1).

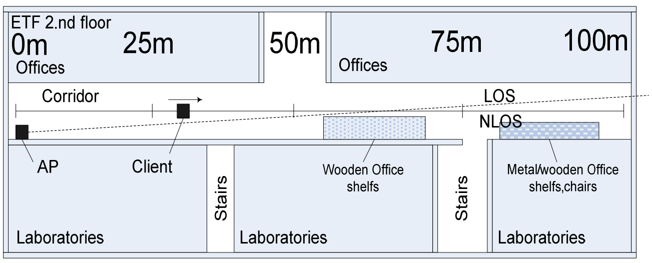

Fig. 1. Overview of measurement environment

The distance till 70m are LOS environment, after 70m NLOS environment. An AP was located 2.5m from floor, 0.5m from ceil and 5m from end wall. Client was located in the middle of corridor on 0.6m height, like most of users normaly work with laptop computers. We moved client through corridor from beggining wall 0m, AP location (5m), to 100m and take measurements in each 5m, with client adapter facing to the AP.

The measurements were taken with a commercialy available MIMO-OFDM system, whitch allows to work with 802.11g and 802.11n (draft) WLAN protocols, see Table 1.

Table 1. Measuring system hardware

Hardware	*Model*	*Protocol*	*Firmware*
AP	Linksys WRT300N V2.0	802.11g/n	2.00.06
Client	Linksys WPC300N	802.11n	6.0.2.9
Client	Repotec RPWB7108	802.11g	3.0.1.0

All hardware settings was kept to manufacturer default. Linksys are using new chip Atheros AR5416 XSPAN, that can be switched to 2x2, 2x3 and 3x3 MIMO-OFDM modes, and are backward compatible with SISO systems.

The measurements were taken across time, space and frequency. For measurements we have choosed center channel in 2.437 GHz (ch. 6) 1x1 SISO system and 2.437 GHz + 2.427 GHz (ch. 4) wideband channel 3x3 MIMO system, where the system bandwidth was 20 MHz, and for additional wideband channel also 20MHz.

The arrangement for AP is shown in Fig. 2. (vertically/horizontally polarized elements and distanced: V/H/dist.). We have used wall mount distribution for AP, and check possibility to position AP in maximum case.

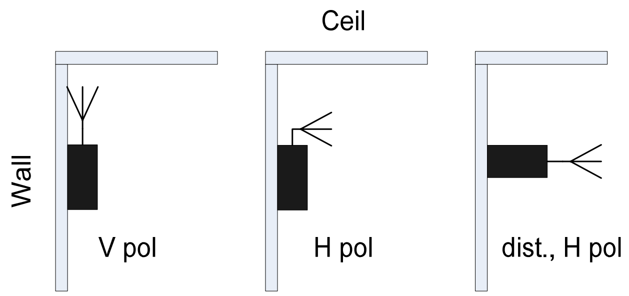

Fig. 2. AP setup for corridor measurements

We have used GPL Iperf V2.0.2 software for traffic and statistics generation. We took archived data file of exactly 100MB in size for bandwidth and data transfer speed measurement where one to three simultaneous data stream transfers in each measurement point was used (Fig. 3). While collected channel properties we also checked compability of software layer (7,6,5,4) with hardware layer (3,2) in anechoic chamber.

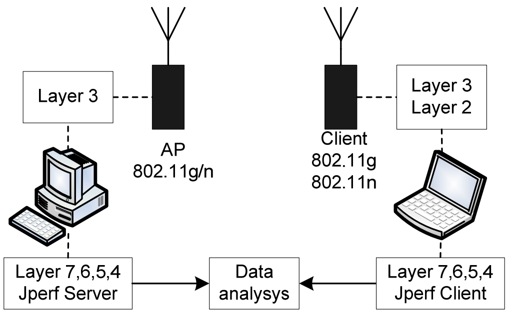

Fig. 3. Measurement system setup

Measurement results

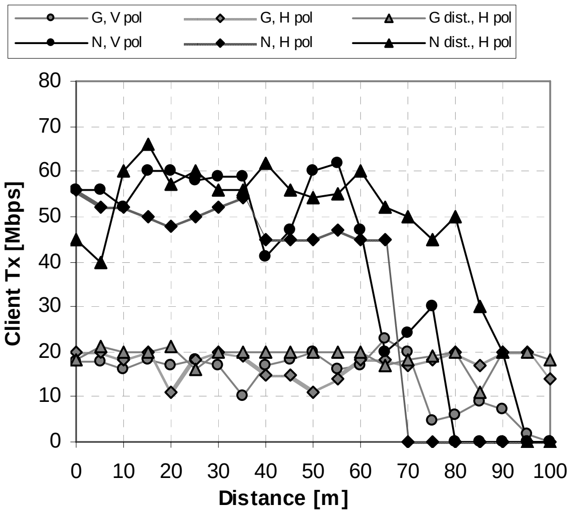

Fig. 4. Client transmiting distance and bandwidth estimation to AP

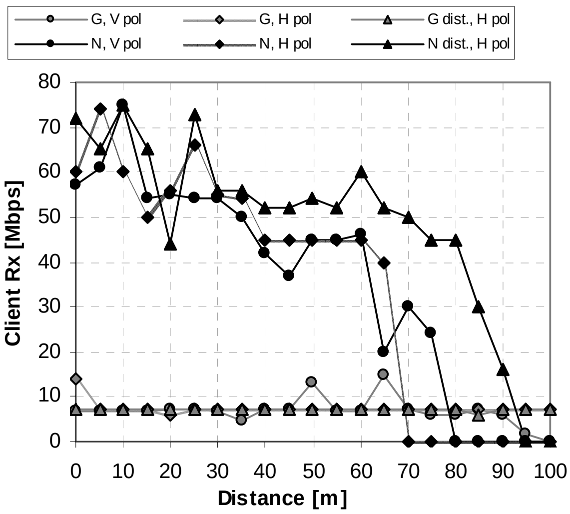

Fig. 5. Client receiving distance and bandwidh estimation to AP

Statistics for transfered data was collected for one second interval and data transmission speed can be expressed as Mbps. Distance and bandwidth estimation for Client side are shown in Fig. 4, for Tx side and Fig. 5, for Rx side.

The ratio of the fixed and a fluctuating power components have been defined as the Ricean K-factor. The K-factor was an important parameter that defines probability of fade of a certain depth and, therefore, have affected on system performance for distance and bandwidth estimation (Fig. 6).

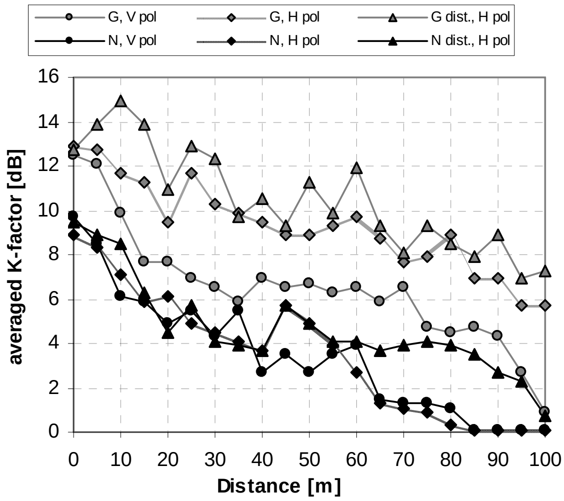

Fig. 6. Average Ricean K-factor vs. distance and polarisation for 802.11g and 802.11n devices in long corridor

Conclusions

1. In this paper, we have presented a commercialy available 3x3 MIMO channel system distance and bandwidth estimation for LOS and NLOS environment. We have choosed different polarisations and previous measured scenarios with different fixtures. The best scenario was distanced H. polarization (one wavelenght) configuration (Fig. 2), it have minimized reflections to nearest wall and gave better coverage performance to NLOS environment. We have concluded that there is possibility to mount AP in the same way to ceil, and get better results as well as wall mounted.

2. Analytical model of Ricean and Rayleigh were compared to measurements. In system model and analysis part we have assumed that antennas with small inter-element spacing would be better as Rx neither Tx data., Fig. 4., and Fig. 5., confirms that.

3. Trasfered data packets have been collected and statistics for signal power level and data transmission speed verified. For both, SISO and MIMO systems most of the Rx sensitivity performance have been good until -70dBm.

4. We also have compared Rayleigh and Rician distribution measured in anechoic chamber for data transfer comparison. There was no signifficant difference in range for Rician distribution till 30m in LOS.

5. Long corridor is not suitable for NLOS observation. It is necessary to reduce the signal power level or use signal absorption materials without reflection.

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We presented the distance and bandwidth estimation measurements for fixed environment multiple-input-multiple-output (MIMO) wideband radio channel, based on orthogonal frequency-division-multiplexing (OFDM). Channel capacity measurements experiment have been carried out in an indoor line-of-sight (LOS) and non-line-of-sight (NLOS) corridor environment. Channel bandwidth were measured systematically with lineary varying distance in a static indoor environment. Measurements have shown that in the indoor LOS and NLOS environment MIMO systems have achieved sufficiently higher channel capacity because the MIMO channel is more robust to correlation when the signal-to-noise-ratio (SNR) is high. Influence of antenna polarisation was taken in fact. Measurements were also taken in anechoic chamber, to realise higher SNR. Ill. 6, bibl. 8 (in English; summaries in English, Russian and Lithuanian).

А. Рушко, В. Новиков, Г. Балодис. Расстояние и оценка полосы пропускания для канала MIMO // Электроника и электротехника. – Каунас: Технология, 2007. – № 8(80). – P. 49–52.

Представлены оценки расстояния и размера полосы пропускания в неподвижной окружающей среде для широкополосного радиоканала типа многократный-вход-многократный-выход (MIMO), основанного на ортогонально-частотном мультиплексировании (OFDM). Полный эксперимент полосы пропускания канала был выполнен по прямому лучу обзора (LOS) и по не прямому лучу обзора (NLOS) в длинном коридоре. Полоса пропускания канала была взвешена систематически с линейно изменяющимся расстоянием в статической внутренней окружающей среде. Измерения показали, что во внутренней LOS и окружающей среде NLOS системы MIMO достигли значительно более высокой вместимости канала, потому что канал MIMO является более устойчивым к корреляции, когда отношение сигнал/шум (SNR) высокое. Также было взято в оценку влияние поляризации антенны. Также проводились измерения полосы пропускания в безэховой камере, чтобы достичь более высокое SNR. Ил. 6, библ. 8 (на английском языке; рефераты на английском, русском и литовском яз.).

A. Rusko, V. Novikovs, G. Balodis. MIMO kanalo atstumo ir pralaidumo juostos nustatymas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 8(80). – P. 49–52.

Pateikti nekintančioje aplinkoje esančio MIMO plačiajuosčio radijo kanalo atstumo ir pralaidumo juostos matavimai. Kanalas naudoja ortogonalų dažninį multipleksavimą (OFDM). Kanalo pajėgumo matavimai atlikti koridoriuje tiesioginio matymo zonoje (LOS) ir netiesioginio matymo zonoje (NLOS). Kanalo pralaidumo juosta pastato viduje matuota sistemiškai, tiesiškai keičiant atstumą. Matavimai parodė, jog vidaus LOS ir NLOS aplinkoje MIMO sistemos pasižymėjo kur kas geresniu kanalo pajėgumu, nes MIMO kanalas yra atsparesnis koreliacijai, kai signalo ir triukšmo santykis yra didelis. Tyrimuose atsižvelgta į antenos poliarizaciją. Matavimai taip pat atlikti aido neturinčioje patalpoje, siekiant gauti didesnį signalo ir triukšmo santykį. Il. 6, bibl. 8 (anglų kalba; santraukos anglų rusų ir lietuvių k.).