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Time Variation Effects of Weather Conditions in Rural MUSA-MIMO-OFDM Channels

Nisal L. Ratnayake*, Karla Ziri-Castro*, Hajime Suzuki†
*School of Engineering Systems
Queensland University of Technology
Brisbane, Australia
*Email:n.ratnayake@qut.edu.au
†CSIRO ICT Centre
Epping NSW 1710, Australia

***Abstract*—This paper presents channel measurements and weather data collection experiments conducted in a rural environment for an innovative Multi-User-Single-Antenna (MUSA) MIMO-OFDM technology, proposed for rural areas. MUSA-MIMO-OFDM uplink channels are established by placing six user terminals (UT) around one access point (AP). Generated terrain profiles and relative received power plots are presented based on the experimental data. According to the relative received signal, MUSA-MIMO-OFDM uplink channels experience temporal fading. Moreover, the correlation between the relative received power and weather variables are presented. Results show that all weather variables exhibit a negative average correlation with received power. Wind speed records the highest average negative correlation coefficient of -0.35. Local maxima of negative correlation, ranging from 0.49 to 0.78, between the weather variables and relative received signals were registered between 5-6 a.m. The highest measured correlation (-0.78) of this time of the day was exhibited by wind speed. These results show the extend of time variation effects experienced by MUSA-MIMO-OFDM channels deployed in rural environments.**

***Index Terms* -MIMO, Rural Wireless Channels, Channel Measurements, Weather Effects**

I. INTRODUCTION

Multiple-input multiple-output (MIMO) systems which use multi element antennas at the transmitter and the receiver have emerged as a promising solution for the increasing demand of higher data rates, better quality of service, and higher network capacity. A major advantage of MIMO systems is the ability to use multipath propagation, traditionally a pitfall of wireless transmission, in a beneficial way to users. In a favourable radio environment such as "rich scattering" [1], MIMO can increase the spectrum efficiency by N-folds if N antennas are used at both the transmitter and receiver ends.

While a typical rural environment does not exhibit rich multipath scattering [2], MIMO can be utilized to increase the spectrum efficiency in rural environment by implementing the novel multi-user single-antenna (MUSA) MIMO proposed in [3]. MUSA-MIMO consists of multiple user terminals (UTs) each equipped with a single antenna and a central access point (AP) equipped with multiple antennas. MUSA-MIMO performs space division multiple access (SDMA) to increase spectrum efficiency by M-folds where M is the number of SDMA UTs. MUSA-MIMO can be combined with orthogonal frequency division multiplexing (OFDM) to relax timing requirements for synchronizing multiple UTs spread in a large geographical area [4]. MUSA-MIMO-OFDM has been practically implemented to demonstrate the spectrum efficiency improvement by six times compared to a conventional single-transmitter single-receiver system in a rural area [5]. The proposed MUSA-MIMO-OFDM system utilizes TV frequency spectrum (which may become available after analogue TV services are ceased), antenna beamforming techniques, and high transmission towers. These properties enable the proposed MUSA-MIMO-OFDM system to be a long range fixed wireless access solution with predominant line-of-sight (LOS) paths [6].

The performance and the stability of the MUSA-MIMO-OFDM are expected to be dependent of MUSA-MIMO-OFDM channel and its temporal variation. According to the literature, vegetation [7], rain [8], wind [9], [7] and moving scatterers [10] are identified as main contributors for the variations in the fixed wireless links for outdoor channels. Suzuki et al. [9] investigated the effect of wind speed on wireless broadband channels in urban and suburban environments. According to [11], a correlation between signal variation and local wind speed is observed in an outdoor-to-indoor link (suburban area) at 2.4 GHz. An increment in the signal variation during the day (08.00 am-08.00 pm) was also experienced.

Several researchers [8], [9], [7] have investigated how wireless channels behave under different weather conditions. According to literature, outdoor wireless channels experience temporal variations in the presence of vegetation and diverse weather conditions [12]. Rain and wind were found to be the major contributors which introduce temporal variations in outdoor wireless channels. Therefore, this paper investigates the effect of weather conditions on MUSA-MIMO-OFDM point-to-multi-point wireless broadband technology in rural areas.

The paper is organized according to the following order. Next section presents the experiment set up and the channel measurement procedure. The succeeding section provides measurement results and analysis of MUSA-MIMO-OFDM channels. Finally, the conclusions and future work are presented.

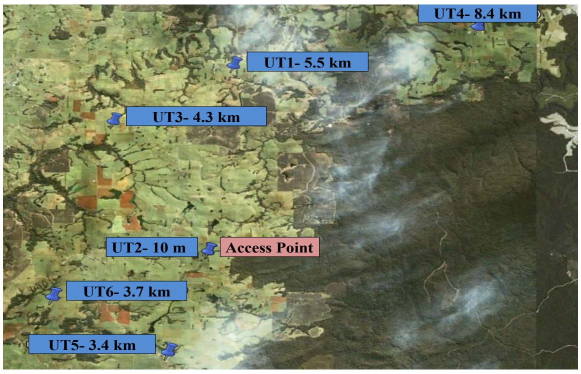

Figure 1. Relative position and distances between the AP and UTs [5]

Figure 2. AP array structure [5]

II. Experimental Set up

A MUSA-MIMO-OFDM hardware demonstrator has been developed by CSIRO and the experiment was conducted in a farmland region near Smithton in Tasmania, Australia [5]. A MIMO-OFDM uplink channel was established between six UT transmitting antennas and twelve AP receiving antennas. Figure 1 illustrates relative position and distance between the AP and UTs.

A. MUSA-MIMO-OFDM Uplink Channel

The system operated in one 7 MHz wide channel with 1705 occupied OFDM sub-carriers [5]. The centre frequency of operation was 641.5 MHz. At a given instant of time, 12x6x1705 channels were established between the AP and UTs, as 12 AP antennas, 6 UTs around the AP and 1705 occupied OFDM sub-carriers were established.

B. Channel Measurements

The MIMO-OFDM uplink channel data and weather data were collected during the field trial experiments. Approximately 30 GB of channel data were collected over 6 days. The sampling interval of the channel data was 5 s. Weather conditions at the AP were also recorded during the channel data collection time period. A Davis Vantage Pro2 weather station was used to record weather data. Receiver and weather station times were synchronized to ensure that both measurements were collected at the same time.

C. Access Point Antenna Array

The AP antenna array was installed on a transmission tower at 71 m from the ground. The antenna array is a 12 element uniform circular array with vertically polarized folded dipole antennas [5]. Twelve elements are placed on three layers with each layer supporting four antenna elements. The neighbouring layers are separated by approximately 40 cm to avoid antenna mutual coupling [3]. The AP antenna array structure is shown in Figure 2.

D. User Terminal Antenna

Six UTs are positioned at six farms around the transmission tower. The distances from UTs to AP ranged from 10 m to 8.4 km. At most UT sites, highly directional Yagi antennas were mounted at 9 m height and directed towards the AP [5]. UT2 was on a tripod about 1.5 m height from the AP. Each antenna has 9 elements, 11.5 dBi nominal gain and are vertically polarized. Figure 3(a) shows UT1 antenna directed towards the AP.

(a) UT antenna directed towards AP

(b) Weather station at AP

Figure 3. UT 1 and weather station

E. Weather Station

The weather station was mounted on a tripod and placed near the AP to measure weather conditions. Figure 3(b) shows the weather station at the measurement site. Wind speed, rain, humidity, barometric pressure, solar radiation and air density have been recorded in a data logger attached to the weather station. Weather Data was recorded at 60 seconds intervals and throughout the six days of the channel measurements including day time and night time. Weather data were recorded from 4:17 p.m. on day 1 to 9:29 a.m. on day 6.

III. MUSA-MIMO-OFDM Channel Measurements

A. Terrain Profile

In order to understand the channel condition, a digital elevation map (DEM) was used to analyze the terrain profile

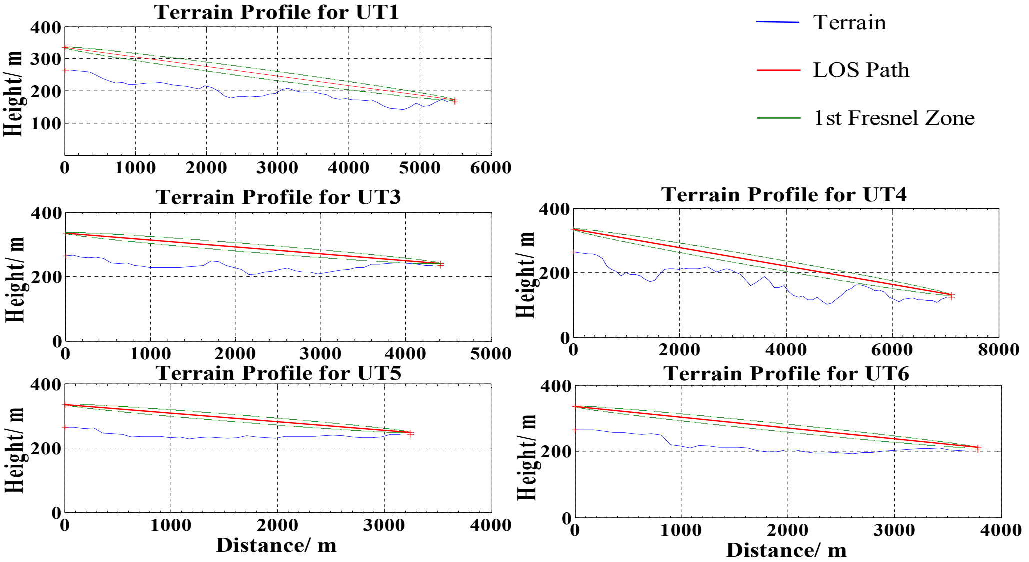

Figure 4. Terrain profiles between user terminals and access point

between the AP and each UT.

The best available DEM for the rural area under investigation is a 3 arc-seconds DEM obtained from the Shuttle Radar Topography Mission (SRTM3) version 2_1 elevation data [13]. A Matlab routine was developed to generate the terrain profiles for UTs around the AP. The curvature of the earth is not taken into account in this model as the distances of interest are small. According to Figure 4, the LOS path is not obstructed for any of the UTs around the AP. The terrain profile for UT2 was not included in Figure 4, as the length of UT2 link (10m) is smaller than the resolution of the DEM (90m).

B. Received Signal

According to the terrain profile analysis, the first Fresnel zone is not obstructed for any AP-UT antenna combination. However, the received signal experiences fading in both time and frequency. Figure 5 exhibits a sample snapshot of the measured channel for all AP-UT antenna combinations at 2:05:50 p.m. on day 2.

Each row represents a UT (1 to 6) and a column represents an AP antenna (1 to 12). Each subplot in the figure shows the relative received power in dB scale for the occupied 1705 OFDM subcarriers. The highlighted subplots show the antenna combinations experiencing strong frequency selective fading on that instant. The strongest frequency selective fading was recorded as -56.6 dB at AP2-UT2 for this instant. However, we note that this channel may not be typical for actual deployed system, as the UT2 was located only 10 m away from the ground of the transmission tower. The observations on dynamic range of relative power plots show variations, as high as -30dB in dynamic range.

C. Correlation between Relative Power and Weather Variables

In order to identify any correlation between the weather condition and channel relative power, the correlation coefficient (r) between the relative power and measured weather variables were calculated for all 12x6x1705 channel combinations. Figure 6 illustrates a sample plot of correlation coefficients between the relative power and measured weather variables for the AP antenna1-UT1 link for all OFDM subcarriers from 5:00 a.m.-6:00 a.m. on day 2. The correlation plot for rain is zero as no rain was experienced during this hour. Table 1 illustrates the mean correlation coefficient for all the subcarriers (μ_r) and the absolute maximum correlation coefficient $|r_{max}|$ for 5 hours in day 1 and 2. Also, it presents the average, mean correlation coefficient $\mu_{r(avg)}$ for all 5 hours.

Table I
Correlation coefficients for a 5 hour window

Weather Variables	Day1 (3 p.m.-4 p.m.)		Day2 (5a.m.-6 a.m)		Day2 (9a.m.-10a.m.)		Day2 (10a.m.-11a.m.)		Day2 (12p.m.-1p.m.)		5 Hour
	μ_r	$\lvert r_{max}\rvert$	μ_r	$\lvert r_{max}\rvert$	μ_r	$\lvert r_{max}\rvert$	μ_r	$\lvert r_{max}\rvert$	μ_r	$\lvert r_{max}\rvert$	$\mu_{r(avg)}$
Wind Speed	-0.16	0.21	-0.44	0.78	-0.64	0.65	-0.18	0.16	-0.33	0.16	-0.35
Rain	0	0	0	0	0	0	-0.14	0.2	0	0	N/A
Humidity	-0.13	0.17	-0.42	0.49	-0.44	0.48	-0.12	0.15	-0.32	0.15	-0.286
Air Density	0.23	0.28	-0.29	0.74	0.29	0.34	-0.23	0.28	-0.32	0.28	-0.064
Barometric Pressure	0.32	0.37	-0.44	0.77	0.36	0.41	-0.06	0.14	-0.25	0.14	-0.014
Solar Radiation	-0.14	0.17	-0.46	0.52	-0.55	0.59	0.02	0.08	0.22	0.08	-0.182

According to Table 1, wind speed records the highest negative μ_r (-0.64) at 9:00 a.m.-10:00 a.m. on day 2. Barometric pressure exhibits the lowest negative μ_r of -0.06 on day 2 at 10:00 a.m.-11:00 a.m. In general, the highest correlation coefficients were observed between 5:00-6:00 a.m. on day 2.

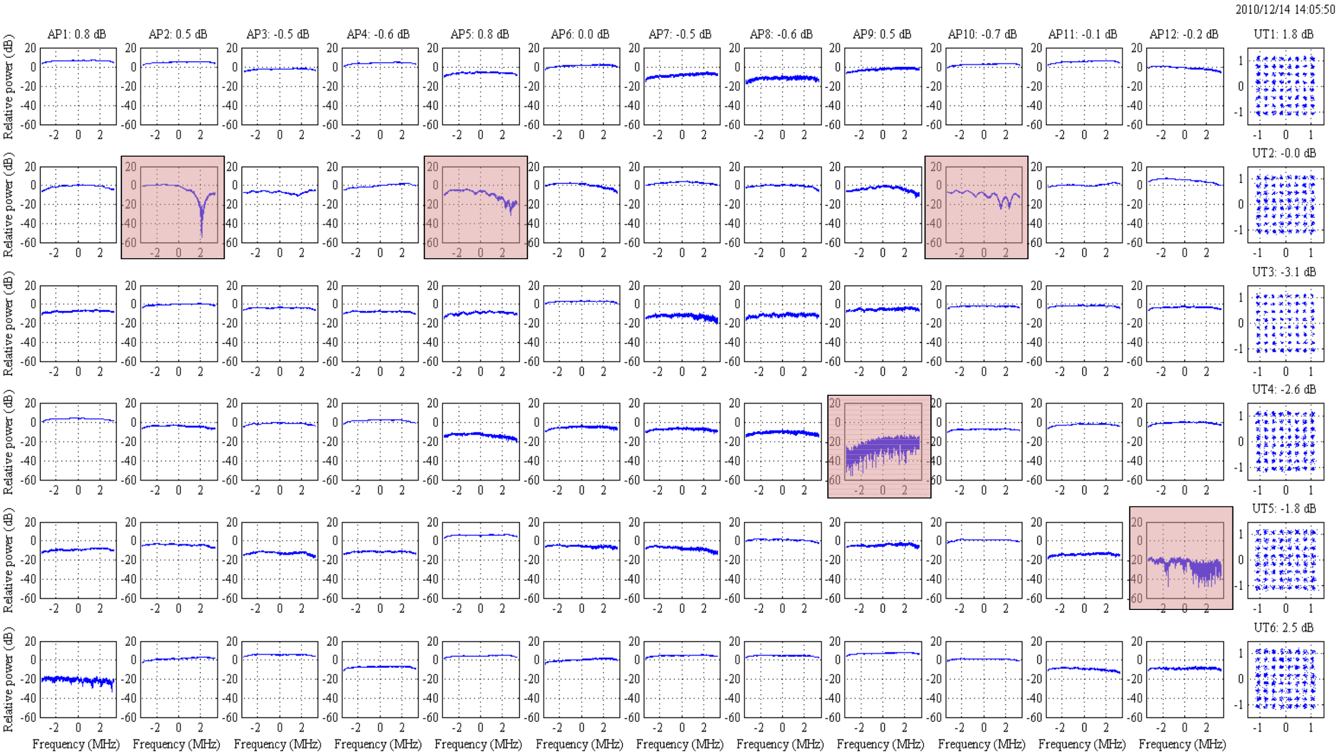

Figure 5. Snapshot of the channel

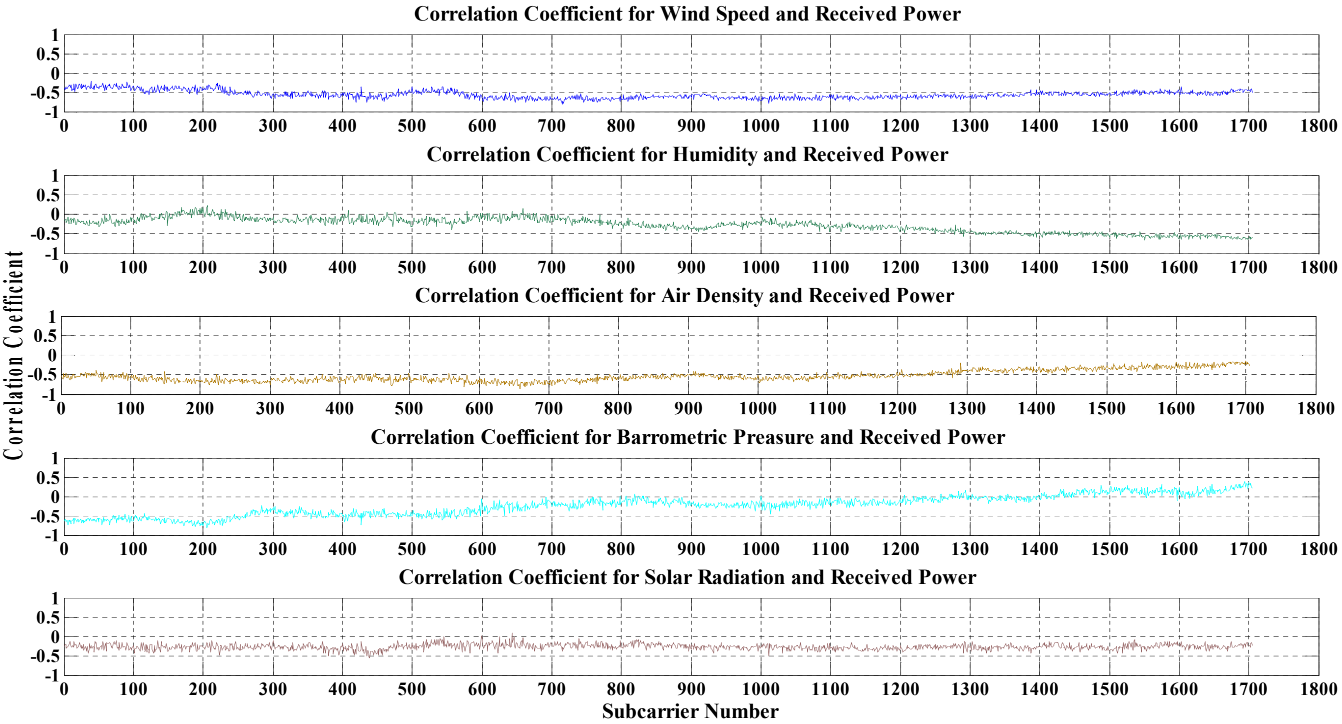

Figure 6. Correlation plot for UT1-AP1 link form 5.00 a.m.-6.00a.m. on day 2

For all 5 hours wind speed and humidity show a negative mean correlation coefficient, whereas air density, solar radiation, and barometric pressure show both negative and positive mean correlation coefficients. Therefore, air density, solar radiation, and barometric pressure appear to have a weak correlation with the received relative power. Rain was experienced only in one hour (Day 2 10:00 a.m. to 11:00 a.m.) during this 5 hour experiment window and recored μ_r as -0.14. However, more measurements under rain are needed to thoroughly analyze the effects of rain. Considering the overall average $\mu_{r(avg)}$ for 5 hours, wind speed has the highest negative correlation (-0.35) among these weather variables. After averaging μ_r for 5 hours, all these weather variables show a negative correlation with the received power. Therefore, the relative received power is influenced by wind speed at the vicinity of the receiver antenna of a MUSA-MIMO-OFDM link. The negative correlation measured between the relative received power and wind speed has to be considered when designing/planning the deployment of MUSA-MIMO in rural areas.

IV. Conclusions

This paper discusses the weather data collection and channel measurement experiments conducted in a rural environment (Tasmania, Australia) for the innovative MUSA-MIMO-OFDM uplink channels. Also, a terrain profile analysis for UTs around the AP is presented. According to the relative received signal, MUSA-MIMO-OFDM uplink channels experience temporal fading. The observations on dynamic range of relative power plots show variations, as high as -30dB in dynamic range. Moreover, correlation coefficients between the relative power and weather parameters are presented in this paper. All weather variables show a negative average correlation with received power for 5 hours. Wind speed has the highest average negative correlation coefficient of -0.35 for a 5 hour measurement window over two days. The maximum correlation coefficients were measured between 5:00-6:00 a.m. in the morning on day 2. During this time, the highest measured correlation coefficient of -0.78 was exhibited by wind speed. These effects of weather conditions in the received signal for a MUSA-MIMO-OFDM channels have to be taken into account when planning the deployment of MUSA-MIMO-OFDM systems to deliver high-speed wireless broadband services in rural areas. Further experimental data will be used to model MUSA-MIMO-OFDM channels in the rural environments.

V. Acknowledgments

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