Wireless Communication Performance Using Fabric Antennas

Summer 2013 Internship Report

Abhipray Sahoo

Electrical & Computer Engineering Department
Rice University
sahoo@rice.edu

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1 Introduction

Developments in wearable computing and e-Textiles have opened up possibilities of the integration of wireless functionality into clothes [1]. Being robust, light weight and flexible, fabric antennas are a step in that direction.

This report presents an experiment-based performance characterization of fabric fractal WiFi antennas developed at NASA Johnson Space Center. The main tests carried out evaluate the capacity, throughput and range achieved by the use of the fabric antennas. Additionally, qualitative assessment of the performance of the antennas as a function of flexure was made using image and video transmission. All of the tests were also performed on off-the-shelf whip antennas with loading coils as pictured in Figure 1(b).

The conclusion drawn from the characterization is that the fabric antennas and whip antennas have comparable performance at 2.452 GHz. The performance of wireless system using fabric antennas depended on the relative positioning of the fabric and in most positions, outperformed the system using whip antennas.

(a) Fabric antenna

(b) Whip antenna

Figure 1: Test antennas whose performance was evaluated

2 Preliminary Tests

2.1 Choosing the Performance Metric

Many common metrics, such as bit error rate(BER) vs signal to noise ratio (SNR), involve the accurate calculation of the average energy per bit to noise ratio (E_b/N_0). However, measuring the average energy per bit to noise ratio (E_b/N_0) in an experimental evaluation poses many difficulties since the noise can be multiplicative and/or additive and may depend on the receiver settings. For our purposes of comparing the test antennas (fabric against whip), it is sufficient to vary the transmission power and in effect, E_b. To evaluate the quality of signal transmission using the test antennas, we measured the Average RMS Error Vector Magnitude(EVM) as a function of transmission power.

2.2 Experiment setup

The experiment was carried out using the WARPLab framework [2] on two WARP [6] boards. The basic WARPLab setup was used– nodes connected to a PC running MATLAB via an ethernet switch. Both the nodes share the same clock helping correct carrier frequency offset problems without processing required in MATLAB. The packet used for the metric evaluation contained training data for channel estimation and a randomly generated vector of bits. For each packet, the baseband samples were modulated using 4-QAM, up-sampled using a square root raised cosine filter and up-converted (to avoid DC attenuation at radio interface) in MATLAB. A buffer in the WARP board stores the samples until a trigger command that initiate the transmission is sent. The receiving WARP node then forwards the received samples to MATLAB via ethernet. After training the received samples with the channel estimation data, downconversion, downsampling and demodulation of the received constellation, the RMS EVM and BER are calculated in MATLAB.

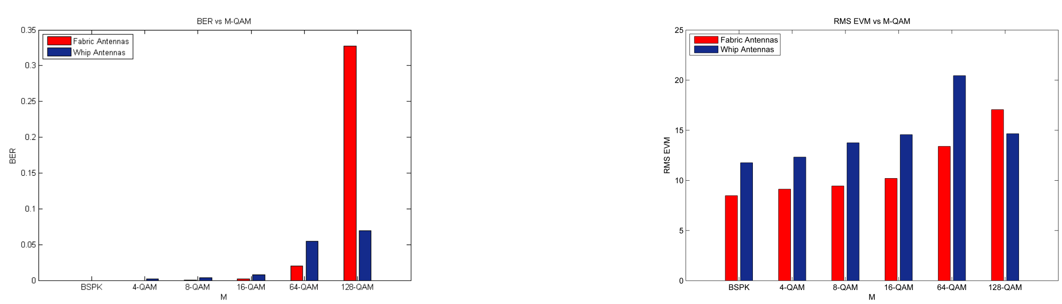
To vary the transmission power, we varied the RF gain setting on the Maxim MAX2829 transceiver on the WARP board. We then sent an appropriate number of packets each containing a random vector of bits at each RF gain setting and computed the average of the EVM and BER calculations. The RF Gain settings were converted to absolute Tx power dBm values using the plot of Tx Power Output vs RF Gain setting in the data sheet [4, p. 17] for the transceiver. The plot image was digitized, data points extracted and further approximated using polynomial curve fitting. The maximum gain of the power amplifier was taken to be 22 dBm.

One antenna of a single type (fabric or whip) was connected to each node, separated by 42 cm. The experiment was carried out for both fabric antennas and whip antennas. In the case of fabric antennas, two positions were analyzed–

- Position 1: Antennas facing each other, vertical to the surface on which they were kept
- Position 2: Antennas facing upwards, flat on the surface on which they were kept

2.3 Results

A test was made to observe the relationship between average RMS EVM and BER. The fabric antennas were kept in position 2. The average RMS EVM and BER were calculated as a function of 6 different modulation schemes at a constant transmitter RF gain. 300 packets, containing different number of bits depending on the modulation scheme (for example, 128-QAM packets contained 27223 bits) were transmitted to make the calculation on the receiving side.



(a) (b)

Figure 2: Average BER and average RMS EVM as a function of modulation scheme

As expected, for both antennas, performance deteriorates as order of modulation scheme increases. Reasons for this might also include the unequal number of bits transmitted to calculate the metrics– fewer bits for lower order scheme. More interesting for our purpose of comparing antennas is the similar performance of both whip and fabric antennas. RMS EVM and BER for whip antennas is on average lower than that for whip antennas at position 2. However, at 128-QAM, fabric antennas turn out to be far more resilient to bit errors.

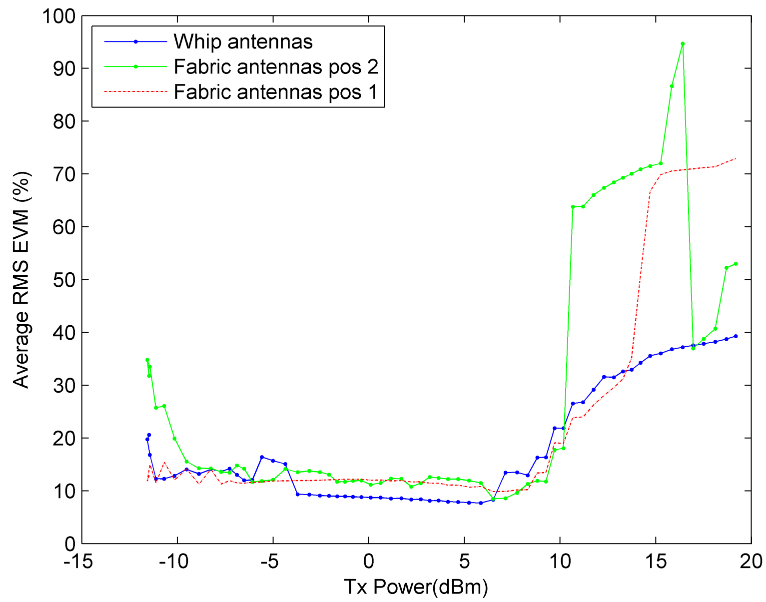


Figure 3: Average RMS EVM as a function of transmit power

The average RMS EVM as a function of transmission power is also computed for both antennas. In this test, it appears that the RMS EVM for whip antennas is least followed by fabric antennas in position 1 and position 2. Since EVM can also be considered a proxy for SNR, this shows that the SNR at the receiver for fabric antennas is worse than for whip antennas. An interesting feature in all three cases is the rapid increase of RMS EVM at around 7 dBm. This sudden increase in EVM might be happening at the receiver side. The plot of EVM vs Input power [4, p. 16] for the transceiver on the datasheet reveals a sudden increase in EVM from 10 dBm onwards (for this experiment the low noise amplifier was set to low gain).

3 Throughput and Range Test

3.1 Performance Metrics

To evaluate the performance of the antennas on a network level, the following metrics are used:

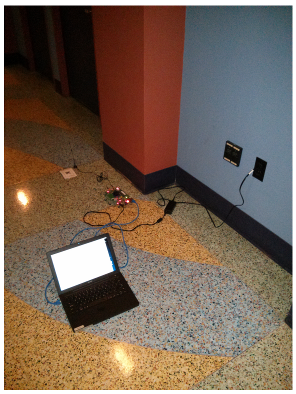
- Data bandwidth: The average rate of successful data transfer
- Jitter: packet delay variation
- Packet loss percentage

3.2 Experiment Setup

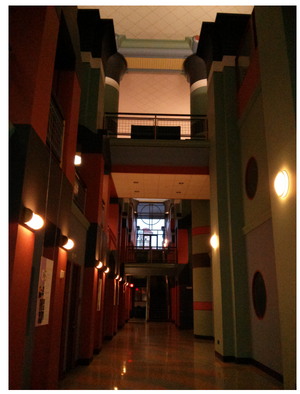
Two WARP nodes are programmed with OFDM physical layer and CSMA MAC layer and are each connected to a separate PC. To the PC, the WARP nodes appear as regular network interfaces. The software used to measure throughput is iPerf [5]. One of the nodes(PC and WARP board) is setup as a server and the other as a client.

Throughput measurements were made by sending 1470 byte UDP datagrams from client to server for appropriate durations of time and computing the metrics at the server end.

Initial testing was done with an antenna separation of 42 cm. The same throughput measurements were made for different values of antenna separation. The experiment was carried out in an open passage in Duncan Hall at Rice University, with the antennas in always placed in position 1 at line of sight of each other.



(a) Client node



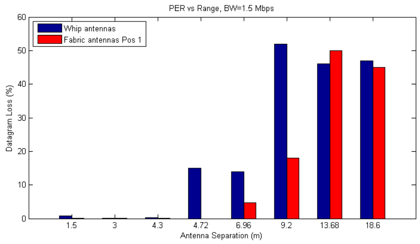
(b) Hallway where testing took place

Figure 4: Throughput Measurement Experiment Setup

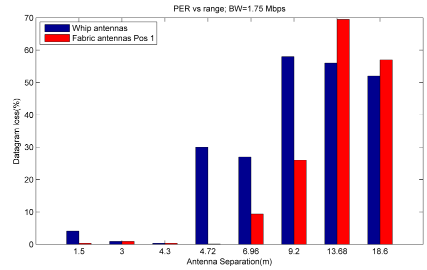
3.3 Results

From the throughput results, the fabric antennas in position 1, on average, perform better than the whip antennas in all three metric tests (bandwidth, jitter and datagram loss). As expected, the Packet Error Rate (PER) and jitter increase with increasing antenna separation. At some points, the PER or jitter might vary from the expected value, possibly due to reflections along the hallway. However, what is important is the comparison between the two sets of antennas at each position; the data collected shows visible improvement in throughput with the use of fabric antennas.

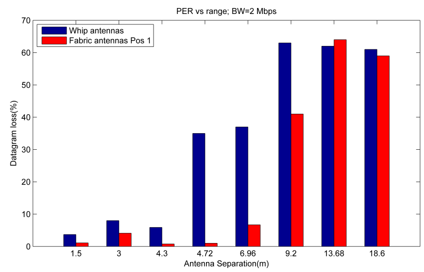
Between the two positions of fabric antennas, position 1 gives much better performance than position 2. This throughput performance supremacy of position 1 of fabric antennas suggests the directional nature if the fabric antennas; it has highest antenna gain in the direction perpendicular to the plane of the white side.



(a) UDP bandwidth set at 1.5 Mbps



(b) UDP bandwidth set at 1.75 Mbps



(c) UDP bandwidth set at 2 Mbps

Figure 5: Throughput performance against antenna separation

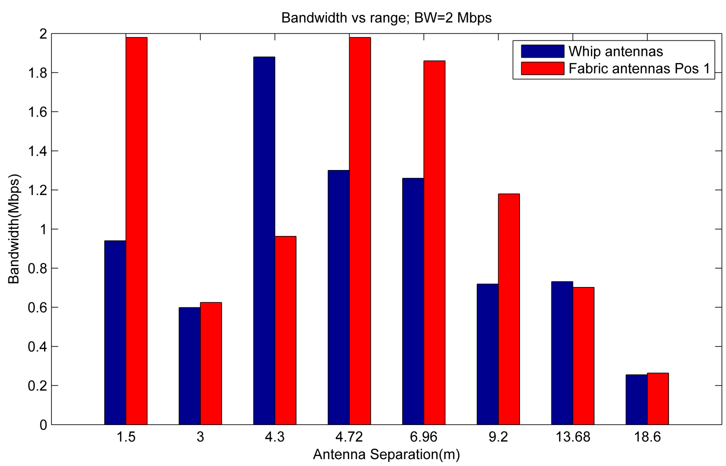


Figure 6: Actual bandwidth when UDP transmission bandwidth is set to 2 Mbps

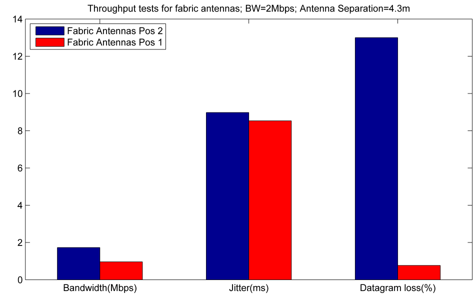
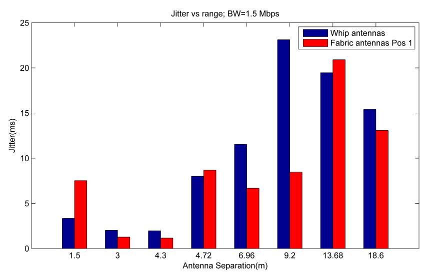
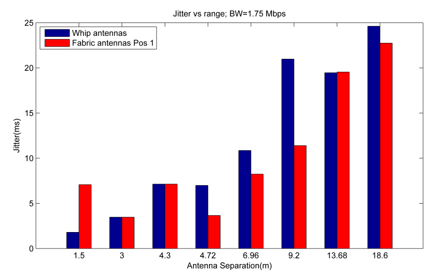


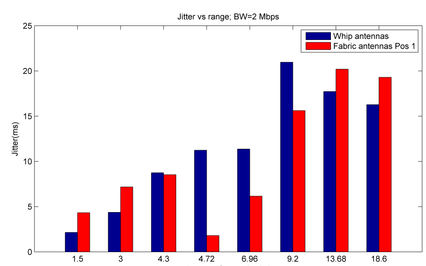
Figure 8: Throughput test for two positions of fabric antennas at constant antenna separation(4.3m) and UDP bandwidth(2Mbps)



(a) UDP bandwidth set at 1.5 Mbps



(b) UDP bandwidth set at 1.75 Mbps



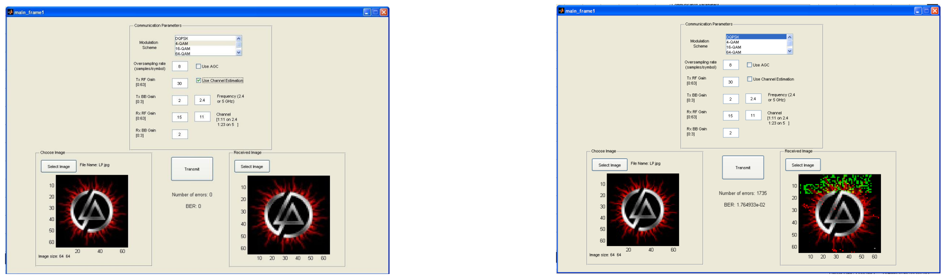
(c) UDP bandwidth set at 2 Mbps

Figure 7: Jitter against antenna separation

4 Qualitative assessment of effect of flexure

4.1 Image Transmission

To quickly evaluate the performance of the test antenna in conjunction with different communication system parameters, a graphical user interface(GUI) was developed. The GUI enables the user to quickly change modulation scheme, transmission power, automatic gain control (AGC), use of channel estimation, etc. and see the effect of these settings on data transmission. The data chosen to transmit is jpeg and png images since this would give a quick visual insight into the system's performance. The image data is converted to a single bit stream and split into transmission packets.



(a) Example with zero BER

(b) Example with non-zero BER

Figure 9: The Image Transmission GUI

4.2 Video Transmission

Using real-time video transmission, we could learn the qualitative effect of flexure and relative positioning of the fabric antennas. To achieve real-time video transmission, we connected two WARP nodes (hooked up to the test antennas) each to a PC. The WARP nodes were programmed with OFDM physical layer and CSMA MAC layer. The PCs each ran VLC media player, a software that enables UDP streaming.

4.3 Observations

The fabric antennas perform remarkably well under different positions. There is no noticeable drop in image/video quality with no bending of the antennas in many different relative positions at a separation of 20 cm. Noticeable image quality loss arises when the antennas are within a few centimeters from each other (likely the near-field region) and when completely folded in half. Performance is also poor when the gray side of the antenna face each other. During real-time video transmission, quick relative motion of antennas leads to lagging of the frames and poorer image quality but is not as prominent as when antennas are folded in half. Almost all other degrees of bending had no effect on performance.

5 Conclusion

Fabric antennas have been demonstrated here to possess similar electrical properties as off-the-shelf antennas. Compared to the test whip antennas, they even performed better in some positions. The throughput test results and EVM results summarize the performance advantage. For example, from the data collected for PER vs antenna separation at different UDP bandwidths, use of fabric antennas, on average, resulted in 46.87% less PER than whip antennas. The qualitative assessment using video and image data transmission showed the antennas' consistent performance at different degrees of flexure. The highly conformal property of these antennas could enable its easy integration into body worn systems or any other systems that require flexible antennas.

6 Acknowledgments

I would like to thank Dr. Ashutosh Sabharwal for supporting and giving me such a great opportunity to work on this project. This project would also have not been possible without the constant guidance and support of Jingwen Bai and Evan Everett.

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