Scalar Network Analysis of Wireless Channels Using IEEE 802.11g Transmissions

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***Abstract*— In this work we demonstrate the feasibility of scalar network analysis of wireless channels using an IEEE 802.11g waveform with a separate receiver. We explore the concept using a laboratory grade Orthogonal Frequency Division Multiplexing (OFDM) signal generator and spectrum analyzer. We also demonstrate the technique with field test equipment. All results are confirmed using a network analyzer. We find that utilizing field test equipment allows us to obtain valid channel responses and statistics.**

Keywords—channel characterization; scalar network analysis; IEEE 802.11g; OFDM.

I. Introduction

When the distance between transmitter and receiver is on the order of a few tens of meters, the complex channel response can be obtained with a microwave network analyzer. Indoor measurements taken using this method have been reported by various sources (see for example [1-4]). For larger distances, it is impractical to run cables from both antennas to the network analyzer. Two techniques that have been successfully used for channel characterization over larger distances are the transmission of short time-domain pulses [5] and the spread spectrum sliding correlator method [6]. The above techniques require relatively expensive equipment to implement, however.

As an alternative, we report the use of IEEE 802.11g packets to obtain the scalar channel response, using the configuration shown in Fig. 1. This technique does not require connecting cables and, when implemented with commercial IEEE 802.11g products and a portable field spectrum analyzer, can be relatively inexpensive.

Figure 1. Proposed measurement setup.

II. Signal Generator and Spectrum Analyzer Measurements

We used a Hewlett Packard E4433B ESG-D series signal generator to transmit IEEE 802.11g-like signals continuously into the channel, a 3m long, circular, metal ventilation duct with flat metal end caps. We chose this channel for its relatively long delay spread and narrow correlation bandwidth; we felt it would provide sufficient structure across the frequency band of interest to test the efficacy of the proposed measurement technique. Further, such an environment is fully enclosed and extremely static, allowing easy comparison of the measurement techniques. The received signal was recorded using a Hewlett Packard 8593E spectrum analyzer set to "max hold." To fully cover the frequency span from 2.4-2.5GHz, we incremented the center frequency of the transmitted signal by 8 MHz after each spectrum analyzer sweep. We then calibrated our channel characterization by repeating the measurement with the cables through-connected and dividing the measured channel magnitude by the magnitude of the cable response. Beyond the obvious correction to remove the distortion of the signal added by the cables, the calibration step also provided normalization of the received power to the transmitted power, giving the channel gain directly.

To verify that this channel characterization was valid, we used an Agilent E8358A network analyzer to measure the same channel, and we compared the results of the two measurements. Fig. 2 shows the frequency response of the channel as measured by the signal generator/spectrum analyzer combination and by the network analyzer. The mean error of the two measurements is 0.3765dB, and the mean-squared error is 12.08dB, indicating very good agreement between the two techniques.

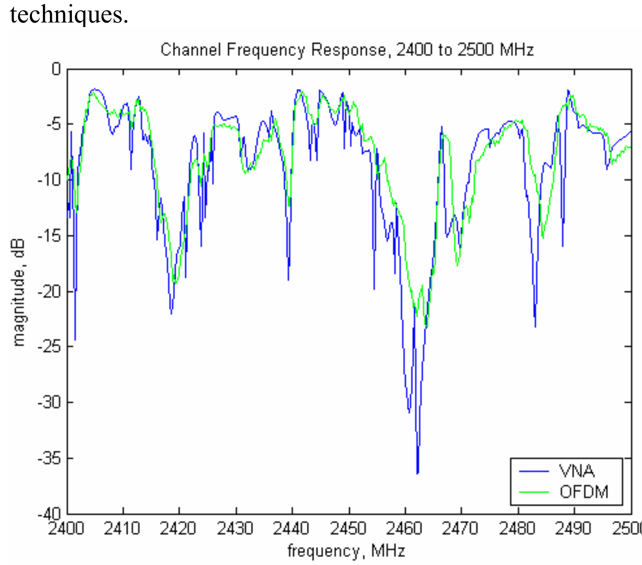

Figure 2. Magnitude response of channel.

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Fig. 3 shows the autocorrelations of the spectrum analyzer and the network analyzer channel measurements. The former yielded a 50% correlation bandwidth of 46.69MHz and a 90% correlation bandwidth of 3.063MHz. The latter yielded a 50% correlation bandwidth of 45.20MHz and a 90% correlation bandwidth of 2.22MHz. This demonstrates good agreement between the statistics of the measured channels.

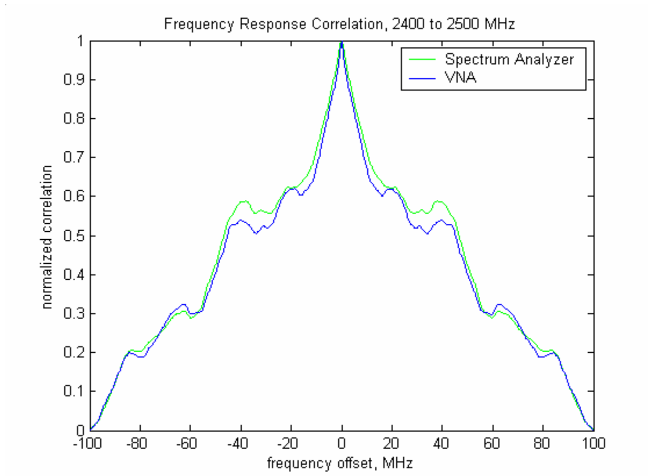

Figure 3. Autocorrelations of channel measurements.

III. YELLOWJACKET AND IEEE 802.11G MEASUREMENTS

To ensure this technique is feasible in a field test scenario, the following measurements were conducted using a Linksys IEEE 802.11g access point (AP) as a signal source and a handheld signal analyzer designed for use in the 2.4 GHz ISM band as a receiver. The signal analyzer was a YellowJacket made by Berkeley Varitronics. The YellowJacket has a spectrum analyzer mode which provides 64 points across a 22 MHz bandwidth centered at any of the 14 channels in the frequency band used by the IEEE 802.11 standard. The analyzer is capable of recording approximately 10 signal sweeps per second. To provide data for the AP to transmit, pings with maximum-sized payloads were sent continuously to the subnet broadcast IP address. The YellowJacket was used to capture the spectrum of IEEE 802.11g signals over a two minute period. The captured spectrum was averaged over all sweeps that had an average power level above the noise floor (to disregard sweeps taken during times between packet transmissions).

Before measuring an actual channel, an ideal reference sweep measurement was taken via a direct cable connection from AP to signal analyzer with sufficient attenuation to place the received signal in the measurable range of the signal analyzer. The multiple sweep averaging technique described above was repeated, and the resulting reference sweep is shown in Fig. 4. As seen in the figure, only the middle portion of the OFDM signal (between the vertical bars) is used in order to ensure that there is no significant loss in the dynamic range of the measurement. This reference sweep is then subtracted from measured channels to remove the inherent spectral shape of the OFDM signal.

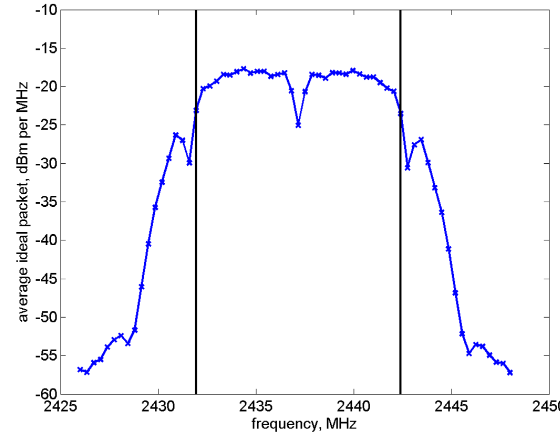

Figure 4. Average measured spectrum response of IEEE 802.11g packets using a YellowJacket signal analyzer.

Measurements of six different channels were taken using a network analyzer and the IEEE 802.11g AP and signal analyzer. The channels measured were resonant metal duct networks, which were static over the duration of the measurements. Fig. 5 shows the six measurements. As can be seen, there is good agreement in the curves of all six cases.

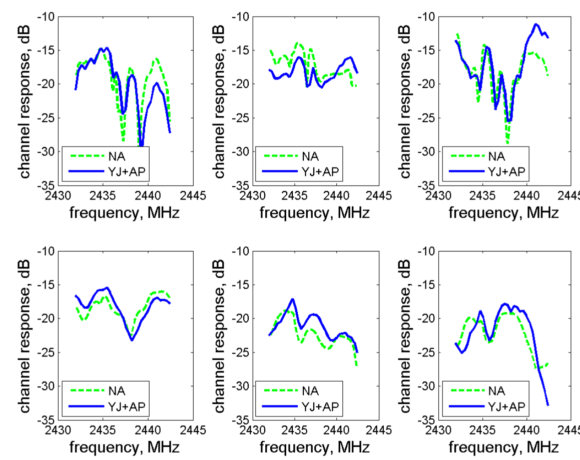

Figure 5. Comparison of network analyzer (NA) based and AP to YellowJacket (YJ+AP) based measurement techniques for six different measurement cases.

IV. ADDITIONAL MEASUREMENTS

To extend the previous measurements and measure a wider bandwidth in a more generic wireless channel, we applied the same technique used in the previous section to a measurement in a cluttered room. The layout of the room is show in Fig. 6. In these measurements, the same AP was used at the TX location, but an inexpensive handheld spectrum analyzer, the Anritsu MS2711b, was used to record the response at the RX location. The AP was configured for "g only" mode. Since the measurements were made in a quasi-controlled environment, some automation was used to allow each measurement to be made without user intervention. To decrease the time required for a measurement to be made and to allow an automated measurement, the AP was set to transmit beacons at very frequent intervals (once every 1.024 milliseconds instead of the default 102.4 milliseconds). Additionally, a Perl script on a computer connected to the AP via an Ethernet cable was used to automatically switch to the next IEEE 802.11g channel every 10 seconds, beginning at 1 and ending at 13. The spectrum analyzer was set to "max hold" and a fairly slow sweep time of 2.87 seconds to ensure a low noise floor and to capture a large number of packets from each of the 13 channels. As in the previous sections, a measurement with the AP cabled directly to the spectrum analyzer was also used to remove the response of the cable and to measure the expected shape of the IEEE 802.11g packets. For comparison the measurement was also repeated with the network analyzer. Since the two measurements to be compared were made at different times, every effort was made to perform the measurements when no people were present and without changing any aspect of the environment.

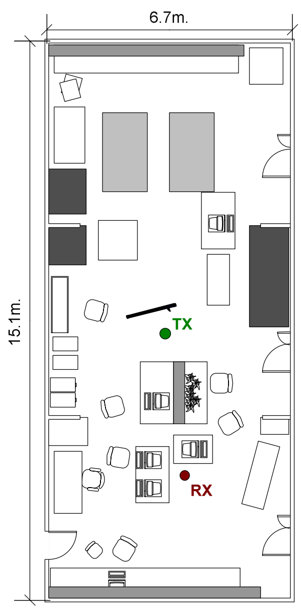

Figure 6. Layout of room for measurement

The measured frequency response is shown in Fig. 7. The figure shows the response over the 2.4 to 2.4835 GHz ISM band. As can be seen from the figure, the general trend of the measurements shows good agreement, considering the measurements were made several minutes apart. In addition, the point-by-point average difference of the responses is about 1.36 dB with a mean-squared error of 19 dB. The errors toward the edges of the frequency range are due to the lack of transmitted power by IEEE 802.11g packets at these frequencies. Additionally, the sharp null is missed by the spectrum analyzer due to a higher noise floor than that of the network analyzer.

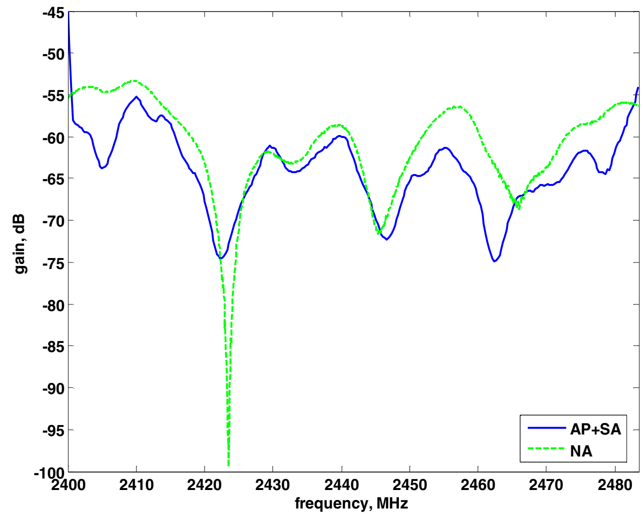

Figure 7. Measured channel respoinse in large room

It should be noted that this measurement technique could be further improved by running the channel changing script directly on the AP, running the script on a computer with a beaconing wireless card or using several IEEE 802.11g devices operating on different channels. In addition, it is not necessary to use all 13 of the channels to measure the full frequency response because the channels overlap significantly. Experimentation indicated that every 2nd or 3rd channel could be used. These techniques should enable the AP to sweep the 2.4 to 2.4835 GHz frequency range in just a few sweeps of a spectrum analyzer. Thus, feedback could be available to a user looking directly at the spectrum analyzer with minimal delay.

V. EVALUATION OF TECHNIQUE

This method has several advantages over other channel characterization techniques in that it does not require reference cables and can be implemented with equipment that is both relatively inexpensive and easy to acquire. This allows for measurements to be made over distances or in areas where running cables would be impractical as well as in instances when budget limitations do not allow for more expensive equipment such as a network analyzer.

In comparing measurements made using IEEE 802.11g packets and measurements made using a network analyzer, one notes that this method can only provide scalar channel data, which can be somewhat limiting. Also, while the data from the spectrum analyzer was very similar to that of the network analyzer, with similar statistics, it was not exactly the same: some allowance for error has to be made when making measurements with this method.

Perhaps the most limiting factor in using IEEE 802.11g packets and a spectrum analyzer to measure a channel is in the sweep time. Although it could be made somewhat faster than our implementation, it is still slower than other comparable measurements, making it less useful for finding the instantaneous measurement of a dynamic channel. It could still be of use for finding aggregate channel responses.

VI. CONCLUSION

We have shown that IEEE 802.11g signals can be used quite effectively to measure channel frequency responses. OFDM is particularly well-suited to this kind of application, due to its flatness in spectral shape; however, other waveforms could theoretically be used, allowing measurements to be made with any available transmitter. This, in addition to the relatively low cost of implementation, makes this technique an attractive field measurement technique.

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