Comparison of QPSK and 64QAM EVM for an OFDM WLAN Signal at 2.4 GHz and 4.9 GHz in a Multipath Environment*

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Introduction

As discussed in [1], error vector magnitude (EVM) is a standard figure of merit for assessing the quality of digitally-modulated telecommunication signals. EVM expresses the difference between the normalized magnitude and phase of an ideal symbol and a demodulated symbol. McKinley *et al*. showed analytically in [2] that when symbols of the received signal are normalized such that their mean-square value equals one, a consistent value for EVM can be calculated in static, linear environments, irrespective of modulation type.

In this work, we verify experimentally the consistency of EVM across modulation types of orthogonal frequency-division multiplexed (OFDM) wireless local-area network (WLAN) signals in two dedicated laboratory setups. We compared EVMs obtained for different modulation types in both an idealized distortion-free and a realistic multipath environment. Our goal is to study the effect of signal impairments on the constellation diagram through EVM, although other figures of merit, such as bit-error rate (BER) or energy-per-bit to spectral-noise density (E_b/N_o), could be studied as well.

Lab Setup and Measurements

Measurement repeatability is needed to compare EVMs across modulation types. We accomplished this with two linear time-invariant set-ups, in which we tested the effects of simple channel distortion on EVM for different modulation types: bipolar phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), 16-symbol quadrature amplitude modulation (16QAM), and 64-symbol quadrature amplitude modulation (64QAM).

Fig. 1 gives a block diagram of these setups. We used a vector signal generator to modulate signals as specified in the IEEE 802.11a™ Standard [3]. Our carrier frequency was 4.95 GHz, as is used in public-safety applications. These signals were downconverted to 1 GHz and then sent to the vector signal analyzer (VSA). In Fig. 1(a), a cable connects the signal generator to the receiver. This is a low-distortion, best-case scenario. In Fig. 1(b), a power divider splits the signal: one path has a cable, and the other has an impedance tuner to increase the EVM by introducing phase and impedance-mismatch distortion.

Fig. 2 shows that, although the EVM changed from less than 1 % to about 1.7 % between the two set-ups, the EVM variation between modulation types for each set-up was less than 0.05 %. The average symbol power for each data point received by the VSA was about 1.77 μW for the low-distortion case and about 28.5 nW for the high-distortion case. Thus, the experiment indicates that a linear time-invariant channel will give the same EVM for the same average symbol power, independent of the modulation type used. This shows why a simpler modulation type, such as QPSK, is preferred over a more complicated modulation type, such as 64QAM, when characterizing a difficult propagation environment.

Multipath Setup and Measurements

In the previous section, we had two well controlled, low-distortion environments, and different OFDM modulation types gave the same EVM within each. In this section, we examined a less controlled, free-field environment with higher distortion: multipath. Multipath channels are often time-varying. As such, they change stochastically between measurements, making it next to impossible to directly compare EVM values for different modulation types. Consequently, in this work, we study a static multipath case.

One method to make a time-variant channel static is to acquire sequential signals before the channel changes [4]. An 802.11a-based system uses this method when pilot subcarriers immediately precede data subcarriers [3]. We used a second method that stabilizes the multipath over a period of time. Fig. 3 diagrams the multipath environment used. As in Fig. 1, we used the signal generator in combination with a downconverter cascaded with a VSA. In addition, to transmit signals down a 26 m tunnel, we used an amplifier and directional antenna, with a gain of 9.3 dBi at 2.4 GHz and 10.6 dBi at 5.2 GHz, as determined by measurements made at NIST. This focused the signal down the tunnel and limited multipath effects to the tunnel and the room containing the directional receiving antenna. We set the receiving antenna to eliminate any line-of-sight path with the transmitter. We rotated the receiving directional antenna from 0 to 330° in 15-30° steps while measuring the EVM at each position. Because we used directional antennas having beamwidths on the order of a few tens of degrees, for each measurement, we acquired only a limited amount of the total scattering in the room. This provided a range of multipath values for our EVM study. We focused on eliminating the effects of antenna movement, and any other movement, in the room during the measurements.

In this experiment, we compared two different OFDM modulation types: QPSK and 64QAM. We took three EVM measurements for each modulation type at each antenna position and angle. The maximum standard deviation of the three measurements for EVM values below 10 % was 1.96 % at 2.412 GHz and 1.81 % at 4.95 GHz. Figs. 4 and 5 display EVM points that are less than or equal to 10 % for the two positions shown in Fig. 3 at 2.412 GHz and 4.95 GHz. For EVM values above several percent, most receivers would lose synchronization, so these values have been omitted. As indicated by the spread of some EVM data points in Figs. 4 and 5, repeatability was difficult for high EVM levels. However, our repeatability was sufficient to indicate that this was a static multipath environment.

Conclusions

Theoretically, EVM is the same for all modulation types if the channel, transmitter, and receiver are static, the signal power remains constant, and normalization is used such that the mean-square value over all symbols is unity. We confirmed this experimentally in low- and medium-distortion linear, time-invariant environments. Furthermore, we showed that in a static multipath environment, the EVM levels for QPSK and 64QAM modulations agree to within 1 % to 3 % when the EVM value is less than 10 %. This implies that the EVM for QPSK modulation could predict the EVM for a 64QAM modulated signal.

Acknowledgement
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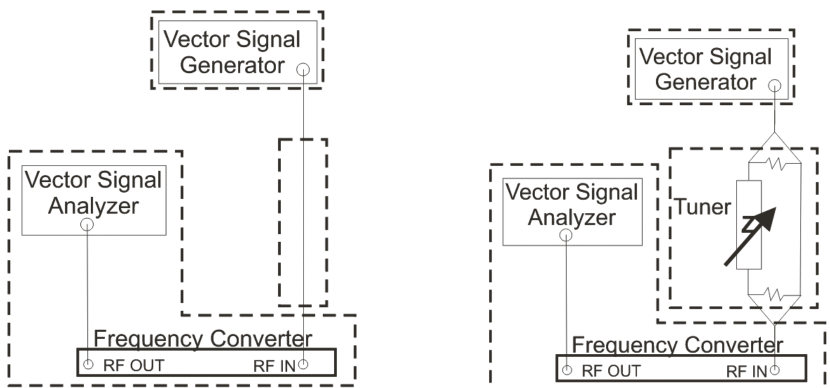

(a) (b)

Fig. 1: Lab setup for low-distortion (left) and medium-distortion (right) cases.

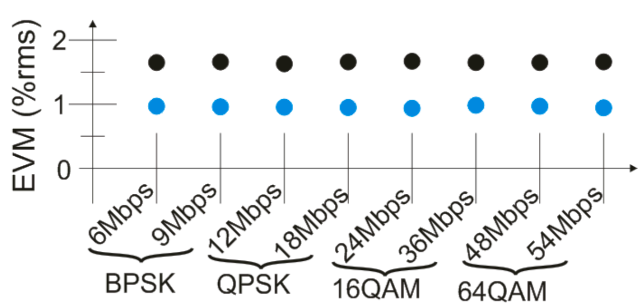

Fig. 2: EVM for the modulation types used in the 802.11a Standard for a low-distortion case (blue) and a medium-distortion case (black).

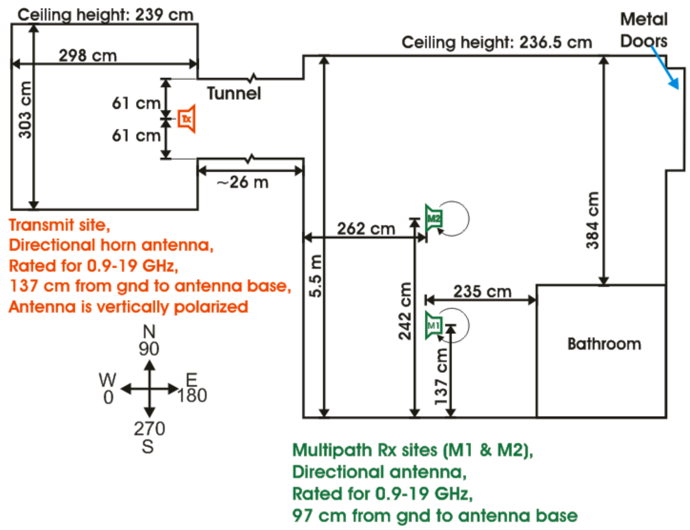

Fig. 3: Diagram of multipath environment for multipath measurements.

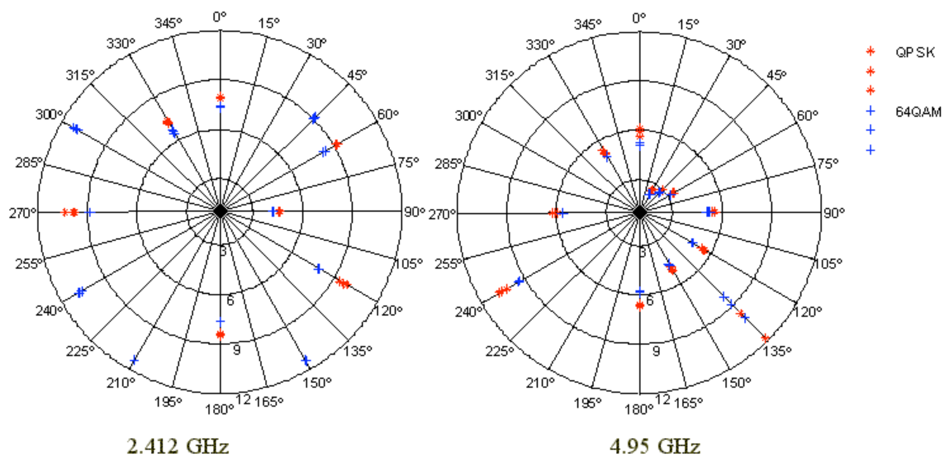

Fig. 4: Rx position M1 (closest to wall) EVM results for QPSK and 64QAM at 2.412 GHz and 4.95 GHz. The radial scale is percent EVM.

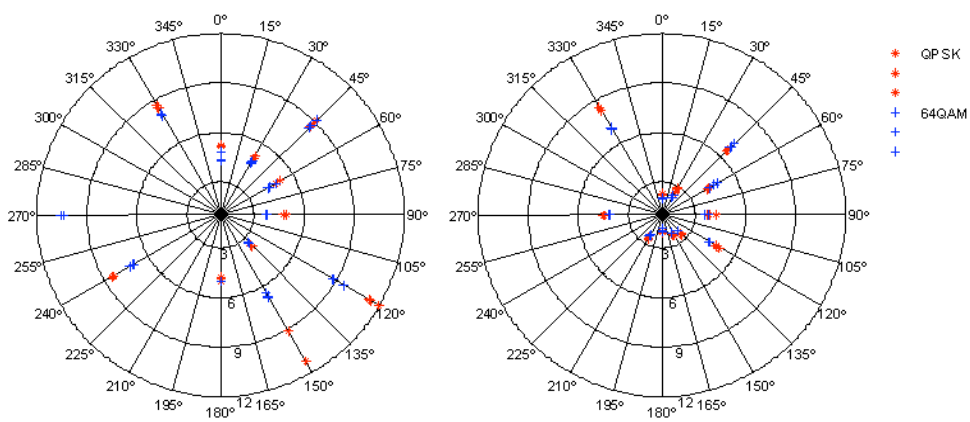

Fig. 5: Rx position M2 (closest to tunnel) EVM results for QPSK and 64QAM at 2.412 GHz and 4.95 GHz. The radial scale is percent EVM.