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Evaluating WLAN Design Tradeoffs Using Circuit and System Simulation

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This article presents an example of how simulation of a WLAN system can be used to evaluate the effects of circuit design on overall system BER and PER performance

Wireless Local Area Network (WLAN) represents one of the technologies with huge potential global markets for office and household data transmission, portable and mobile terminals, laptops and industrial applications. With WLAN the user can utilize wireless connection to the Internet at home or in airports, hotels, trains, conference centers and so on. Even in a small office, a cable infrastructure for a wired local network can represent significant inconvenience, while a WLAN-based system is flexible and very fast to set up, extend and modify.

WLAN Simulation

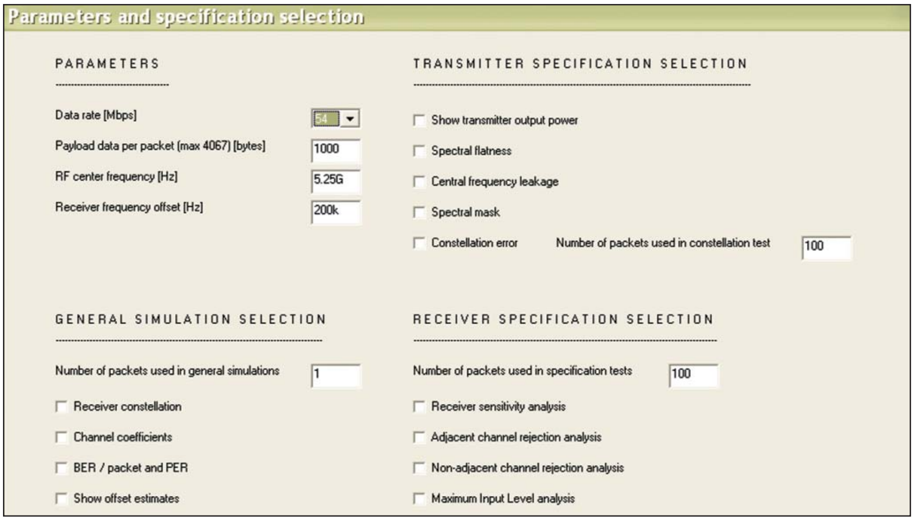
WLAN has become essentially a synonym for the technology defined in IEEE standard 802.11, also called Wi-Fi. APLAC System Simulator provides modeling and simulation capabilities for the physical layer of WLAN, as defined in 802.11a and 802.11b, including signal generation in baseband, RF parts and radio channel.

WLAN is based on OFDM (Orthogonal Frequency Division Multiplexing) with 52 parallel subcarriers. The different data rates are realized through different baseband modulation schemes and different coding rates. A noisy channel requires robust modulation and heavy coding, resulting in low data rate, while under low-noise conditions the situation is the opposite. Supported data rates vary between 6 Mbps and 54 Mbps in the “a” standard, and 1 to 11 Mbps in the “b” standard.

In WLAN, data is transmitted as packets with predefined length. In APLAC’s WLAN module, each detail of the packet is appropriately modeled. The user selects the data rate and the message, then the corresponding baseband signal is created as it would in a real system. Appropriate scrambling, encoding and interleaving procedures are modeled, as well as their inverse counterparts in the receiver to allow realistic BER (Bit Error Rate) and PER (Packet Error Rate) performance measurements of the system.

There are several issues that one may want to simulate in a WLAN system. For sure, one ultimate goal is to meet specifications and to be able to optimize the RF section for best performance. With APLAC WLAN module, a system designer can easily evaluate system performance with respect to such characteristics as QA-modulator noise and imbalance, filters, PA nonlinearity, radio channel, LNA and so on. APLAC supports the creation of customized test benches, and a specification-oriented user interface for the WLAN system evaluation has been developed. This test bench is available from www.aplac.com, in the “downloads” section.

In the “Parameters and specification selection” form (Figure 1) the user sets the data rate, the amount of payload data, RF center frequency, and an optional frequency offset of the receiver. The offset is an interesting parameter, as the system must deal with at least a couple of tens of kHz offset. As many specifications involve PER, the user sets also the number of packets to be transmitted. The transmitter output power, spectral flatness, central frequency leakage, spectral mask and constellation error are all subject to specifica-



Parameters and specification selection

PARAMETERS

Data rate [Mbps] 54
Payload data per packet (max 4067) [bytes] 1000
RF center frequency [Hz] 5.25G
Receiver frequency offset [Hz] 200k

TRANSMITTER SPECIFICATION SELECTION

☐ Show transmitter output power
☐ Spectral flatness
☐ Central frequency leakage
☐ Spectral mask
☐ Constellation error   Number of packets used in constellation test 100

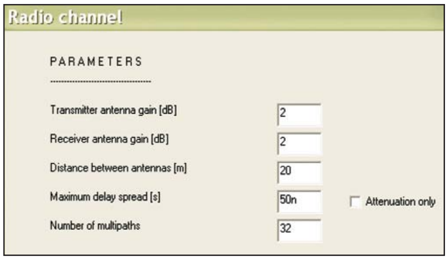
GENERAL SIMULATION SELECTION

Number of packets used in general simulations 1
☐ Receiver constellation
☐ Channel coefficients
☐ BER / packet and PER
☐ Show offset estimates

RECEIVER SPECIFICATION SELECTION

Number of packets used in specification tests 100
☐ Receiver sensitivity analysis
☐ Adjacent channel rejection analysis
☐ Non-adjacent channel rejection analysis
☐ Maximum Input Level analysis

Figure 1 · Parameter setting and specification selection form.



Radio channel

PARAMETERS

Transmitter antenna gain [dB] 2
Receiver antenna gain [dB] 2
Distance between antennas [m] 20
Maximum delay spread [s] 50n   ☐ Attenuation only
Number of multipaths 32

Figure 2 · The radio channel can be defined through physical parameters like antenna gains and path distance.

tion limitation, and any combination of them can be chosen to be tested. Similarly, for the receiver, one can test the sensitivity, adjacent channel rejection, non-adjacent channel rejection and maximum input level tolerance, as they are specified in the 802.11a standard.

In the "Radio channel" form (Figure 2), one specifies the radio channel through transmitter and receiver antenna gains, distance between antennas, maximum delay spread, and number of multipath components assumed. The corresponding channel is modeled as a multipath channel, with the reflected waves having random phase and exponentially decaying amplitude on the average, varying the amplitude of each reflection from packet to packet according to a Rayleigh distribution. Alternatively, one can choose attenuation only, which is determined from the antenna gains and frequency.

With this setup, WLAN system evaluation is easy. The designer needs just to parameterize the RF parts, and perform the specification tests. APLAC gives a report after the simulation about the passed/failed tests, which makes identification of problems straightforward.

As an example, let us consider evaluation of this WLAN system:

Transmitter:

- LO phase noise –110dBc/Hz @ 100 kHz offset; noise floor –174 dBc/Hz
- Upconversion mixers in transmitter QA-modulator: gain 22 dB; NF 20 dB; IIP3 = 10 dBm
- Tolerance against IQ imbalance in gain and phase are to be studied
- Transmitter PA: gain 5 dB; NF 10 dB; 1 dB input compression point 15 dBm
- The baseband signal from the DSP is assumed to be sample-and-hold type waveform with significant mirror images. It is oversampled by 4x in order to move the images further away and to make the filtering easier. The filter in front of the QA-modulator is a first-order 10 MHz LPF.

Channel:

- 2 dB transmitter and receiver antenna gains
- 5.25 GHz center frequency
- Distance between antennas 20 m
- Only attenuation is taken into account first (no multipath propagation)

Receiver:

- LO phase noise –110 dBc/Hz @ 100kHz offset; noise floor –174 dBc/Hz
- 1st order BPF with 20 MHz BW in the receiver antenna input
- LNA NF 1 dB; gain 13 dB
- Demodulation mixers: gain 10 dB; NF 1 dB
- 5th order Butterworth 20 MHz LPFs, followed by:
- Amplifier with 20 dB gain; 5 dB NF
- Tolerance against frequency offset to be studied

Thus, we have three parameters to be studied: gaindiff, phasediff and offset. We start by running a simulation with gaindiff=phasediff=offset=0. We select all specifications to be tested at 54 Mbps data rate. Initially, it is recommended to use small payload in receiver specification simulations, say 100 bytes. This speeds up the evaluation, yet reveals the problems. In the end one should test with 1,000 bytes per packet.

It turns out that with the RF section defined above, the transmitter spectral mask is slightly violated, as is evident from Figure 3. Transmitter spectral flatness, central frequency leakage and constellation error are all passed.

From the results report we also notice that the receiver sensitivity test (sensitivity limit = –65 dBm) corresponds to 48 m distance between the antennas. Similarly, for adjacent and non-adjacent channel rejection tests, the desired signal level is –62 dBm corresponding to 33 m distance. Thus, the intended usage within 20 m is safe in terms of sensitivity limits. Putting it differently, there is the option to use less transmit power if

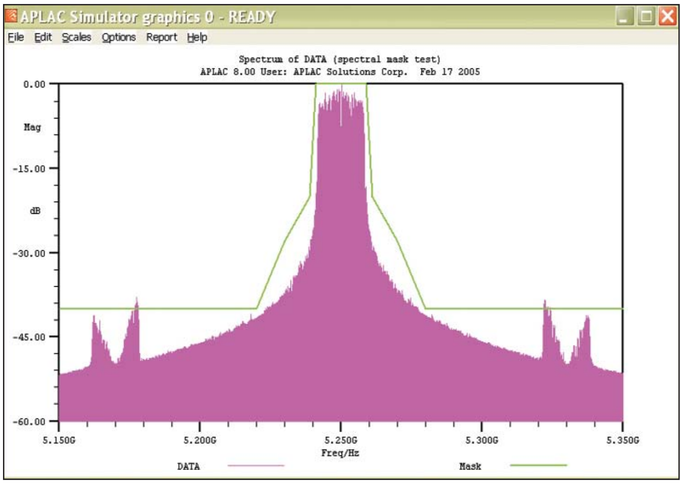


Figure 3 · Transmitter signal spectrum and spectral mask specification.

necessary, and this way tradeoff with the linearity requirement of the PA.

It turns out that NACR specification is severely violated. The performance improves by selecting 2nd order baseband filter in the transmitter, then reducing transmitter mixer NF from 20 dB to 12 dB, and selecting receiver baseband filter bandwidth as 17 MHz instead of 20 MHz and increasing its order from 5 to 6. After these modifications, the PER is around 2-5%. Looking at the report in detail reveals that in the failed packets usually just a few bits were missed. Nevertheless, only the CRC-check counts, so a single bit failure leads to failure of the whole packet. With this correction, all receiver specifications are met. At the same time, however, the spectral flatness specification is violated. Tuning transmitter filter bandwidth and improving transmitter PA linearity and noise clears the case—but now receiver ACR is violated! It soon turns out that transmitter spectral flatness and mask are conflicting goals, and fine-tuning transmitter filter has pronounced effect to the ACR. Therefore, as a solution, one has to increase the transmitter filter order to three.

Finally, the following RF parameters result in a WLAN system that satisfies the specifications:

Transmitter:
- Filter: 3rd order Butterworth 10 MHz LPF
- Upconversion mixers: gain 22 dB; NF 12 dB; IIP3 10 dBm
- Transmitter PA: gain 5 dB; NF 5 dB; ICP 25 dBm

Receiver:
- 1st order BPF with 20 MHz BW in the receiver antenna input
- LNA: gain 13 dB; NF 1 dB
- Demodulation mixers: gain 10 dB; NF 1 dB
- 6th order Butterworth 17 MHz LPFs
- Baseband amplifier: gain 20 dB; NF 5 dB

Now, we are in a position to study the transmitter imperfections (amplitude and phase imbalance, frequency offset). The frequency accuracy specification for the LO is 20 ppm, so at 5 GHz roughly 100 kHz offset is possible. To find acceptable limits for each of these imperfections we first try one parameter at a time, and finally evaluate “corners” to find safe independent limits for the parameters.

Amplitude and phase imbalances greatly affect the constellation error, by stretching and tilting the constellation. The criteria are especially strict for high data rates, therefore, the QA modulator should be designed with excellent symmetry. For the frequency offset, the specification defines a detection and derotation process for the receiver DSP. When this process is done efficiently, any offset less than 200 kHz will cause little trouble.

Results of the study:
- Amplitude imbalance: 0.1 dB is tolerable. For 24 Mbps, 0.3 dB is tolerable.
- Phase imbalance: 0.4 degrees is tolerable. For 24 Mbps, 2 degrees is tolerable.
- Frequency offset: 200 kHz offset is tolerable

Summarizing, according to the simulations, a WLAN system whose RF parts meet the specifications discussed above, will meet 802.11a specifications for all supported data rates (6 to 54 Mbps) over at least 30 m distance, given the transmitter and receiver antennas have 2 dB gain and there is no significant multipath propagation involved. Emulating an office environment and taking the multipath propagation into account with a maximum of 50 ns delay spread affects mostly the ACR and NACR, increasing the PER to about 20-25% (averaged over a variety of momentary multipath environments—during one packet the channel is assumed stationary).

The system evaluation and specification is very easy and straightforward with the test bench available for APLAC system simulator and WLAN module (WLAN80211a_transceiver_spex_channel.n), downloadable at www.aplac.com downloads section.

Author Information

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