Wireless local-area network planners and consumers now have the option to choose between 2.4-GHz (802.11b) and 5-GHz (802.11a) technologies for their network designs. Unfortunately, the information that has been available to date has left many confused and misinformed about the actual performance and network capacity of each.

A thorough analysis of the performance of both 802.11b and 802.11a products in common network deployments can help alleviate the confusion and help readers make an informed choice. The analysis will use published information, published data and the system performance parameters readily available from the Federal Communications Commission (FCC), International Telecommunications Union (ITU) and the Institute for Electrical and Electronic Engineers (IEEE).

Two recently published papers compare the network capacity of 802.11a and 802.11b WLANs. One paper concluded that 802.11b networks offer superior performance to 802.11a, but it only arrives at that conclusion after assuming that all 802.11a solutions transmit at 15 dBm—which isn’t an accurate assumption. The second paper shows clear network capacity advantages of 802.11a over 802.11b; however, the analysis is based upon a system that does not meet the full specifications of 802.11a, so the paper does not provide a truly accurate representation of the full performance of optimized 802.11a systems.

This article assesses the network capacity of wireless LANs by first looking at the network capacity offered by current 802.11a solutions (when not encumbered by technology limitations or misrepresented by performance restrictions) when compared with a practical 802.11b deployment. Next, it will explore practical deployment scenarios for both 802.11a (current and optimized) and 802.11b, including three-cell and eight-cell configurations.

### Measuring performance

The primary industry-standard performance metrics used to define connectivity for a WLAN deployment include range, coverage and rate-weighted coverage.

#### Transmit power:

The regulatory standards from the FCC set upper bounds on transmitted power for 802.11a systems operating in the United States. The limit in the 5.15- to 5.25-GHz band is +16.02 dBm and in the 5.25- to 5.35-GHz band it is +23.01 dBm. The maximum upper bound on transmit power for 802.11b transmissions is +30 dBm.

**Transmit power:** The regulatory standards from the FCC set upper bounds on transmitted power for 802.11a systems operating in the United States. The limit in the 5.15- to 5.25-GHz band is +16.02 dBm and in the 5.25- to 5.35-GHz band it is +23.01 dBm. The maximum upper bound on transmit power for 802.11b transmissions is +30 dBm.

**Receiver (Rx) sensitivity:** According to the IEEE, an 802.11b receiver should be able to detect a –76-dBm signal and demodulate it with a BER of less than or equal to 10e–5 in the absence of adja-
Wireless LAN Design

The receiver (SRx) is related to the transmit power (STx) as shown in Equation 1. Here, \( C \) = the speed of light (m/s), \( f \) (Hz) = the center frequency and \( N \) = the path-loss coefficient (dimensionless). The ITU recommends using \( N = 3.1 \) for 5-GHz and \( N = 3 \) for 2.4-GHz applications.

### Range comparisons

Some published analyses argue that 802.11b provides superior range when compared with 802.11a. However, those conclusions are based on an incorrect assumption that both 802.11b and 802.11a radiate at the same transmit power. This is not necessarily the case, since optimized 802.11a solutions can transmit at +23 dBm as compared with practicable (meaning real-life devices) 802.11b effective isotropic-radiated-power (EIRP) values of +15 to +19 dBm.

Another possible error in miscalculation arises from choosing an incorrect path-loss coefficient (\( N \)), leading to an assumption that 802.11b solutions have a range of 100 meters with +15-dBm EIRP.

Using those numbers, we can calculate that the \( N \) used in the 802.11b calculations was approximately 2.535 (Equation 2). This is less than the ITU’s recommended figure of 3.

However, using the EIRP values quoted from published papers, together with the ITU reference model and path-loss coefficient \( N = 3 \), the maximum theoretical range of an 802.11b network operating at the maximum EIRP of 30 dBm is 154 meters, declining significantly at an EIRP of +19 dBm to 66.4 meters, then to 48.4 meters at +15 dBm.

The same analysis also uses \( N = 3 \) in its 802.11a calculations, resulting in a 802.11a range calculation that appears to be very small next to that of 802.11b. However, as mentioned above, the ITU recommends \( N = 3.1 \) for 802.11a calculations. When those ITU-recommended figures are used, the range of 802.11a improves, relative to 802.11b, giving 54 Mbits/s at a distance of 14 meters, down to 6 Mbits/s at 51 meters.

In addition, conventional 802.11a WLANs transmit at +18-dBm EIRP.
To make the problem tractable, one must assume at any given time there is only one station (STA), or user, transmitting in each cell. The collision avoidance and back-off behavior of the 802.11 media-access controller (MAC) make this a good assumption in distributed-coordinate function mode, while in the point-coordinate function mode the assumption is nearly literally valid. Owing to the high degree of asymmetry of traffic flow, it may also be assumed that the only potentially jamming stations are the APs in other cells.

From the spectral masks and channel allocations described by the IEEE, one can infer the fraction of spectral leakage (θ) from one adjacent channel is 4.282853E-3 (–23.68 dB) for an 802.11a network and 3.63273E-4 (–34.40 dB) for an 802.11b network.

Three-cell networks

Consider a network of three cells (see Fig. 3). Since 802.11b affords only three frequency channels, one of the three cells (for example, Cell III) experiences ACI from the other two cells.

The greatest interference noise power (IN) is experienced by a user belonging to Cell III located at point G in Fig. 3. Using Equation 1, the IN value at G is as shown in Equation 3.

Similarly, the desired signal power is given by Equation 4. The signal-to-interference noise ratio is therefore equal to \( \text{SINR} = \frac{2}{f} \), which is 31.39 dB. By comparing this number with Fig. 2 (a), one sees that all 802.11b data rates can be supported. The size of the network in Fig. 3 can be calculated by finding the radius of each hexagon (this is a function of the Tx power and the minimum Rx sensitivity). As mentioned previously, due to ACI it is necessary to use a minimum Rx sensitivity of –70 dBm. Note that a +15-dBm solution can cover 7,397.9 square meters at 11 Mbits/s, while a +19-dBm model will offer better range (41.8 meters as opposed to 30.8 meters), and therefore a larger total area of coverage (13,670.2 square meters).

The 802.11a standard has more channel flexibility, so if a 54-Mbits/s handoff rate is required, the designer can choose channels 1, 5 and 8 for Cells I, II and III, for instance, so that there is no adjacent-channel interference. In this case, the APs in Cell I and Cell III can radiate at +23.01-dBm EIRP, while the AP in Cell II can radiate at +16.02-dBm EIRP. Consequently, Cells I and III each cover 1,145.75 square meters, while Cell II covers 439.07 square meters, with a total coverage of 2,730.6 square meters. Although this total coverage area is less than the 802.11b examples, the network has a throughput capacity of 54 Mbits/s.

Having calculated coverage dictated by the IEEE 802.11a standard, what can real-world systems deliver? With an optimized 802.11a solution, designed to deliver 23 dBm, the coverage of a three-cell deployment with 54 Mbits/s would be...
reach 2,730.6 square meters.

Alternatively, if a data rate of 12 Mbits/s is preferred (to reduce costs or the number of APs), then channels 5, 7 and 8 can be used for Cells II, III and I respectively. This will result in ACI only between channels 7 and 8 and all APs can radiate +23.01 dBm. In this example, the interference noise power is as shown in Equation 5, so that the least SINR is $f^{-1}$, or 23.68 dB. As a result, all but the two highest OFDM rates are accessible. Maintaining at least 12 Mbits/s requires a cell radius of 47.59 meters (congruent hexagons), so that the total area covered is now about 17,650 square meters.

**Eight-cell networks**

An eight-cell 802.11a network is depicted in Fig. 4. If all of the cells are congruent, then all of the APs must transmit at the same power level. This requires the maximum power of 40 milliwatts (+16.02 dBm). In that case, the greatest interference is experienced by a station belonging to Cell IV, located at vertex G.

The sources of interference are the two ACs, one at 2R and the other at root 7R. Therefore, the least SINR experienced by any station throughout the network is given by Equation 6, or about 31.49 dB. Comparing this number with the S/Ns in Fig. 2 (b), we see that a rate of 54 Mbits/s is accessible throughout the network. The total area covered in this configuration is 2082.4 square meters.

An 802.11b WLAN can be used to cover a similar geometry as the 802.11a example above. The configuration outlined in Fig. 4 was carefully designed for an 802.11a application to mitigate co-channel and adjacent-channel interference, with the most interference being experienced by an STA belonging to cell II located at vertex G. In comparison, a similar 802.11b configuration (see Fig. 5) leads to a co-channel at 2R, a co-channel at root 7R, two adjacent channels at 2R, two adjacent channels at R and one adjacent channel at root 7R. Therefore, the least SINR experienced by any station in the network is as shown in Equation 7, or about 7.45133 dB.

Comparing this with the S/Ns in Fig. 2 (a), it is clear that a rate of 11 Mbits/s is accessible throughout the 802.11b network. Note that a +19-dBm solution can cover 19727.6 square meters at 11 Mbits/s, while a +19-dBm model will offer coverage of 36453.7 square meters.

As a side note, a concern for 802.11b systems is the proposed 22-Mbit/s packet binary convolutional-coding (PBCC) extension that requires approximately 13.8 dB of S/N for a BER less than 10−5. In this case, Equation 1 shows that in 802.11b networks requiring eight or more APs, 22 Mbits/s would not be accessible throughout the entire network.

Future 802.11a solutions that employ low-power, high-performance architectures may be able to transmit up to the maximum FCC limits. As a result, they will offer the range and data rate flexibility that will allow IT managers to tailor solutions to their specific applications and budgets, making an optimized 802.11a system the perfect option.

For related articles see:


References


Jung Yee (jyee@icefyre.com) is chief technology officer at IceFyre Semiconductor Corp. He holds a bachelor’s of applied science degree in electrical engineering from the University of British Columbia.

Hossain Pezeshki-Esfahani (hpezeshki@icefyre.com) is system architect at IceFyre Semiconductor. He has a PhD from the University of Waterloo.