Cirond Technologies Inc.

White Paper

Channel Overlap Calculations for 802.11b Networks

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Introduction

The commercial success of the IEEE 802.11b wireless networking standard is leading to ever more crowded usage of the 2.4GHz ISM band. Current literature suggests that only three independant channels (1, 6, and 11) may be used when using 5.5 or 11Mbps DSSS operation. This paper intends to show that this may be overly restrictive, and that up to 4 channels may be used in instances where maximum density or highest aggregate network bandwith are required. This paper is also intended to be a basis for Cirond Networks' channel placement and allocation software.

Power Spectrum

A 5.5 or 11Mbps DSSS (Direct Sequence Spread Spectrum) modulated signal has a power spectrum (see reference [1]) described by the following equation:

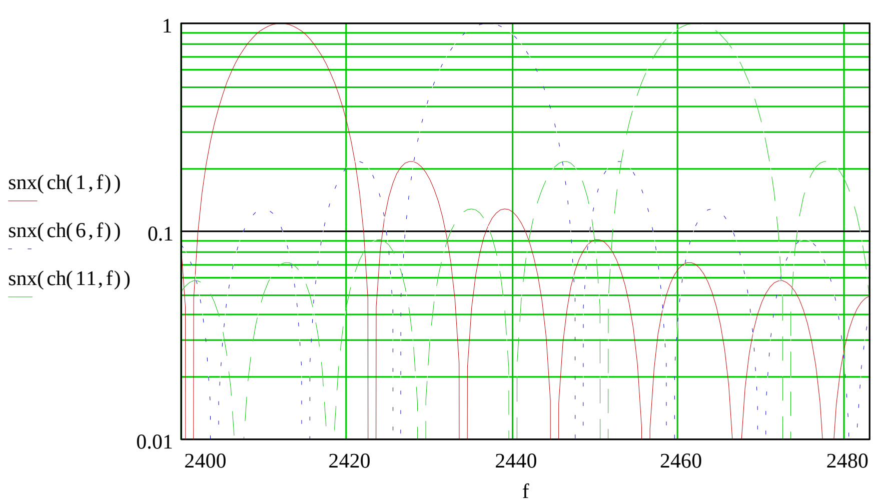
$$\mathrm{snx}(x) := \mathrm{if}\left(x \neq 0, \left|\frac{\sin(2\cdot\pi\cdot x)}{2\cdot\pi\cdot x}\right|, 1\right)$$

The 2.4GHz ISM band is allocated spectrum from 2400 to 2483MHz. The DSSS channel assignments in North America are channels 1 to 11, starting at 2412MHz and spaced at 5MHz intervals to 2462MHz (see reference [4], p. 180). Each channel is about 22MHz wide, so there is substantial overlap. Conventional wisdom allocates channels 1, 6, and 11 as non-overlapping channels since they are spaced 25MHz apart. However, this is severely limiting in the cases where there are more than three access points on the local network and/or interfering stations within the service area. This paper more closely examines the channel overlap issues, with the intent of increasing the number of channels utilized.

$f := 2400, 2400.5 .. 2483$ ISM band frequencies

$nn := 22$ Null-to-null channel band width (reference [1]) in MHz

$$\mathrm{ch}(n, f) := \frac{f - 2412 - (n-1)\cdot 5}{nn}$$ Channel number and frequency conversion factor

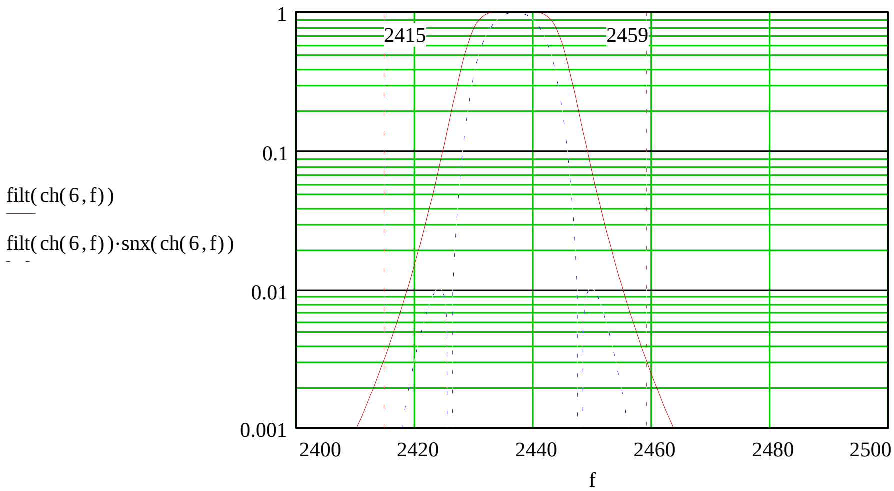


2.4GHz ISM band showing unfiltered ouput on channels 1, 6, and 11

IF Filtering

The power spectrums in the previous section do not take in to account the IF filtering present on both transmit and receive paths of 802.11 WLAN cards. This filter (SAWTECH 855653 - see reference [2]) significantly reduces sidebands transmitted and received. It has a 3dB bandwidth of 17MHz, and a stopband 50dB down at +/- 22MHz.

$$\text{filt}(x) := \frac{1}{1+(2.6\cdot x)^6}$$ IF filter response approximation



Filter response and resulting power spectrum shown for channel 6.

Channel Overlap

One of the key assumptions of this paper is that it is better to have some channel overlap than it is to have substantial co-channel interference. The question that remains is how much channel overlap is tolerable. To assist in that calculation, channel overlap factors are now calculated. The calculation multiplies the filtered transmit (interfering) channel by the receive processing gain and receive filter response at each frequency with significant contribution to the overall response. To gauge the channel to channel overlap (interference) factor, the overlap calculation is integrated over that frequency range. The result is scaled to produce a factor of 1.0 when the channels completely overlap (co-channel = on the same channel).

$$\text{overlap}(n,m,x) := \text{filt}(\text{ch}(n,x))\cdot\text{snx}(\text{ch}(n,x))\cdot\text{filt}(\text{ch}(m,x))\cdot\text{snx}(\text{ch}(m,x))$$

Filtered channel overlap (n to m) over band of interest (x).

$$ko := \int_{2200}^{2700} \text{overlap}(1,1,x)\,dx$$ Co-channel scaling value $ko = 9.2655$

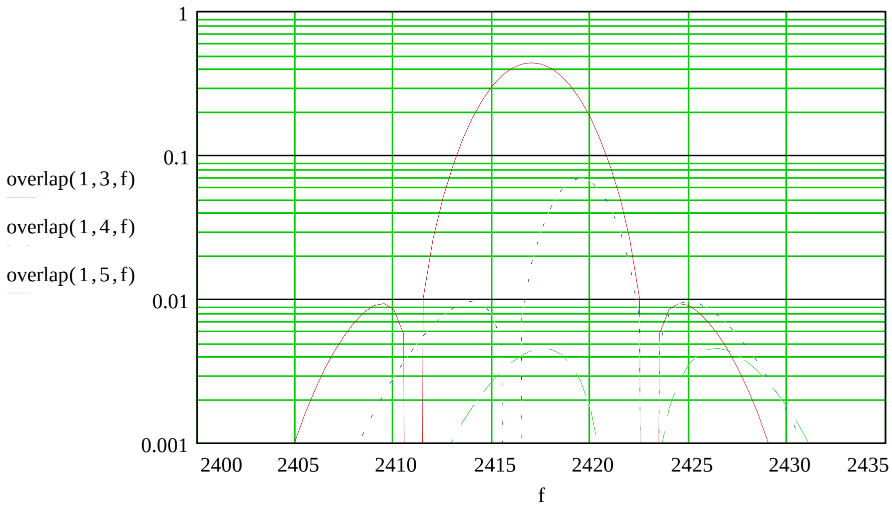
$$k := 0..10 \qquad olf_k := \frac{1}{ko}\cdot\int_{2200}^{2700} \text{overlap}(1,k+1,x)\,dx \qquad chsp_k := k$$

chsp =	olf =
0	1
1	0.7272
2	0.2714
3	0.0375
4	0.0054
5	0.0008
6	0.0002
7	0
8	0
9	0
10	0

Table 1

Channel to channel overlap factors. chsp = overlap channel spacing, 0 for co-channel factor. This calculation shows that channel spacing of 3 or 4 may be useful in some situations. 2 channel separation produces about 27% interference, 3 channel separation produces about 4% interference, and 4 channel separation produces about 0.5% interference. NOTE - these are preliminary, theoretical number based on a number of assumptions. Actual results will vary for different chipset and filter configurations.

$f := 2400, 2400.5 .. 2435$



Channel overlaps 1 to 3, 1 to 4, and 1 to 5.

Inclusion of Channel Energy Measurements

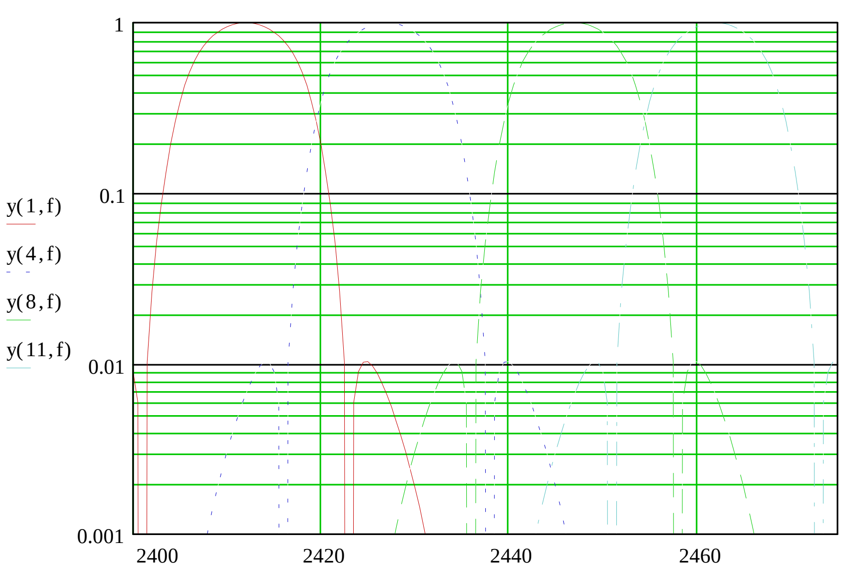
When a wireless network card is used to measure channel energies, each channel energy measured will already include leakage energy from adjacent channels. Therefore, the channel to channel scaling factors from table 1 should not be applied to these measurements. When planning the placement of access points, calculations for interference at a given physical location should use the larger of the measured on-channel energy or the calculated overlapping channel energy.

Proposed High Density Channel Assignment

For high density situations, consider the channel assignments 1, 4, 8, and 11. These channels are spaced 3, 4, and 3 apart, and have the advantage that channel 6 (which is the default channel, and will be the most common interfering channel) is not used. In Europe, five channels could be used - 1, 4, 7, 10, and 13.

$f := 2400, 2400.5 .. 2483$

$y(x,f) := \mathrm{filt}(\mathrm{ch}(x,f)) \cdot \mathrm{snx}(\mathrm{ch}(x,f))$ Filtered channel



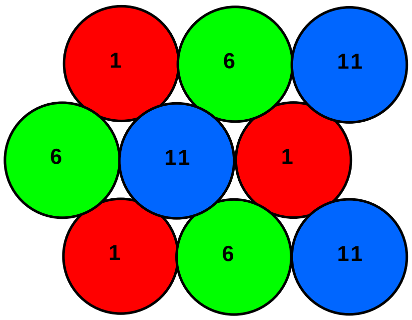
Channels 1, 4, 8, and 11 with filter applied.

Frequency Re-Use Plan

With 4 channels to work with instead of 3, there is more flexibility in the frequency re-use plan. This will likely be especially important in 3 dimensional set-ups such as a high rise office building.

3 Channels, 2-D:

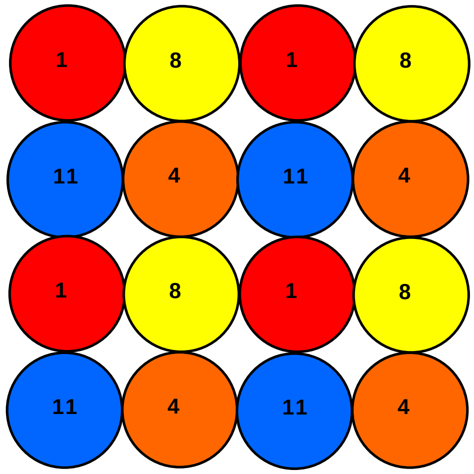
$\sqrt{3}$ Co-channel distance relative to node distance



4 Channels, 2-D:

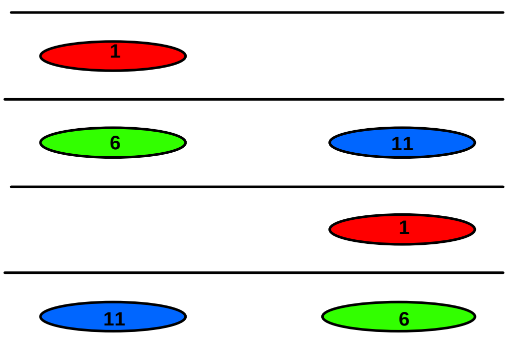
2.0 Co-channel distance relative to node distance

$\sqrt{2}$ Channel 1-4 and 8-11 overlap distance relative to node distance



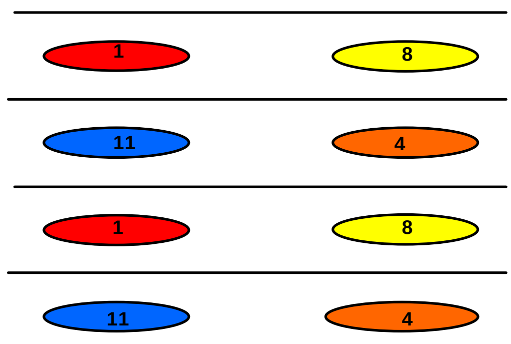
3 Channels, 3-D:

Every second floor can only have 1 AP.



4 Channels, 3-D:

Each floor can have 2 AP.



Interpretation of Channel Overlap Factors

The key premise behind calulating channel overlap factors is the intent to use them to determine the approximate degree of interference to be found on a specific channel at a specific location when planning a wireless network layout. The degree of inference tolerable (jamming margin - see reference [1]) is determined by a number of factors. The receiver's physical location, required signal to noise level, and the effective desired channel received power determine how much interference can be tolerated. The interfering channel(s) physical location, transmit power, and channel spacing determine the fundamental interference level. However, please note that these numbers are approximate since they will be substantially affected by multipath propagation of both the desired and interfering stations.

The PRISM II chip set receiver's jamming margin is calculated in reference [1] as -1.6dB for a BPSK signal. Given that the 5.5 and 11Mbps required signal to noise is similar (required Eb/N0 is lower, but processing gain is lower by about the same amount), we will use a jamming margin of -2dB for our calculations. This implies that an interfering signal must be 2dB or more lower (after channel overlap factor modification from table 1) than the signal of interest to prevent performance degradation. Note that additional fade margin will have to be added when operating in a multipath environment.

For example, assume we are operating a network with 4 WAP's, one each on channel 1, 4, 8, and 11. We wish to determine how much interference will be caused by this overlapping of channels. We assume that channels 8 and 11 do not interfere with channel 1 (overlap factors are about 0). At a given point in space, we determine the received power from each channel of interest. We shall use 3 points for this example:

Point A:	$pa\_ch1 := -40$	$pa\_ch4 := -50$	dBm
Point B:	$pb\_ch1 := -55$	$pb\_ch4 := -30$	dBm
Point C:	$pc\_ch1 := -65$	$pc\_ch4 := -30$	dBm

From table 1, we find the overlap factor for 3 channels separation (4 - 1): $olf_3 = 0.0375$ $\quad lolf := 20 \cdot \log(olf_3)$

The power difference this implies is: $lolf = -28.5$ dB

At point A: interference from channel 4: $pa\_ch4 + lolf = -78.5$ dB

Jamming margin at point A is: $(pa\_ch1 - 2) - (pa\_ch4 + lolf) = 36.5$ dB

Therefore, point A has plenty of margin. Calculations for points B and C:

Point B: Interference: $pb\_ch4 + lolf = -58.5$ dB

Jamming margin: $(pb\_ch1 - 2) - (pb\_ch4 + lolf) = 1.5$ dB (barely any margin)

Point C: Interference: $pc\_ch4 + lolf = -58.5$ dB

Jamming margin: $(pc\_ch1 - 2) - (pc\_ch4 + lolf) = -8.5$ dB (channel 1 is jammed)

Obviously, these calculations can become extremely difficult in any real world situation with more than a handful of access points and user's measurement points. However, they are well suited for incorporation in to a software package designed to assist in the placement and channel assignment of access points on a wireless network. This software could create a grid (3 dimensional in an advanced version) on which could be placed access points, interference sources, and measurement points. At each measurement point, a vector could be calculated with one element for each access point and interference source defined in the program. Each element would represent the signal strength of that source as viewed from that measurement point (signal propagation losses will be covered in a later section). From this vector, a number of useful things could be calculated. One of the most useful is the signal strength and signal to noise of each access point. Another would be finding the maximum signal to noise to determine the best access point for use at a given location. The minimum signal strength channel would be the one to choose for placing a new access point. A coverage limits map could also be generated, where at least one access point is determined to have sufficient signal to noise.

Propagation Losses

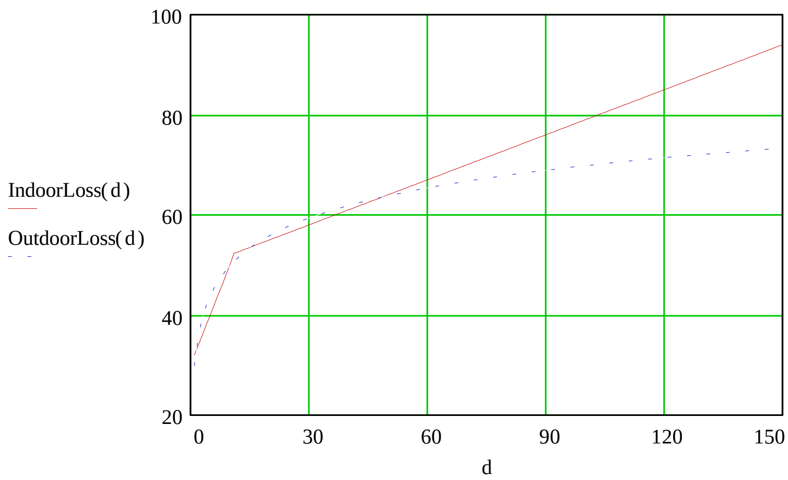
Reference [3] gives a good tutorial on a link budget analysis, path losses, and multipath propagation. For our simplified analysis, multipath will not be considered. However, we will use the indoor path loss 'rule of thumb' cited in [3], which is 50dB attenuation in the first 10 feet, followed by 30dB more loss per additional 100 feet. A more refined analysis should consider more accurate representations of indoor loss and also the transistion to free space (outdoor) path loss outside the building.

$IndoorLoss(x) := if(x \le 10, 30 + 2 \cdot x, 49 + 0.3 \cdot x)$ Path loss in dB, x in feet, indoor 'rule of thumb'

$\lambda := \frac{3 \cdot 10^8}{0.3048 \cdot 2.43 \cdot 10^9}$ $\quad \lambda = 0.405$ Wavelength in feet (at 2.43GHz)

$OutdoorLoss(x) := 20 \cdot \log\left(4 \cdot \pi \cdot \frac{x}{\lambda}\right)$ Free space loss in dB, x in feet

$d := 1..150$



Indoor and outdoor path loss estimations in dB, distance in feet.

We now consider a 2 dimensional model of total RF signal strength in an area covered by three access points. We assume -82dBm RX sensitivity, -2dB jamming margin, and 30dB fade margin for good coverage, so the -50dBm signal strength contour defines good coverage limits. 20dB fade margin (-60dBm) should provide marginal coverage limits.

$i := 0..40 \qquad j := 0..40 \qquad scale := 5 \qquad dist(x,y) := \sqrt{x^2 + y^2}$ Distances in feet

$apx_0 := 30 \quad apy_0 := 20 \quad ch_0 := 1 \quad p_0 := 15$ Access point 1 x, y location in feet, channel, power in dBm

$apx_1 := 110 \quad apy_1 := 180 \quad ch_1 := 4 \quad p_1 := 15$ Access point 2 x, y location in feet, channel, power in dBm

$apx_2 := 160 \quad apy_2 := 50 \quad ch_2 := 8 \quad p_2 := 15$ Access point 3 x, y location in feet, channel, power in dBm

$$sig(n) := 10^{\left(\frac{p_n - IndoorLoss\left(dist\left(apx_n - i\cdot scale, apy_n - j\cdot scale\right)\right)}{20}\right)}$$

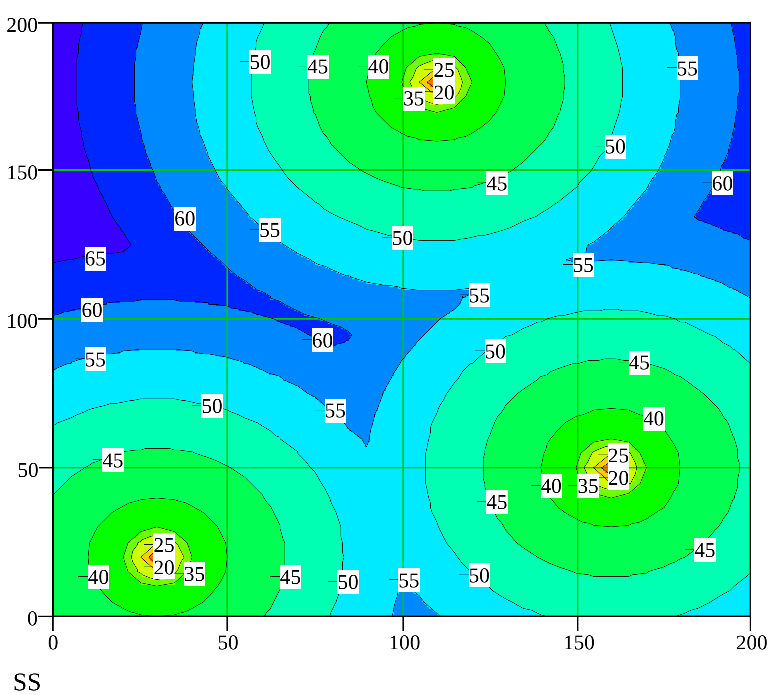
$dist\left(apx_0 - apx_1, apy_0 - apy_1\right) = 179$

$dist\left(apx_0 - apx_2, apy_0 - apy_2\right) = 133$

$dist\left(apx_1 - apx_2, apy_1 - apy_2\right) = 139$

$max3(a,b,c) := if(a>b, if(a>c, a, if(b>c, b, c)), if(b>c, b, if(a>c, a, c)))$ 3 argument maximum test

$SS_{i,j} := 20\cdot\log(max3(sig(0), sig(1), sig(2)))$



Signal strength 2D map, shown in dBm (transmitters at equal power). This is a simplified map which does not take in to account channel overlap or interference. Good coverage area is defined by the -50 dBm contour as discussed above. Marginal coverage extends to -60dBm, and shows a coverage hole between access points 1 and 2.

Signal to Noise Calculations

We now bring all of the preceding sections together to calculate signal to noise ratios for a device utilizing the access points as defined in the preceding section. The signal to noise procedure is to determine the strongest signal, then apply the overlap interference factors to each the weaker channels and take the ratio of the strong signal to the sum of the scaled interfering channels. We also account for the receiver sensitivity factor.

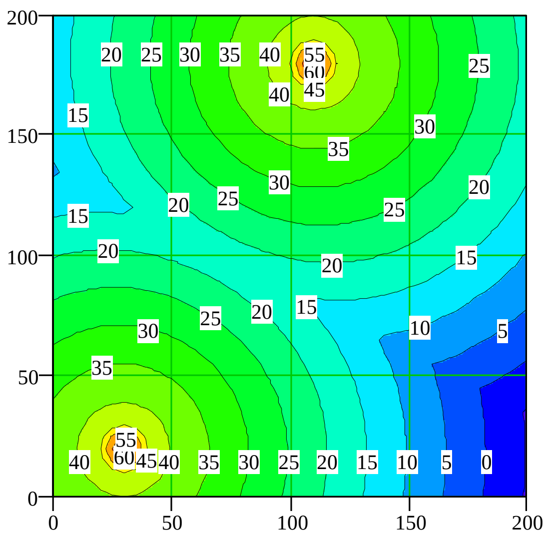
$rx := 10^{\left[\frac{-82-(-2)}{20}\right]}$ $\quad rx = 0.0001 \quad$ Receive sensitivity with jamming margin

$$SNR12_{i,j} := 20\cdot\log\left(\text{if}\left(sig(0)>sig(1), \frac{sig(0)}{sig(1)\cdot olf_{|ch_0-ch_1|}+rx}, \frac{sig(1)}{sig(0)\cdot olf_{|ch_0-ch_1|}+rx}\right)\right)$$

$$SNR13_{i,j} := 20\cdot\log\left(\text{if}\left(sig(0)>sig(2), \frac{sig(0)}{sig(2)\cdot olf_{|ch_0-ch_1|}+rx}, \frac{sig(2)}{sig(0)\cdot olf_{|ch_0-ch_1|}+rx}\right)\right)$$

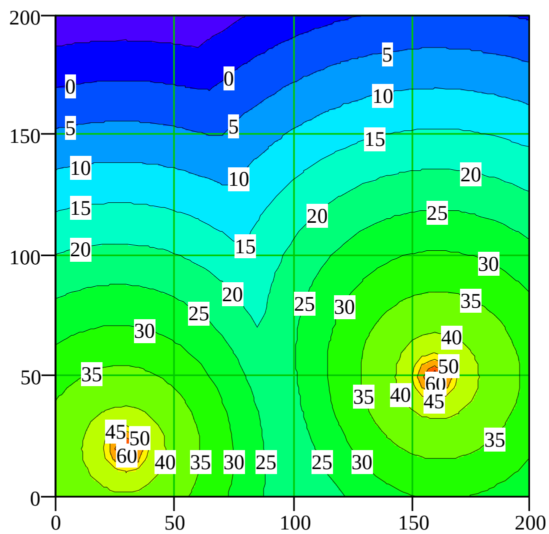
$$SNR23_{i,j} := 20\cdot\log\left(\text{if}\left(sig(1)>sig(2), \frac{sig(1)}{sig(2)\cdot olf_{|ch_0-ch_1|}+rx}, \frac{sig(2)}{sig(1)\cdot olf_{|ch_0-ch_1|}+rx}\right)\right)$$

To provide a simple illustration, we first consider only each pair of access points in isolation, calculating the signal to noise in accessing the stronger of only these two. Each of these maps is different in that the access point channel spacing is different in each case.



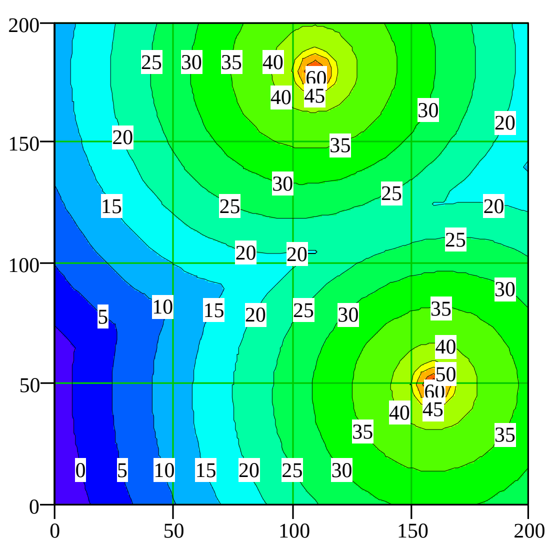
SNR12

AP 1 to 2, channel spacing: $|ch_1 - ch_0| = 3$



SNR13

AP 1 to 3, channel spacing: $|ch_2 - ch_0| = 7$



SNR23

AP 2 to 3, channel spacing: $|ch_2 - ch_1| = 4$

Now, let's combine the results for all access points.

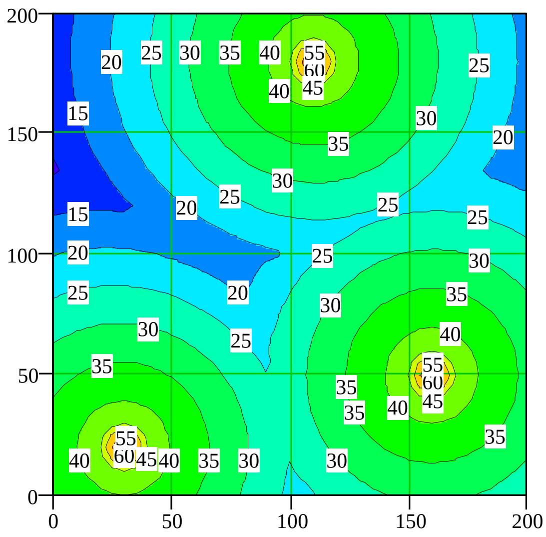
First determine the which access point is strongest:

$$Amax_{i,j} := \text{if}(\text{sig}(0)>\text{sig}(1), \text{if}(\text{sig}(0)>\text{sig}(2), 0, \text{if}(\text{sig}(1)>\text{sig}(2), 1, 2)), \text{if}(\text{sig}(1)>\text{sig}(2), 1, \text{if}(\text{sig}(0)>\text{sig}(2), 0, 2)))$$

Now, calculate the signal to noise at each point:

$$\text{noise}(n) := \text{if}\left(n=0, \text{sig}(1)\cdot \text{olf}_{|ch_0 - ch_1|} + \text{sig}(2)\cdot \text{olf}_{|ch_0 - ch_2|}, \text{if}\left(n=1, \text{sig}(0)\cdot \text{olf}_{|ch_0 - ch_1|} + \text{sig}(2)\cdot \text{olf}_{|ch_1 - ch_2|}, \text{sig}(0)\cdot \text{olf}_{|ch_0 - ch_2}\right.\right.$$

$$SNR_{i,j} := 20\cdot \log\left(\frac{\text{sig}(Amax_{i,j})}{\text{noise}(Amax_{i,j}) + rx}\right)$$



SNR

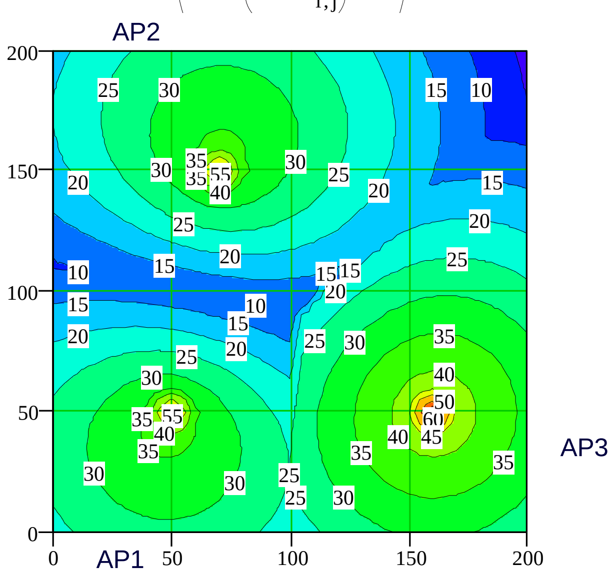
This plot shows that the limiting factor in this arrangement of access points is the signal level, and not the interference between access points (the minimum SNR is 20dB and follows the -60dBm signal contour, instead of the 35dB minimum interference contour).

Now, let's move the channels closer together in frequency (using channels 1, 3, and 6) so they overlap more, and move the access points closer together as well.

$ch_1 := 3$ $ch_2 := 6$ $apx_0 := 50$ $apy_0 := 50$ $apx_1 := 70$ $apy_1 := 150$

$\text{dist}(apx_0 - apx_1, apy_0 - apy_1) = 102$ $\text{dist}(apx_0 - apx_2, apy_0 - apy_2) = 110$ $\text{dist}(apx_1 - apx_2, apy_1 - apy_2) = 135$

$$SNR_{i,j} := 20\cdot \log\left(\frac{\text{sig}(Amax_{i,j})}{\text{noise}(Amax_{i,j}) + rx}\right)$$



SNR

This plot shows that the limiting factor is now the interference between access points 1 and 2. The minimum SNR is 10dB in an area of strong signal strength. Observe how the contour lines are distorted by the interference instead of being circles.

Conclusion

This paper has demonstrated some of the fundamental factors to consider for setting up a 802.11b network. We considered channel selection, transmit power, and physical placement of access points for an indoor network. We demonstrated the theoretical possibility and ramifications of increasing the number of channels usable within the 2.4GHz ISM band allocated for 802.11b. Note that the channel overlap and interference level calculations could also be applied (with appropriate modifications) to 802.11a and 802.11g applications as well. Note that due to the proposed modulation methods and spectral occupancy of 802.11g, it is less suited for four channel allocation within channels 1 through 11.

References

[1] Intersil AN9820, *A Condensed Review of Spread Spectrum Techniques for ISM Band Systems*, May 2000

[2] Intersil TB380, *Choosing the IF Frequency for the PRISM II 11Mbps Radio Reference Design*, June 2000

[3] Intersil AN9804, *Tutorial on Basic Link Budget Analysis*, June 1998

[4] Jim Geier, *Wireless LANs: Implementing Interoperable Networks*, Macmillan Technical Publishing, 1999.