Considerations for a 5 GHz WLAN Modulation Method

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Introduction

The current 802.11 modulations include both FH and DS spread spectrum modulations. As we consider 20 Mbit/s data rates, it seems that Direct Sequence Spread Spectrum is irrelevant. In FH we were able to get away with a simple GFSK modulation, as the multipath in an indoor environment is relatively short, when compared to symbol duration (1 microsecond). For the 20 Mbit/s data rates a more modern modulation method is required.

This submission will briefly overview three modulation methods:

- OFDM (Orthogonal Frequency Division Multiplex)
- QPSK/QAM (Quadrature Phase Shift Keying/Quadrature Amplitude Modulation)
- GMSK/OQPS/OQAM (Gaussian Minimum Shift Keying/Offset Quadrature Phase Shift Keying/Offset Quadrature Amplitude Modulation)

Our conclusion from the comparison presented is that GMSK/OQPS/OQAM is the most appropriate method for WLAN (GMSK and OQPSK are almost equivalent). Given that conclusion, what are the best parameters? GMSK is used today in European HIPERLAN type I with parameters of 24 Mbit/sec modulation with a BCH(31,25,3) error correcting code which reduces the rate to 20 Mbit/s. This seems fine; then, why not adopt the HIPERLAN? First HIPERLAN is a bundle - the high speed PHY comes with a MAC which is very different from 802.11 MAC. Second, we think several modifications to the HIPERLAN PHY are appropriate.

We propose to combine the GMSK (alias OQPSK) with OQAM. The GMSK is a constant envelope modulation - it enables efficient use of saturated power amplifiers. Interpreting GMSK as an OQPSK modulation enables us to define a second layer utilizing Offset QAM with a double rate. As the pulse shape is derived from a GMSK (constant envelope) modulation, the peak-to-average ratio of the resulting waveforms is excellent, and the power amplifier runs at high efficiency. The combination of OQPSK with OQAM as a second layer with double data rate raises the question, should we achieve the 20 Mbit/s objective as a basic rate (and then have 40 Mbit/s as a higher rate) or should we have 20 Mbit/s as a high rate (and settle for 10 Mbit/s as a basic rate)? Or, something in between (e.g. 15/30 Mbit/s)? My guess is 20/40 Mbit/s, even though it is most demanding in implementation.

Modulation Method Comparison

Data rates of 20 Mbit/s and beyond are targeted by the next generation of 802.11 PHY. At data rates this high the simple reception methods based on differential detection or limiter-discriminator detection will no longer provide the reliability needed due to multipath which can smear data over several bits. Therefore, we will need modulation methods which are adapted to heavy multipath environment. Coherent quadrature modulation methods such as QAM or Offset QAM can be equalized using linear or DFE (Decision Feedback Equalizer) methods. Another method getting popular is OFDM (Orthogonal Frequency Division Multiplex), which mitigates multipath by virtually spreading the data over a multitude of narrowband channels, within each of which the multipath distortion is low. Follows a short overview of these alternatives.

Orthogonal Frequency Division Multiplex (OFDM)

The principle of operation of OFDM is to subdivide the frequency band into narrow frequency slots and then apply a modulation method (for example DQPSK, QPSK or QAM) to each of the channels. The multiplexing on the transmit side and demultiplexing on the receive side is accomplished using a Fourier Transform (implemented by FFT). In order to avoid ISI (InterSymbol Interference) problems a fraction of the beginning is repeated at the end of each time slot.

The OFDM is an extremely elegant method of converting a channel with heavy multipath (several peaks, dips and notches within the frequency band) into a multitude of ISI-free (although fading) channels. The complexity of the method grows slowly (logarithmically) with the multipath delay spread. Yet, there are several significant problems with OFDM modulation.

The main problem of the OFDM is it's large peak-to-average power ratio. This results from the fact that at each moment the instantaneous amplitude is combined from multiple contributions from independent data bits, being summed with random phases. The resulting distribution is almost Gaussian (two dimensional, with Rayleigh distributed envelope), with large occasional excursions. When such excursions occur and are clipped by the RF power amplifier, an energy is spilled into adjacent channels; in addition, the distortion caused by the clipping increases the error probability. The result of the problem described is that OFDM systems are usually operated with large backoff in power amplifiers. While this can be tolerated in base stations (or in broadcasting - OFDM is used in new Digital Audio Broadcasting standard), it incurs significant penalty both in RF amplifier cost and in power consumption on mobile battery operated stations. The backoff requirements can be as high as 10-15 dB!

Another problem of the OFDM is sensitivity to frequency accuracy and to phase noise. As the data is conveyed via multiple narrowband channels, the phase noise immunity is dominated by width of a single channel and not by the width of the whole transmission bandwidth. This problem induces stringent requirements on the quality of oscillators employed in such equipment. This problem is even more annoying if we strive to use same modulation method at progressively higher frequencies (e.g. 19 GHz in Japan).

Last but not the least, the frequency selective multipath is translated by the Fourier Transform into multiple flat-fading channels. Some of those channels may be so severely faded that they are rendered unusable. In this situation error correcting code which recovers the information even when some fraction of the channels is unusable is a must. I would consider it a "feature" rather than a disadvantage - nearing the third millennium we should not be affraid from error correcting codes!

OFDM seems to be the the preferred method in recent European WATM initiatives. There are research publications regarding reduction of peak-to-average ratio by special (rate reducing) codes and obtaining transmit diversity by transmitting different frequency slices via different antennae.

Quadrature Phase Shift Keying / Quadrature Amplitude Modulation (QPSK/QAM)

QPSK is a long known textbook modulation format. The two quadrature components are multiplied by +1 or -1, according to the bit we want to convey, and then summed together. If the quadrature components are multiplied by +3/+1/-1/-3 (according to couple of bits), QAM is obtained. By using appropriate waveshapes, the spectrum of the signal transmitted can be confined to the bandwidth equal to the symbol rate with some small excess (square-root raised-cosine shape with 33%-50% is typical in radio equipment).

The algorithms for detection of QPSK/QAM are well known. Moreover, equalization methods for mitigating multipath are well known - a combination of Feed-Forward Equalizer with a Decision Feedback Equalizer can handle even channels with notches within received signal band. In fact, the capability of Decision Feedback Equalizer to reconstruct the energy in bands wiped out by frequency selective fading replaces to some extent the need for error correction as was described in OFDM case. Recent articles argue that in terms of channel capacity (in information-theoretic sense) the two modulation methods are quite equivalent.

The main drawback of QPSK/QAM is the implementation complexity, when long reverberation is expected in the channel. The complexity is linear in equalizer length, and as the data rate gets higher the equalizer length increases as well, therefore the complexity is quadratic in data rate.

Another disadvantage of QPSK with SRRC pulse shape is relatively high peak to average ratio. Although the situation is not as bad as in OFDM, some 3-4 dB penalty may be incurred in RF output power relatively to saturated amplifier.

Gaussian MSK / Offset QPSK / Offset QAM

The Offset QPSK and Offset QAM differ from the regular QPSK/QAM in that the data streams modulating the two quadrature (“I” and “Q”) components are staggered by half of a symbol’s interval. Offset QPSK produced with a “half sine in time” symbol waveform produces the well known “Minimum Shift Keying” (MSK) modulation type. The MSK is famous for being constant envelope waveform and having an interpretation both as an Frequency Shift Keying (sometimes MSK is acronymed FFSK, for Fast FSK) and as Offset Quadrature modulation. As such it is amenable to both incoherent (discriminator) and coherent detection. GMSK stands for Gaussian MSK and it means that the phase trajectory is smoothed by a Gaussian low-pass filter. This waveform cannot any longer be represented exactly as an Offset Quadrature modulation, but it turns out that the representation is very good if “half sine in time” waveform is filtered by a Gaussian filter. The resulting waveform is not constant-envelope anymore, but the resulting amplitude variations are small (less than 1 dB for BT=0.3 Gaussian Filter) and passing the OQPSK through a limiter produces a modest rise in sidelobes and a negligible receiver degradation.

Once GMSK is replaced by an OQPSK waveform, additional layer can be defined by using multiple amplitude levels. This variation is called sometimes as Multi-Amplitude MSK (MAMSK). The trajectories of MSK/OQPSK and MAMSK/OQAM on I/Q plane are depicted in figure 1. The black squares indicate possible positions in odd instants of time and the black circles indicate even instants of time For example, using 4 levels doubles the data rate, at expense of reducing the distance from decision thresholds by a factor of three (9.5 dB sensitivity reduction).

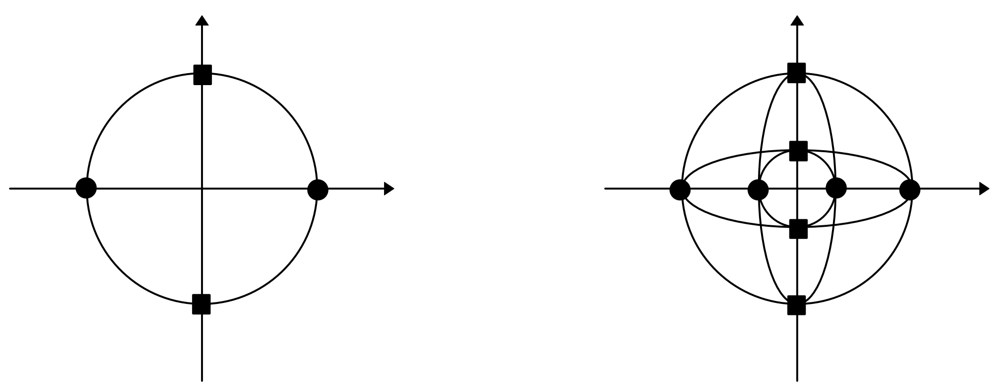

Fig. 1: Trajectories of MSK/OQPSK and OQAM

The Multi-Amplitude MSK has the nice property that although there are several amplitude levels, the outer circular orbit exhibits no overshoots and therefore incurs no penalty on the peak-to-average power ratio. There is still a need for a small backoff in power amplifiers, to avoid variation in ratio between the inner and the outer circles and avoiding skew due to AM-to-PM distortion. Passing the described MSK/MAMSK waveform through a Gaussian filter introduces slight amplitude variations which result in some small additional penalty in peak-to-average power ratio.

QAM and OQAM are of comparable complexity, although the complexity of equalization for OQAM is slightly higher that that of QAM, due to need to process certain data twice per symbol, instead of once. On a positive side, OQPSK is known to exhibit slightly better tolerance to phase noise than QPSK. Together with the better peak-to-average properties of OQPSK and OQAM (as compared to QPSK and QAM, and certainly with OFDM), this is our preferred modulation method.

If GMSK, why not HIPERLAN?

Having GMSK as a preferred modulation method raises a dilemma: HIPERLAN already uses it, why not accept it? There are two answers to that. First, we want to retain the 802.11 MAC, which does not fit into the HIPERLAN concept. Second, my feeling is that some of the choices made by HIPERLAN are worth reconsidering.

Low Bit Rate (LBR) can be eliminated

HIPERLAN defines a Low Bit Rate portion of the transmission used for control messages (and maybe for crude synchronization). The data rate in this part is 16 time (!) slower than the data rate (or some 13 times slower that the coded rate). It seems that this huge rate reduction is also used for maintaining connection at very large distances, typical of outdoor environment. My feeling is that being more oriented to local area networks, improving the robustness of control messages can be achieved by, for example, an error correcting code with just 1:2 rate loss.

Synch Sequence can be shortened

HIPERLAN uses a 450 bit sequence derived from a 511 bit long shift-register sequence. It is possible to redesign it so that shorter sequence can be used, e.g. 200-300 bits. This needs to be considered in view of different implementations of receivers, so that simpler implementations will not be ruled out by excessively short preamble.

Another Error Correction Coding?

The BCH(31,26,3) code with interleaving used by HIPERLAN seems pretty good and simple. Yet, especially in view of possibility to use multilevel modulation, trellis/convolutional coding might be considered.

Summary

My recommendation is to use GMSK/OQPSK with parameters similar to HIPERLAN (BT=0.3); to define a higher level based on OQAM at double data rate; and to reconsider preamble and error correction issues relatively to decisions taken in HIPERLAN.