

---

**Submission  
IEEE P802.11  
Wireless LANs**

---

Title:           **Selection Basis for 5 GHz PHYs**  
Date:           **March 10, 1998**

Author:         **Chandos A. Rypinski**  
                  **Ubiquity Communication Inc.**  
                  **Petaluma, CA 94954 USA**  
                  **Tel/fax: +1 707 792 5392/5399**  
                  **e-m: Error! Bookmark not defined.**

---

## **Overview**

The intent of this paper is to provide a basis for selection dependent more on achieved functionalities and requirements and less on highest performance on a particular criteria.

### ***Recommendation Summary***

It is recommended that the 5 GHz PHYs be classified into three groups:

- Multi-carrier (OFDM)
- Single-carrier (QAM, DQPSK, OQPSK)
- Single-carrier with coded symbol (CDMA, DBOK)

The arguments should be separated into two groups:

- 1) ***constrained to that between one and the others within the same category with the objective of getting down to three proposals, and***
- 2) ***which of the three groups shall be included in the Standard.***

In some aspect each of these categories will be best, and will be represented by a strong constituency. The Committee should urge those in each category to consolidate their proposal into a single recommendation.

Then the committee must decide whether one, two or three of these will be the chosen standard.

### ***General Recommendation for All PHYs***

It is further recommended that a pulse shape be defined which can be used with almost all of the proposed code forms, and which will enable a consistent and low level of out-of-band emissions. The pulse shape is equally applicable to coherent and non-coherent demodulation. ***(This pulse shape is the subject of a separate contribution.)*** An effect of this choice will be to eliminate a class of differences between offerings.

### ***Summary of Decisive Criteria for Selection***

The following are considered to be the most important criteria in choosing the PHY definition. The reasons for emphasizing these criteria are presented. Also, the three main classes of PHY are evaluated against these criteria.

- **Out-of-band Emissions**
- **Frequency Reuse**
- **Aggregate system Capacity**
- **Acquisition Time**

## Discussion of Criteria for Selection

This paper is about the considerations leading to a PHY choice(s) by 802.11 for the 5.15-5.35 GHz band. Tutorial material is included for continuity and to assure complete understanding.

The selection will be largely decided by the anticipated operating characteristics and perceived cost of implementation. A selection will be a tradeoff between spectrum utilization, power drain and cost. All of the capacity, system model and modulation method issues are contained within the larger issue of spectrum utilization.

## Discussion of Selection Criteria

The choice can be pre-decided by selection the relative importance of different considerations. For this reason there must be some kind of agreement on the problem to be addressed.

### *Model*

The *recommended basic model* is enterprise-wide use of radio access. The coverage will be obtained from a number of radio access points in groups of one or more each associated with a work group server. This is the primary scenario, but many others are equally well served with same definitions.

*No assumption is made which impairs the use of either connectionless or connection-type service or both. No assumption is made which precludes the co-existence of ad hoc peer-to-peer groups, however this not assumed to be the primary use.* There is an assumption that some interference will be present from radios not complying with the Standard. There is some congruence with the present 802.11 ESS with PCF, however this model is NOT specific enough to either enable or preclude the present 802.11 model assumptions.

### *Critical Attributes*

These attributes are very important to the usefulness and suitability of any implementation, but not all of them are also a basis for choosing one PHY over another.

power drain:	Primarily dependent on sleep provisions and MAC provisions for limited receiving time rather than circuit power drain
interference resistance:	Primarily but not limited to like-signal from adjoining coverage's with frequency reuse. This property is strongest with simple modulations and enhanced with channel coding
low o-o-b emissions:	Assumes that present FCC rules for out-of-band emissions cannot be compromised at maximum power and that the guard band space relative to band-edge is a minimum value
multi-path resistance:	Narrow band systems may require space diversity, FEC and use of directive antennas to mitigate Rayleigh fading
acquisition speed:	Systems must not use too much channel time for acquisition when transferring short payloads
transmit power amp linearity:	Complex modulation waveforms generated at baseband usually require linear amplifiers that must be operated at a backed-off power level 6 or more dB down from the 1 dB compression point
o-o-b receiver interference:	This point is important, but is not necessarily part of the standard unless minimized vulnerability to military radar in the 5.35-5.7 GHz band is a public-interest requirement, and it could appear in sharing rules
low manufacturing cost:	Obvious, and always a consideration.

### *Decisive Considerations*

Shown below are considerations which alone might eliminate a proposal from further consideration because of the importance of the end result.

#### Out-of-band Emissions

In the NII band, the width of the channel is determined at the 26 dB down points. Out-of-band emissions are limited to -37 dB down 10 MHz outside of the allocated band. While it is possible to obtain a contribution to the higher value with analog filtering, this is unlikely to be cost effective. It is also true that this requirement can be met using a smaller part of the channel bandwidth reducing the raw throughput.

These values of o-o-b emissions may become absolute power maximums referred to highest allowed transmit power. In this case requirements could also be met by backing off transmit power from the allowed levels.

If this requirement is met at baseband data signal that is then multiplied by a carrier frequency, linear amplification is required at all subsequent stages. Such linear amplification generally requires a backoff of 6-9 dB from 1 the dB compression point to avoid growth in spectrum width. This limits transmit efficiency, and is economically undesirable.

The appropriate modulation for an individual pulse is a partial response waveshape generated over a window of about 8 bits. The result is a transmit spectrum in which the sidelobe maximum after the first null are in the range of 32-40 dB down. If this waveform is maintained through the modulation process to the double sideband radio frequency, there will be material benefits in bandwidth utilization and ease of rf filtering.

This pulse shape is equally applicable to PPM, AM, QPSK/QAM and spread spectrum independently of the channel coding used. The pulses can be coded in phase, amplitude and time, and then overlaid, without losing the desirable spectrum shape.

This is a known, public domain technique now used in several other contexts, and it could be present in some of the present proposals (e.g., NEC).

If a like result is attempted with bit-at-a-time filtering there is no possibility of success. The filter will either have too slow a frequency roll-off or it will cause intersymbol interference and as a consequence show smaller eye openings.

#### Frequency Reuse

The main required property for frequency reuse is a minimized required signal-to-interference ratio for successful data reception. This favors simpler and more robust two and four-level modulations over N-level types.

This is the consideration which minimizes the number of channels required for 100% area coverage. For spread spectrum channel coding that enables reception with a small or negative signal-to-interference ratio, it is possible to use the same frequency for overlapping coverages. This is an enormous simplification of access protocol when all stations are on the same rf channel within one system.

Resistance to like signal interference is necessary for large scale systems. Resistance to any signal that is legally usable is a further consideration, but may not be as important.

#### Aggregate system Capacity

Aggregate capacity is the capacity of an isolated cell or cluster divided by the number of independent channels necessary to obtain 100% coverage within a fixed given bandwidth. It is true that random access systems are not analyzed this way, but it is also true that distant signal sources can cause unnecessary deferral and errors not properly considered in simple simulations.

The code division multiple access spread spectrum modulation can be the best system on this criteria because overlapping coverages with different channel codes can use the same rf channel. Such a system was proposed to IEEE 802.11 by Jonathon Cheah in 1992.

Typical required signal-to-interference ratios before considering fade allowance are:

Discriminator fm (e.g., GMSK):	15 dB)
Coherently detected PSK:	9 dB
11-bit Barker time offset coherently detected):	-1 dB
32-bit symbol cdma coherently detected	-6 dB

The above values are approximate relative values. Absolute values depend upon the definition of satisfactory operation and detail of detector function. A substantial fade margin must be added for narrowband systems and a much lower level for those with chipping rate high enough to resolve multiple paths. ***When all of these factors and frequency reuse are considered, the higher capacity for a given amount of bandwidth is obtained from appropriately designed spread spectrum systems.***

The degree to which maximization of aggregate capacity should be compromised in favor of capacity for an isolated system is a subjective matter. The range of possibilities will make differences of 2-8X in aggregate capacity.

### Acquisition Time

This important attribute is often neglected and under-rated. The acquisition is a per-burst overhead added to each radio transmission. It is a dominant cause of overhead loss of channel time with shorter bursts. It makes an Ack message a real luxury if it is very long. The components of the acquisition time are the acquisition of bit/symbol clock, adaptive equalization training, gain setting, antenna selection and a start delimiter. ***The benefit of a simpler modulation that is more robust against interference and fading may be reduced loss of channel time by the elimination of one or more of these acquisition functions.***

A significant factor in access delay to the channel is the burst length. A shorter burst not only improve access delay, but also reduces error exposure before an ack or resend can be obtained. Systems with longer acquisition times become biased toward longer bursts per transfer.

A modulation may have long acquisition time from recovery of a carrier reference frequency, or from a long training symbol with adaptive equalization. Regardless of the technical advantage, an acquisition time which is a material fraction of a 48 or 64 octet payload can seriously reduce payload throughput for a given bandwidth. Certain forms of channel coding and modulation enhance speed of acquisition of bit and symbol clock to as little as a few bits. After bit/symbol clock is acquired, a bit-stream-encoded start delimiter is normally transmitted as the last part of the acquisition sequence.

### Comments On PHY Proposals

Grouped into three classes, the six PHY proposals for the 5 GHz band have been summarized in P802.11-98/60. The proposals are considered as much as possible by their general characteristics representing a class. They are not the result of a careful study of the detail presented. It is possible that some characteristics may not be understood. Nonetheless, the comments should provide information useful in making a choice.

### ***OFDM—Lucent Technologies and NTT***

These well analyzed and presented technologies are the result of a tradeoff accepting fading to avoid intersymbol interference as a result of propagation time dispersion. It is many parallel slow-rate channels each conventionally phase modulated. The separation and selection is based on ***orthogonality after integration*** where energy from an adjacent channel is present but integrates to zero at the sampling instant. This method is economically workable only with a digital signal processor of some power.

### History

M. Doelz at the Collins Radio Co. in 1953-60 conceived implementations of phase shift keyed modulations of many types. One of these was "Kineplex" using 16 DQPSK carriers each positioned in the spectral nulls from the  $\sin x/x$  distribution of the others. The carrier spacing was 100 Hz enabling 3200 bps in 1800 Hz of the then available long

distance telephone lines. Using very high Q magnetostrictive resonators, the phase of the preceding pulse was stored for use as the reference for the current pulse. The resulting waveform was integrated over the central part of the symbol interval, sampled and discharged. This system and variants for HF ionospheric scatter propagation worked far better than any of the alternative contemporary methods.

C. Rypinski assisted by P. Walp and G. Somer at LACE, Inc. built a model of a 4 carrier modem for 20 Mbps over telephone pairs described to IEEE 802.9 in 1989. The carriers were at 2, 3, 4 and 5 x the symbol rate with each carrier modulated QPSK. The objective was to moderate the consequences of differences in velocity of propagation as a function of frequency for the telephone pair medium. The model was entirely satisfactory in operation, but was later abandoned for a much simpler and more effective method based on *a priori* knowledge of impulse response.

The common characteristic of these implementations was that *the required service was full-time duplex with exclusive use of the channel*. The properties important to packet traffic were not required, specifically: short acquisition time or a limitation of transmit ON to only when traffic is present.

### Architectural Limitation

An inherent consequence of 48 QPSK modulated carriers is that *one symbol is 96 bits of channel capacity and time*. Because data is transferred in 12 octet multiples, channel time will be used for fill and this may be a new MAC function. It also make the overhead burden for the sending of very short messages, very onerous. With 16-level, the one symbol transfer would be 24 octets—this alone is ample reason for dismissing 16-levels.

For example, the minimum response time to a poll or for an ack would be acquisition plus one symbol. This unsuitability for short bursts could be a disqualifying characteristic for the class.

### O-O-B Emissions Concern

There is an out-of-band emissions consideration that arises because of non-linearities in the power amplifiers. The spectrum shape is as expected with sharp cutoff on either side down to the point where the third order intermodulation appears. This point may be anywhere from 20 to 40 dB down depending on the linearity of the following amplifier chain. The less the backoff, the higher the level at which the third order intermodulation appears. The greater the backoff, the lower the power efficiency of the amplifiers.

Practical designs could require automatic gain control to stabilize transmit drive levels at the required backoff. It might be possible to accommodate some of the 3<sup>rd</sup> order intermodulation within the pass band by reducing the signaling transfer rate bandwidth at 3 dB down also *decreasing the capacity yield* from a given spectrum width.

Improvement in linearity has been demonstrated at lower frequencies by adding negative feedback at the radio signal frequency. For a number of reasons this is very difficult in the 5 GHz band.

### Interference and Fade Resistance Concern

Orthogonality between channels depends not only on the linearity of the transmitter and receiver amplifiers, but also that of the propagation medium. This makes support of this type of modulation with experimental verification in multipath radio environments very important.

Small degradations from medium time dispersion diminish the tolerance available to reject interference of various types. This may make actual systems less advantageous than might be expected when compared with the same carrier modulation on one wideband channel carrying the same amount of information.

### Recommendation

It is recommended that this modulation be considered only for binary and 4-level cases when compared with other modulations. It might also be considered with half or a fourth as many carriers.

Also the channelization and o-o-b emissions must be related to the FCC corner limits at allocation band edges and between channels including the the 37 dB down points.

### *Single Carrier Modulations (NEC, Breezecom, RadioLAN)*

A single modulated carrier is the default assumption, and should be used until good reason is shown for an alternative. The roots for the proposed modulations (MSK, QPSK, OQPSK) go back more than 40 years.

#### Background

The D in DQPSK warrants comments. *Differential QPSK has two meanings.* The original meaning was that the phase of the preceeding symbol is stored (in a ringing resonator) and used as a reference for the current symbol. This has the advantage of very fast acquisition of phase reference and reduced susceptibility to "hit" extension errors. It has the disadvantage of sensitivity degradation of threshold because the reference signal contains channel noise. When averaged by a high Q resonator, this degradation is less than the published 2 dB value.

The second meaning of D is that the code significance is not tied to absolute phase but rather a reversal is 1 and absence of a reversal is a zero. This eliminates the consequences of a 180 degree ambiguity in received phase.

The O in OQPSK is offsetting the in-phase and quadrature phase PSK signal by a half pulse width to achieve a near-constant envelope. Most of the filtering measures to reduce spectrum bandwidth produce envelope ripple in this case. A constant envelope modulation will generally produce 9 dB more signal power than the same amplifier in linear mode. To many designers, this advantage is very dear.

The point of the presentations of K. Feher was to show a method for a constant envelope modulation with lower out-of-band emissions when compared with MSK or many other bit-at-a-time filtering methods. (Note: Methods exist to obtain the linear reproduction of the baseband envelope without using linear rf amplifiers.)

It was early recognized (Doelz, Bruene—Collins Radio) that two quadrature phased offset PSK signals added are identical to the MSK signal. Both signals have a spectrum dominated by the  $\sin(x)/x$  distribution. For decades, the effort has been made to improve this situation with filtering usually in the modulation path to a VCO. The improvements including particularly GSM are marginal. The basic problem is that FM is non-linear and the connection between the bandwidth of the modulating signal and radiated signal is loose.

#### Recommendations

All proposals should be evaluated with 4-level modulation independently of higher level capabilities.

All of these systems should consider the use of the recommended partial response envelope shaping (though the NEC proposal appears to have achieved the end result already).

The NEC and Breezecom proposals should be consolidated into one.

The RadioLAN proposal should be dismissed for the reasons give below.

#### PPM Modulation

*PPM modulation* was extensively considered at Bell Labs in the 50's decade. The individual pulse is subject to the same spectral shaping problems as in other systems. With appropriate time dimensioning, the system can be made insensitive to multipath provided the signal from the shortest path is usable. The system is attractive for cost, ease of implementation and acceptable for power efficiency when compared with other methods with the same average power.

PPM modulation should be considered only for the four-position case with 2 bits per symbol. With one of 16 positions, the use of bandwidth is extravagant (4x bandwidth, 2x information).

The situation is different considering many such systems operating in the same space with overlapping coverage and a high level of usage. The system is probably vulnerable to detecting interfering signals in time space assumed to be empty.

However attractive this system is for isolated use, it will be lower in aggregate carrying capacity than all of the other systems considering an intensive frequency reuse environment.

### ***Single Carrier with Coded Symbol (Micrilor)***

This class of possibilities is well represented by the present lone contributor. This proposal probably offers the highest aggregate capacity from the spectrum, because of the use of a highly coded data symbol with more than 1-bit/symbol and codes to resolve overlapping coverage.

The key factor is whether in overlapping coverage, a user station can separate to signals of equal level solely depending on code differences. If this is possible, then all stations may operate on a common rf channel (using access points). If discrimination requires a positive S/I of a few dB, then a reuse factor of 3 or 4 is probably necessary. This should be compared with a necessary reuse factor of 16 or 25 for the present 802.11 modulations.

Given N approximately orthogonal codes, the space may be used either for increasing bits per symbol or for distinguishing between contiguous groups or coverages. If the ratio of codes used to symbol length is pushed very far, then degree of isolation between codes will be reduced. 2 bits/symbol from using two different codes is a valuable gain, but going beyond this point may require more conditional forms of orthogonality. Walsh codes provide orthogonality at a detector provided that symbol timing is known *a priori*. Interfering signals may be less cooperative about when they begin and end.

Use of GMSK for the channel modulation is a safe non-coherent detection choice, however the limit on o-o-b emissions would enable about 1.3X higher data rate in the same bandwidth using partial response shaping. This is NOT a change from non-coherent to coherent detection.

***A big advantage of this modulation plan is that in common with other DS systems it can work well without diversity, adaptive equalization or very much FEC.*** It can also provide very fast acquisition time enabling short messages to be transmitted with tolerable overhead.

### **Recommendation**

It is important for this modulation to attract support from other vendors on its merits for a success in 802.11. Those who understand and believe that this a fair representative of the class of coded channels should now step forward.

This proposal appears to carry the advantage of spread spectrum in obviating need for elaborate diversity, adaptive equalization and FEC which is most valuable.

***Multi-coded symbol spread spectrum modulation will also enable the use of 100% of the channel capacity with the smallest number of independent radio frequency channels when compared with the two other basic methods.***

The gain from the reduction of required channels is much greater than the loss from the multi-chip symbol when there are multiple codes per symbol used appropriately. This advantage is obtained with a propagation model using 34-38 dB/decade propagation loss (non-optical cluttered path). The advantage is diminished or canceled if there is "brick wall" separation of coverages, and this is suggested by a propagation model with 60 dB/decade loss beyond 50 meters.

No opinion is expressed on the coding detail, though it is believed competent.

### **Closing Comment**

The opinions above are not connected to the commercial interests of any Company including those of the Author.

Chandos A. Rypinski  
Member of IEEE 802.11 from beginning  
Life Fellow, IEEE  
Centennial Medal of the IEEE  
IEEE VTG Avante Garde Award  
Fellow, Radio Club of America