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Wireless LANs

Proposal for High Data Rate 2.4 GHz PHY With Variable Rate Binary Convolutional Coding on QPSK (VR-BCC QPSK)

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Author: Chris Heegard and Matthew B. Shoemake
Alantro Communications, Inc

141 Stony Point Circle, Suite 210
Santa Rosa, CA 95401
Phone: (707) 521-3060
Fax: (707) 521-3066
e-Mail: heegard@alantro.com, shoemake@alantro.com

Abstract

This document consists of a proposal by Alantro Communications, Inc. to the IEEE 802.11 Working Group. This proposal meets the requirements for the project authorization (PAR) for extension of the IEEE Std 802.11-1997 in the 2.4 GHz band to higher data rates.

Variable data rates are achievable by the proposed system. The variation in data rate is obtained through the use of punctured binary convolutional coding (BCC). The system uses QPSK modulation; thus the proposal may be referred to as VR-BCC QPSK, where VR stands for variable rate.

The system uses the same RF modulation as the low rate PHY that has already been approved in IEEE Std 802.11-1997. The addition of a channel equalizer and the powerful 64-state BCC makes the higher data rates robustly achievable.

Section 1 - General Description

The transmission scheme proposed is a variable rate system that uses a variable-rate binary convolutional code (VR-BCC) and modulates onto QPSK. The system operates at a rate of 11 million QPSK symbols per second and achieves data rates of 1, 2, 2.75, 5.5, 11, 14 2/3, 16.5, 17.6, 18 1/3 and 19.25 Mbps. A block diagram of the transmitter is shown below in Figure 1.1.

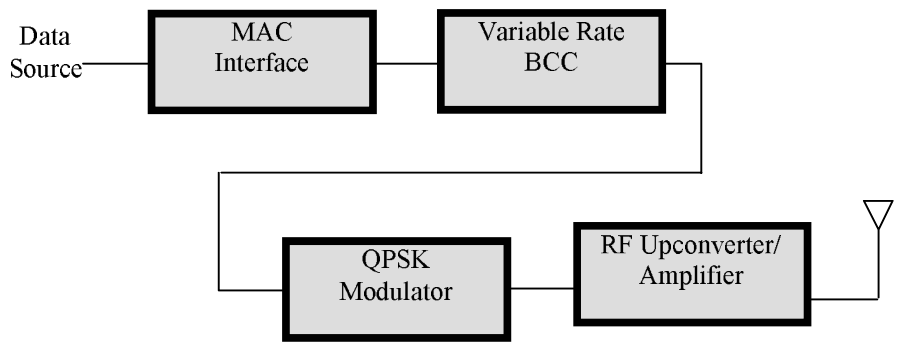

Figure 1.1

The use of a BCC for error control makes variable rate coding viable with little added complexity. A powerful and flexible method for changing the rate, known as *puncturing*, is used to obtain multiple rates from a single generator. In a punctured BCC multiple rates are obtain by periodically puncturing or omitting certain bits that are produced by the generator. This puncturing is done in a fashion that keeps the minimum free distance, d_{free}, of the BCC as high as possible, and as a secondary factor the number of nearest neighbors is minimized. The variable rate BCC block of Figure 1.1 also scrambles the output of the BCC in the payload section only. Generating a constant PN sequence and modulating the encoded data performs this function by it. This scrambling guarantees a randomized channel that among other things helps with noise and interference immunity.

The QPSK modulator and RF upconverter/amplifier remain unchanged from the IEEE 802.11 DS rate (1 Mbps and 2 Mbps) standard that has already been approved. Thus, the proposed system achieves the high rate specification for the 2.4Ghz range called for in the 802.11b PAR, by modifying the coding scheme only. The modulation rate, constellation, and frequency range remain the same as in the low rate standard.

The receiver may also use the same RF pre-amp, down converter and QPSK demodulator as used in the low rate standard. A channel equalizer must now be used to equalize multipath distortion that appears in the frequency band allocated for the standard. A typical receiver is depicted below in Figure 1.2.

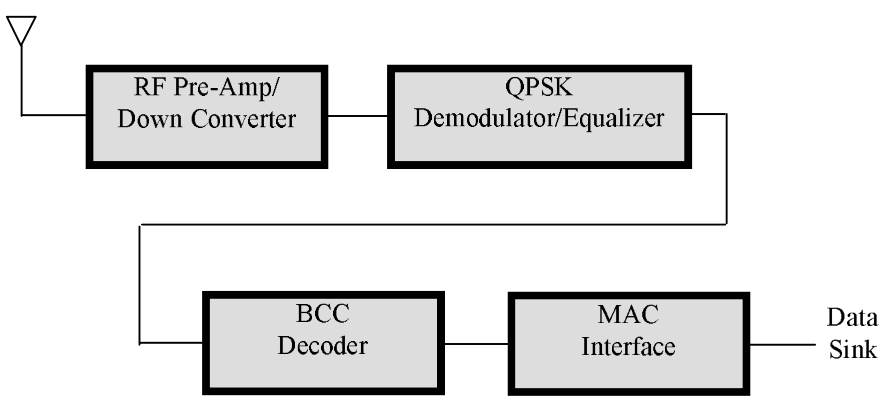

Figure 1.2

1.1 - Important Design Criteria

Given that the RF section remains the same as the existing standard, the critical design criteria may only exist in the BCC encoder and decoder and equalization of the channel. The encoder for the BCC is a finite state machine (FSM) with 64 states. The FSM is easily implemented with low complexity. The output of the FSM must then be punctured to obtain the appropriate rate. This may also be done with very low complexity by means of table look up, since all proposed puncture patterns have a very short period. Conventional means such as a minimum mean squared error linear equalizer (MMSE) or a decision feedback equalizer (DFE) may be employed to equalize the channel.

1.2 - High Level Benefits

The VR-BCC system proposed here exhibits excellent bit error rate (BER) versus signal to noise ratio performance. The choice of a strong error control code that may take advantage of soft decision decoding produces data streams with excellent free distance even after they are transmitted through a multipath channel with noise.

The primary rate of the system, the 11 Mbps mode, provides 550% more data than the existing 2Mbps standard with a cost of only 2dB in channel signal to noise ratio (SNR), Es/No. This data rate/SNR tradeoff is superior to all other proposed 10+Mbps systems.

The fact that the system is variable rate allows for it to adaptively change rates to maximize throughput for a given channel. For a channel that has excessive multipath and noise, the system may operate at a data rate of 2.75 Mbps. In this scenario a powerful rate 0.25 rate BCC with $d_{free} = 20$ is used. In this low rate mode, the data bits are modulated onto BPSK rather than QPSK, thus effecting a 3dB gain in Es/No. This code is capable of achieving a BER of 10^{-5} at an Es/No of –1.9 dB. Compared to the existing standard at 1 Mbps, this code operates at 1.2 dB less power and achieves a rate increase of 275%.

The 5.5 Mbps mode specified in this proposal uses the same code as the 2.75 Mbps mode, but the data is modulated onto QPSK rather than BPSK. This mode achieves a bit error rate of 10^{-5} at an Es/No of 1.1 dB. Compared to the existing 2 Mbps standard, the proposed system in the 5.5 Mbps mode operates with 1.2 dB less SNR and again achieves a rate increase of 275%.

The highest data rate that the proposed system may operate at is 19.25 Mbps. If the channel is equalized well, and the signal to noise ratio is good, the system will operate at this rate using a punctured BCC of rate 7/8. This mode is well in excess of the data rate achieved by 10 Mbps IEEE 802.3 networks.

The VR-BCC system is highly compatible with the existing 802.11. No modification to the RF section will be required. The proposed system uses the same frequency ranges, modulation schemes, modulation rates and same baud spacing as the previously approved low rate physical layer.

1.3 - Complexity

The complexity of the VR-BCC system is moderate and reasonable for a modern data transmission standard. For those who have already implemented the low rate physical layer, the following new pieces of the physical layer will have to be designed:

1) BCC encoder
2) Channel equalizer
3) BCC decoder

Each of these items may be implemented with currently available and standard technologies. No additional research will be required.

The VR-BCC system operates at a symbol rate of 11 Msps, thus with ideal pulse shaping; the required bandwidth is 11 MHz. The low rate physical layer divides the available bandwidth of 90 MHz into three channels of 30 MHz each. Thus in each 30 MHz channel, with ideal pulse shaping, 30 Msps could be transmitted. It is theoretically impossible to transmit an ideal bandpass (i.e., brickwall) spectrum, thus bandwidth expansion is always allowed. (In many systems a raised cosine waveform is used. In wireless systems that must operate with a serious power constraint, such pulse shaping techniques are impractical, since they require amplifier operation in the linear region.)

A bandwidth expansion factor is defined as follows:

$$\alpha = (BW_{used}/BW_{ideal} - 1) * 100\ \%$$

In the low-rate physical layer standard, a bandwidth expansion factor of 172% is used. Thus the modulation scheme itself exhibits a spreading gain of 30/11 ~ 4.3 dB of interference rejection. This same bandwidth expansion is a feature of the proposal.

The proposed VR-BCC uses the same RF modulation scheme as the low rate standard to maintain backward compatibility. Since the requirements of the PAR could be obtained by modifying the coding scheme only and equalizing the channel, the implementation cost and complexity is reduced by maintaining the same RF modulation scheme as the low rate standard.

1.4 - Weaknesses

The proposed system no longer modulates the transmitted data on a Barker chip sequence. The Barker chip sequence has the advantage that it is strongly correlated with itself at one offset and poorly correlated with it at all other offsets. A Barker sequence of length 11 is used in the low-rate standard. The Barker sequence used and its autocorrelation are shown below in Figure 1.3.

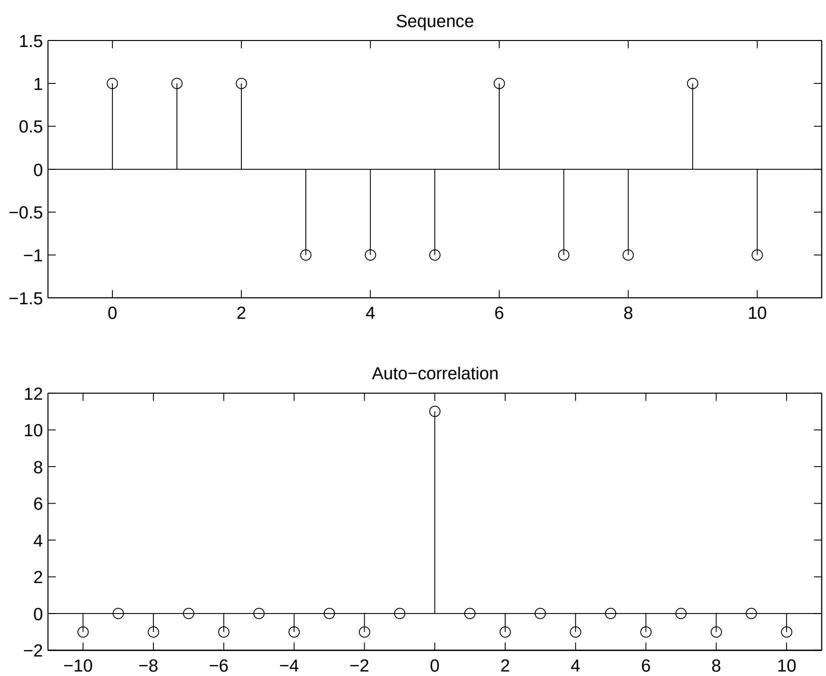

Figure 1.3 – Barker Sequence of Length 11 with Auto-correlation

Due to its strong autocorrelation at only one offset, the Barker sequence allows for the receiver to easily detect the transmitted data by correlating with the Barker sequence. This allows for a reduced complexity in designing the receiver. No equalizer is required at the receiver to achieve low error rates at 1 Mbps and 2 Mbps. The Barker sequence provides an excellent tradeoff between bandwidth and receiver complexity.

Unfortunately, at the rates set forth in the high rate PAR, bandwidth expansion for the sake of reducing decoder complexity is no longer possible. Strong error correcting codes must be used to come closer to utilizing the full capacity of the channel. The result is added complexity at the receiver. A channel equalizer must now be added at the receiver.

This trade-off is somewhat analogous to AM and FM radio. In AM radio, a modulation scheme is used that allows for a low complexity receiver, while in FM radio, the receiver is more complex, but the fidelity is higher than that of AM radio.

In the VR-BCC error control scheme the output of the error control code is modulated directly onto BPSK or QPSK without use of a Barker sequence or other sequence with good auto-correlation properties for assistance with detection and estimation at the receiver. This allows the increase in performance set out in the PAR. Fortunately, in the system proposed here, the increase complexity receiver is still easily implemented with off-the-shelf ASIC technology.

1.5 - Existing Standards with Similar Approach

The use of BCC's in wireless communications is not a new idea. BCC's have been proven effective in wireless systems with multipath, and they have been implemented as commercial products. The IS-95 standard for digital CDMA cellular phones uses a 256-state BCC. The GSM standard uses a four state punctured BCC. Satellite systems, such as the small disk digital TV systems (e.g., DirectTV & Primestar) always deploy such a BCC. In addition, BCC's have been proposed for the 802.11A (5.0 GHz) systems.

1.6 - PAR Criteria

1.6.1 - Broad Market Potential

Due to the high data rates achieved by this proposal, the requirements for broad market potential are met. The high data rates will allow the system to compete with, complement and co-exist with 10Mbps 802.3 networks. The higher rates will allow the possibility of MPEG video, video conferencing, etc. over the wireless network. The variability in rate adds to the robustness of the system by allowing the highest rate possible to be chosen for a given channel with small incremental steps in bits per second.

1.6.2 - Compatibility

The transmission function will have two levels of compatibility with the existing IEEE 802.11(DS) standard. In the most compatible mode, all packets will use the existing long preamble on all packet transmissions. In this mode, all receivers (existing and advanced) will process the preamble of all detected packets; high-speed packets will communicate at the higher rate only in the payload portion of the packet. In the alternate mode, a new high performance preamble will be used for more efficient data transmission. This short preamble will incorporate a design that will aid in the determination of the characteristics of the channel impairments. In this alternative mode, existing product will be able to communicate using the existing standard, via simple energy detection methods, while the newer products can operate at improved throughput. In all cases, the existing IEEE 802.11 MAC protocols and frame structures will be fully supported.

1.6.3 - Distinct Identity

As with the low rate PHY, the high rate PHY extension proposed here will allow the IEEE 802.11 standard to specify a reliable wireless communications system for LAN purposes that is not covered by an other standards body. The extension to high rate will make the 802.11 physical layer specification even more distinctive, since it will substantially increase the data rate to a point that will be competitive with wire based networks. This will allow systems meeting the specification of the high rate system to complement 10 Mbps 802.3 networks.

1.6.4 – Technical Feasibility

The feasibility of the system is demonstrated rigorously in Section 2 of this document. It is shown that the VR-BCC system using the same RF transmitter and receiver along with an equalizer at the receiver can obtain excellent PER versus Eb/No results under a wide array of channel multipath scenarios. The technical complexity of implementing BCC's and equalizers are well known, thus the feasibility of implementation has not only been demonstrated in many instances, but it is well known to a large audience. The technical feasibility has been demonstrated adequately enough that at least one vendor has already agreed to deploy the system described herein.

1.6.5 - Economic Feasibility

The economic feasibility of this proposal is in line with that of the low rate system. Since this proposal is an extension of the low rate system and the target users are similar, the feasibility may be evaluated by analyzing each part of the proposal that differ from the low rate system and determining the economic effect piecewise.

The BCC encoder requires a finite state machine with 64-states to implement. A Viterbi decoder may be implemented at the receiver to decode the BCC. An adaptive or automatic equalizer may be added at the receiver to equalize the channel and deal with the intersymbol interference due to multipath and other forms of interference. Each of these items may be implemented with off-the-shelf ASIC technologies similar to those used in the low rate PHY.

Parts for the RF section have already been developed and commercially sold and may be obtained at reasonable cost.

Section 2 - Comparison Data for VC-BCC 2.4 GHz High Rate PHY

Processing Gain (P.G.) is the sum of three terms: (1) the Coding Gain (C.G.) which is a function of the error controlling capability of the code, (2) the Waveform Gain (W.G.) which follows from the excess bandwidth (e.g., an 11Msps system that occupies a 30MHz channel has a gain of 30/11 = 4.3573dB) and (3) the Rate Gain (R.G.) that measures the improvement in the signal to noise ratio that follows from a reduction in the information rate. Table 2.1 below lists the processing gain for each of the high rates proposed.

Code System	Mod	Data Rate (@11MHz)	Code R (bits/sym)	C.G.	W. G.	R.G.	P.G.
11 Barker	BPSK	1Mbps	1/11	0dB	4.3dB	13.4dB	17.7dB
11 Barker	QPSK	2Mbps	2/11	0dB	4.3dB	10.4dB	14.7dB
(4,1) v=6 BCC	BPSK	2.75Mbps	1/4	5.6dB	4.3dB	9.0dB	18.9dB
(4,1) v=6 BCC	QPSK	5.5Mbps	1/2	5.6dB	4.3dB	6.0dB	15.9dB
(2,1) v=6 BCC	QPSK	11Mbps	1	5.4dB	4.3dB	3.0dB	12.7dB
(3,2) v=6 BCC	QPSK	14.6Mbps	4/3	5.2dB	4.3dB	1.8dB	11.3dB
(4,3) v=6 BCC	QPSK	16.5Mbps	3/2	4.5dB	4.3dB	1.2dB	10.0dB
(5,4) v=6 BCC	QPSK	17.6Mbps	8/5	4.2dB	4.3dB	1.0dB	9.5dB
(6,5) v=6 BCC	QPSK	18.3Mbps	5/3	4.1dB	4.3dB	0.8dB	9.2dB
(8,7) v=6 BCC	QPSK	19.2Mbps	14/8	4.0dB	4.3dB	0.6dB	8.9dB

Table 2.1 - Processing Gain for the VR-BCC /QPSK system

The *Additive White Gaussian Noise* (AWGN) performance is shown in terms of the channel *signal to noise ratio* (SNR), Es/No, and on a rate adjusted SNR, Eb/No, in Table 2.2. The complexity shows the number of additions and comparisons required to decode each bit of information.

Code System	Mod	Data Rate (@ 11MHz)	Code R (bits/sym)	Es/No (10^{-5})	Eb/No (10^{-5})	Adds (per bit)	Cmps (per bit)
11 Barker	BPSK	1Mbps	1/11	-0.7dB	9.7dB	10	1
11 Barker	QPSK	2Mbps	2/11	2.3dB	9.7dB	10	1
(4,1) v=6 BCC	BPSK	2.75Mbps	1/4	-1.9dB	4.1dB	152	64
(4,1) v=6 BCC	QPSK	5.5Mbps	1/2	1.1dB	4.1dB	152	64
(2,1) v=6 BCC	QPSK	11Mbps	1	4.3dB	4.3dB	132	64
(3,2) v=6 BCC	QPSK	14.6Mbps	4/3	2.7dB	4.5dB	99	48
(4,3) v=6 BCC	QPSK	16.5Mbps	3/2	7.0dB	5.2dB	88	42.7
(5,4) v=6 BCC	QPSK	17.6Mbps	8/5	7.7dB	5.5dB	82.5	40
(6,5) v=6 BCC	QPSK	18.3Mbps	5/3	6.4dB	5.6dB	79.2	38.4
(8,7) v=6 BCC	QPSK	19.2Mbps	14/8	5.1dB	5.7dB	75.4	36.6

Table 2.2 - AWGN Performance and Complexity of the VR-BCC /QPSK system

2.1 - Receiver Structure

Implementation

- RF/IF complexity is exactly the same as the low rate PHYs.
- The baseband processing required is the same at the low rate PHYs.
- Equalizer complexity may vary, since vendors may decide to use differing types of equalizers. The proposed system has been successfully decoded with several types of equalizers including DFE, FIR MMSE, and recursive zero-forcing equalizers.
- It is expected that typical gate counts will be as follows:

QPSK Demodulator/Equalizer	44k-55k
BCC Decoder	28k-35k
MAC Interface	4k-5k
TOTAL	**76k-95k**

2.2 Immunity to Multipath Noise

To analyze the tolerance of the VR-BCC/QPSK system, simulations have been run in multipath channels to determine PER versus Eb/No for various values of Trms. This simulation was run for packet lengths of 64 and 1000 bytes. The results are shown below in Figures 2.1-2.3. In figures 2.2 & 2.3, the left most plot indicates the performance of the system with no multipath. These simulations have only been run for the 11 Mbps rate.

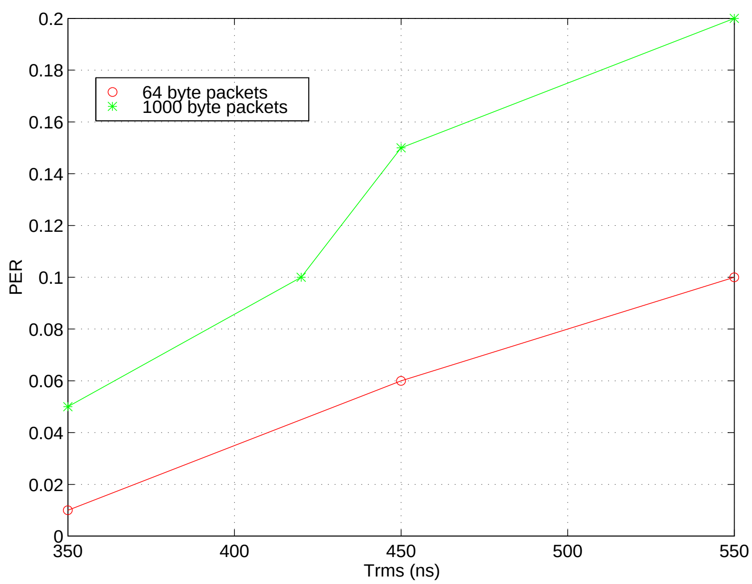

Figure 2.1 – PER versus Trms (No Noise)

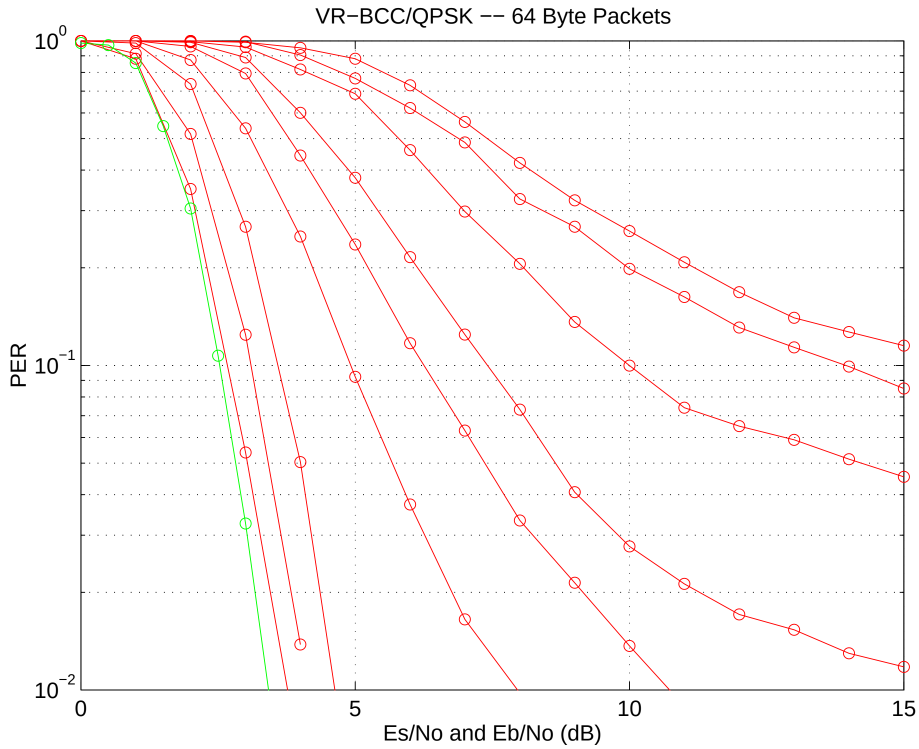

Figure 2.2 – 64 Byte PER vs. Es/No for 11 Mbps No Multipath Case Shown as well as Multipath Cases with Trms = 25, 50, 100, 150, 200, 250, 350, 450, 550 ns

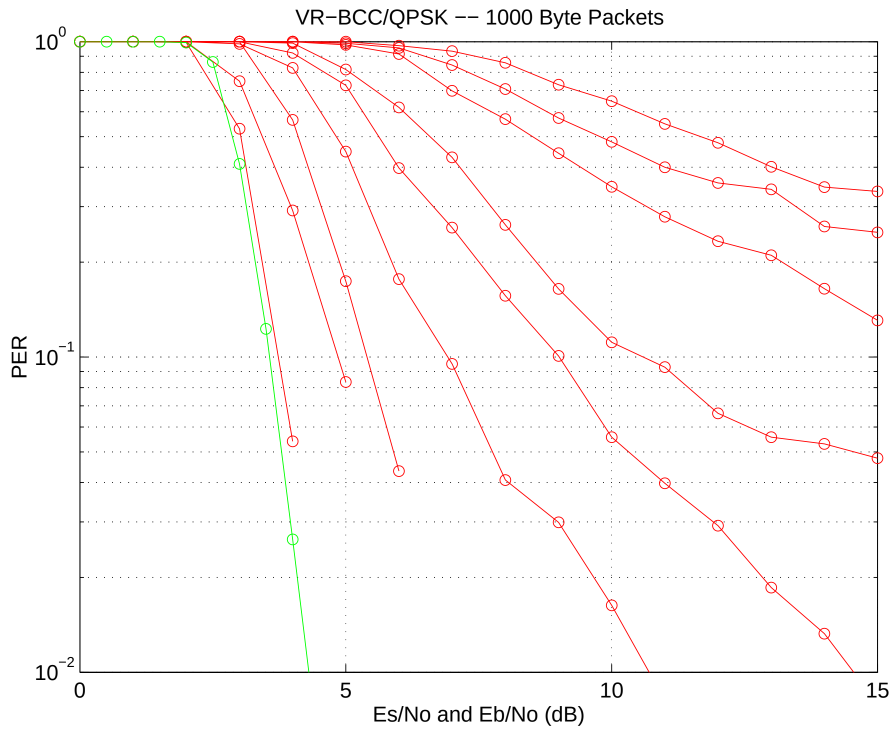

Figure 2.3 – 1000 Byte PER vs. Es/No for 11 Mbps No Multipath Case Shown as well as Multipath Cases with Trms = 25, 50, 100, 150, 200, 250, 350, 450, 550 ns

System performance for channels with AWGN but with no multipath are shown in Figures 2.5 – 2.8 for all rates versus Es/No and versus Eb/No.

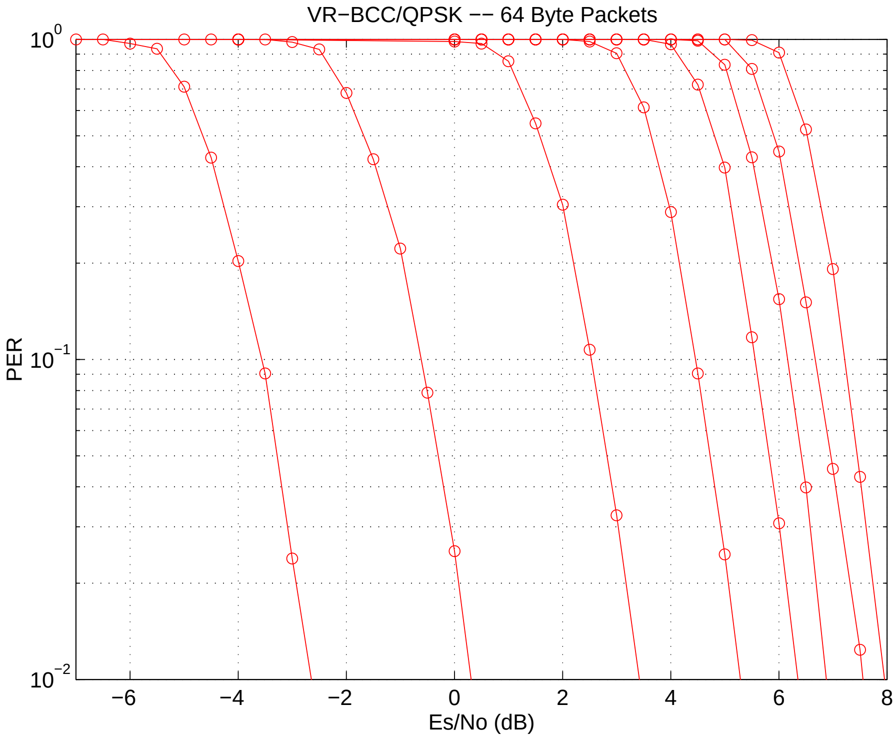

Figure 2.5 – 64 Byte PER vs. Es/No (AWGN only)
Rates of 2.75, 5.5, 11, 14.7, 16.5, 17.6, 18.3 and 19.25 Mbps (from left to right)

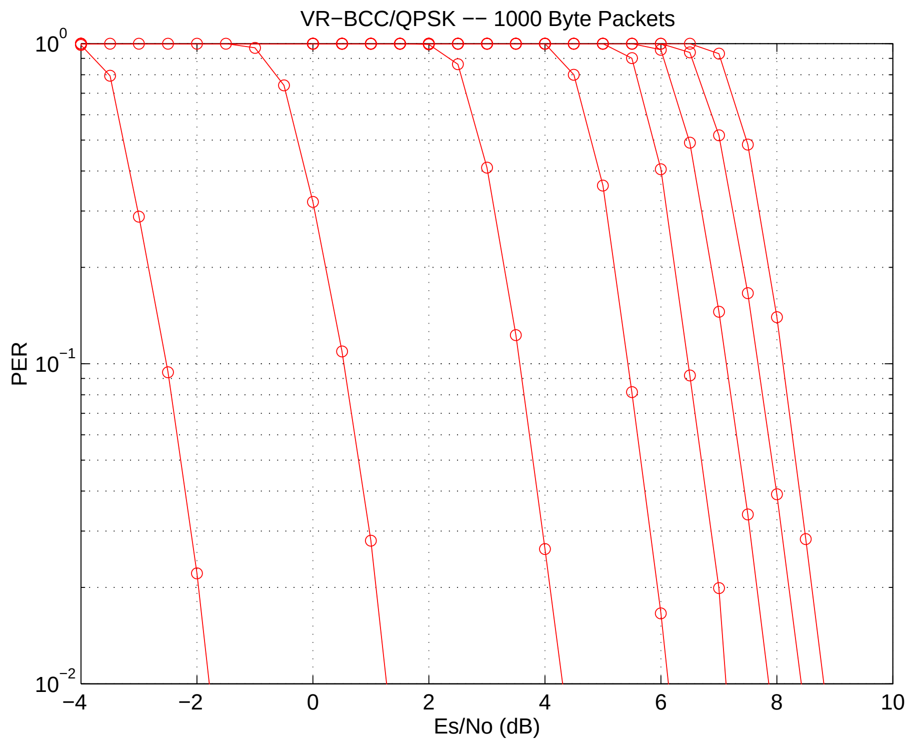

Figure 2.6 – 1000 Byte PER vs. Es/No (AWGN only)
Rates of 2.75, 5.5, 11, 14.7, 16.5, 17.6, 18.3 and 19.25 Mbps (from left to right)

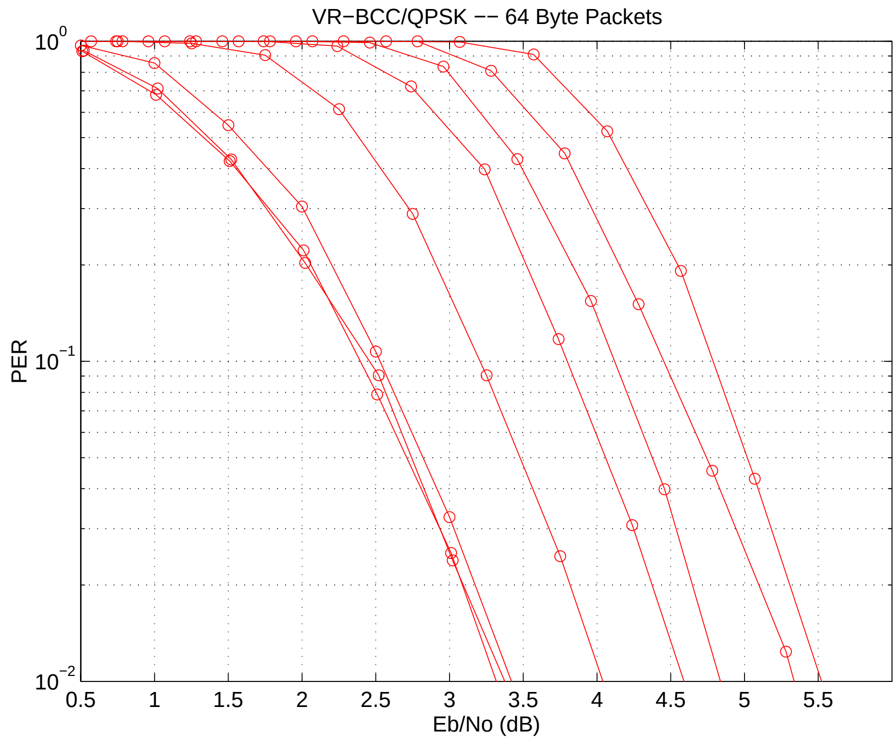

Figure 2.7 – 64 Byte PER vs. Eb/No (AWGN only)
Rates of 2.75, 5.5, 11, 14.7, 16.5, 17.6, 18.3 and 19.25 Mbps (from left to right)

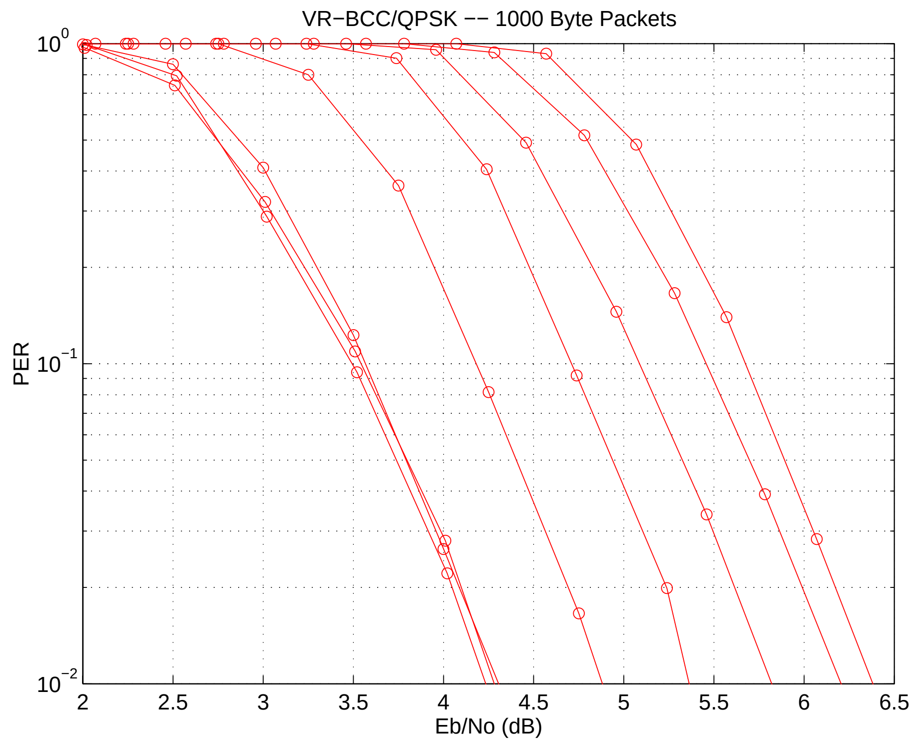

Figure 2.8 – 1000 Byte PER vs. Eb/No (AWGN only)
Rates of 2.75, 5.5, 11, 14.7, 16.5, 17.6, 18.3 and 19.25 Mbps (from left to right)

2.3 - Overhead Related Parameters

2.3.1 – Preamble Length

The length of the preamble will depend on the level of compatibility with the existing 802.11 1/2Mbps DS PHY. The preamble will be used to extract packet and channel parameters such as: start of frame, signal level (AGC), baud timing/phase, carrier timing/phase, and multipath/interference parameters.

In the most compatible mode, the existing preamble will be used in all packet transmissions. This has the advantage of the highest level of compatibility but with a cost of loss in aggregate network throughput and efficient parameter estimation.

With the second, high performance preamble, a smaller overhead is incurred on high rate packets. This preamble has been designed to provide high performance estimates of needed functions such as packet detection, channel parameter estimation and other header functions. Use of this preamble in a mixed environment, which contains legacy 802.11 DS hardware, is possible via MAC co-ordinated transmission. In such a mixed mode environment, the standard rate equipment would be allocated bandwidth on an "as needed" basis. In a pure, high-rate environment, only the transmission of high performance preambles will occur.

2.3.2 – Slot Size

The current, low rate, standard DS standard specifies a slot time of 20 μs. This slot time is also achievable for the high rate standard proposed here. This detection may achieve to a level of 90% confidence by baud detection means. For power consumption reasons, it is not desirable to enable the equalizer and BCC decoder to determine if the channel is being used, thus additional, low-power circuitry will be used to detect channel activity. The equalizer and BCC decoder will be powered down during the detection operation.

2.3.3 – SIFS Time

The SIFS time required for the proposed system is estimated as a sum of several delays. Table 2.3 shows each delay along with the expected or measured value for the VR-BCC/QPSK system. The total in the last row of the table is an estimate of the required SIFS time.

Latency of receiver	2-3 μs
Delay of equalizer	1-2 μs
Delay of BCC decoder	1.6-3 μs
CRC check	1 μs
Tx/Rx turnaround time	3-6 μs
Air propagation time	1μs
TOTAL	**9.6 – 16 μs**

Table 2.3 – SIFS Time

2.4 – Spectral Efficiency and Cell Density Related Parameters

2.4.1 - Channelization

The channelization use is identical to that used in the existing 1 and 2 Mbps DS PHY. The frequency range of 2.412 GHz to 2.484 GHz will be divided into 14 overlapping channels of 30 MHz each. The 14 channels have center frequency that are spaced by 5 MHz, just as in the low rate standard. As with the low rate standard this channelization is very flexible internationally. The channels used from country to country may vary with the rules set out by each individual country's regulatory agencies.

2.4.2 – Cell Planning

The recommended cell planning for non-overlapping cells is as follows and as shown in Figure 2.9. Cells 1,2, and 3 use non-overlapping channels approximately 30 MHz apart. There is not great separation and there would definitely be some interference from nearby cells on the same frequency, but it better than complete overlapping. This layout would work using channels 1,6 and 11 based on the channelization scheme being proposed. On the minus side, this layout causes some problems when roaming from one cell to another since a station would need to check three RF channels before selecting the frequency (i.e. cell) it would use. This could cause some latency in switching cells especially in heavily loaded environments. Due to this latency the user may notice a problem when roaming from one cell to another.

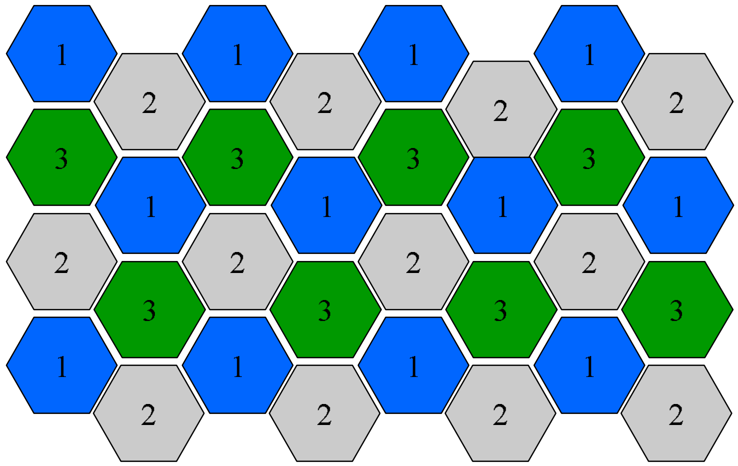

Figure 2.9 - Cell Planning Scheme

2.4.3 – Adjacent Channel Interference

Due to the large bandwidth expansion factor used in this system, it is not difficult to highly attenuate interference from adjacent channels with an analog filter in the RF section that highly attenuates frequencies outside the band of interest. These undesirable frequencies may be attenuated to a point that they have very minimal if any effect on the PER performance of the system.

An analog filter may be designed that drops 37 dB in less than 1 MHz. If such a filter where used, it would for all practical purposes eliminate adjacent interferers. The transmitted signal would still enjoy more than 28 MHz of available bandwidth to transmit a signal at 1 Msps.

2.4.4 – Co-Channel Interference

Due to the fact that the proposed new rates no longer incorporate the Barker sequence as in the low rates, co-channel interference is minimized. Once a training sequence is sent, the channel is equalized to the proper transmitter. Co-channel interference from another undesirable transmitter now looks very much like AWGN since it is no longer chipped by a short spreading sequence.

In addition, the payload section of the frame, which represents the majority of channel traffic, enjoys added immunity, because it is modulated by a constant PN sequence. This PN sequences causes the codeword generated by the VR-BCC to be mapped to a coset of itself. At the receiver this means that it is extremely unlikely that data from an interfering transmitter would resemble a valid codeword at all, and thus would again seem like highly uncorrelated noise.

2.4.5 – Interference Immunity

The FCC proposes that a *processing gain* of 10 dB be achieved by systems operating in the frequency band that is our target. The FCC defines processing gain as the ratio of the SNR required to achieve the desired BER or PER when there is no coding, spreading or other such processing, divided by the required SNR to achieve the same performance when coding, spreading, etc. are enabled. The processing gain for interference immunity achieved by the system proposed here is shown in the last column of Table 2.1.

2.5 – Critical Points

The proposed system is of greater complexity than some other proposals that have been submitted. However, the complexity required to implement this design is not excessively restrictive. The proposed system exhibits substantial performance improvements that warrant the increase in complexity.

2.6 – Intellectual Property

The required intellectual property statements have been officially made and submitted to the IEEE 802.11 working group as document IEEE 802.11-98/83.

2.7 – Interoperability/Coexistence

Since the modulation occupies the same bandwidth as the current system, interpretability and coexistence is possible but at a price. Interoperability would limit the usefulness of the high data rate capabilities and carry with it significant overhead in lost channel capacity. Interoperability would imply that all management level type frames would be sent at the lowest data rate, the PCLP header remains the same as the current DS header and that the PLCP header goes out at the lowest data rate. For the higher data rates an additional training sequence at the higher data rate would be required during the PLCP.

To avoid these overhead problems make interoperability an optional feature. When operating in a high/low rate environment using the exiting PLCP and if a high data rate frame is sent require an extension to the PLCP at the higher rate for training the adaptive filter. When operating in a high rate environment use the proposed PLCP header. The PLCP and management frames would be sent at the 5.5 Mbps rate and the remainder of the frame would be sent at the desired data rate. This will complicate MAC level CCA computations due to the variety of data rates and some throughput will be lost since the MAC only supports time expressions in microseconds.

Interoperability and coexistence are also address in Section 1.6.2 as a PAR criterion.

Section 3 - Summary

Modulation Technique: QPSK

- 1, 2, 2.75, 5.5, 11, 14.7, 16.5, 17.6, 18.3 and 19.25 Mbps data rates supported.
- Use of the punctured binary convolutional codes.
- Moderate implementation complexity.
- Three non-overlapping 30 MHz channels available over the 2.4 GHZ ISM band.
- Fully interoperable with 1,2 Mbps DS IEEE 802.11 systems.
- Fully compliant with the IEEE802.11 defined MAC.
- Short high rate preamble available for improved throughput.

Section 4 - Conclusions

The VR-BCC modulation and coding approach for high rate 2.4GHz PHY forms the basis of the proposed high rate physical layer. The design provides a highly backward compatible and cost efficient means to robustly transmit data at a variety of higher rates that meets and exceeds the requirements of the PAR. The system achieves its excellent performance by using a punctured, variable rate binary convolutional coding scheme that has been successfully implemented in other communications systems such as the IS-95 standard for digital cellular telephones. The proposal is highly backward compatible with the low rate PHY on a number of levels including backward compatibility with the packet preamble and the entire RF/IF subsystem. The proposal does include a higher rate preamble that will improve throughput and still allow compatibility with the low rate PHY. Due to these factors, there is already one vendor committed to implementing the system as proposed here. Upon evaluation of this system by IEEE 802.11 members and other vendors, it is believed that the virtues of this proposal will become quite apparent.