

IEEE P802.15
Wireless Personal Area Networks

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Title	Case for DOQPSK High-Rate Physical Medium Modulation		
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Re:	PHYsical layer modulation detail		
Abstract	<p>Optimized for high tolerance of random and like-signal interference. Constant envelope for higher transmitter PA efficiency. Use I and Q phase for parallel transmission of two bit streams in one channel. Simple decode without rf phase lock on received carrier for LO. Fast acquisition and recovery from propagation-caused phase reversal. Simple radio implementation</p>		
Purpose	To illustrate less obvious factors that should go into the development of the PHY portion of the standard, and to encourage discussion of the tradeoffs that will eventually shape the conclusion reached.		
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Case for DOQPSK High-Rate Physical Medium Modulation

Criteria for Selections

The choice of modulation depends upon what the optimization criteria may be. The selection used includes the following points:

- Simplicity of implementation
- Near constant envelope amplitude
- Resistance to like-signal interference
- Spectrum efficiency

The generation and demodulation of the signal will be described, and then the desirable properties will be asserted under the above criteria. This is a classic modulation already much used, so no effort will be made to present background already well covered in the literature.

Generation of the OQPSK Signal

A reference carrier at the radio frequency is applied in quadrature phase to two mixers. The input to the two mixers is two data signals in which the bit timing is offset by a half bit. It is assumed that one data stream is the odd-numbered and the other the even-numbered bits.

If the bit streams are rectangular logic-level signals, then the spectra of the output is like the well known $\sin(x)/x$ function for square waves. The first pair of minor lobes are about 16 dB down, and they have significant amplitude for many lobes from the main lobe. Less obvious is that the first nulls can be made to move somewhat closer together.

Pulse Shaping with LC Filters

It has been long recognized that phase change done instantaneously is undesirable. Shaping the spectrum of the modulating pulse with a near constant-delay low pass filter (eg., Bessel) is a common and minimal improvement.

The amplitude of the first side lobe can be reduced to 20-24 dB down by this means.

Pulse Shaping with FIR Filters

FIR filters with a length of 5-8 pulse widths can make a big improvement in the side-lobe level depending on the accuracy of tap amplitudes and the linearity of following elements.

Mathematical analysis has provided a predicted spectrum for various numbers of taps and precision in the components. Some of this work could be available for presentation. Even with this, it is not obvious (to this contributor) where the economic tradeoff lies between complexity and benefit. It is unwise to try for too much suppression, because non-linearity in other elements of the system will limit what is actually achieved.

The amplitude envelope with this type of filtering will not be constant, but will have a small amount of ripple. An isolated pulse shape and the envelope shape after assembly into a bit stream are shown in Figures 1 and 2 attached. Depending on the window width of the filter and the accuracy of the tap setting, the amplitude of the first sidelobe can be reduced to 24-30 dB down, and the nulls can will be moved closer in relative to the square wave value. Sidelobe's further out will also be reduced.

A need for this type of filtering would be created by closer stacking of adjacent channels, or an effort to use frequency space closer to the band edge to achieve the necessary "quiet" band control of OOB emissions. This consideration will be a factor in channel definition with respect to the 5.150 GHz band edge.

If this type of filtering is not defined in the standard, the maximum data rate for a fixed channel plan will not be achieved. If the standard defines the channel plan and a worst case emissions limit in the adjacent channel (but not shaping method), then those using this method will achieve a materially higher data transfer rate.

Differential Demodulation of the OQPSK Signal

At either signal or intermediate frequency, an I and Q (vector) demodulator circuit is required. A local oscillator that is very close the incoming signal carrier frequency (but not phase-locked), is applied to each of two mixers in quadrature phase. The incoming signal is split and applied to the mixer inputs. The separate mixer outputs are then amplified linearly to processing level. This amplifier should have AGC. It is believed that the video amplifier may be limiting for signals well above threshold.

Bit Clock Recovery Required

It is necessary to recover bit clock for the detection process. An easy way to do this is to use a burst preamble in which one phase is OFF and the other is modulated by a sine wave at half the isolated phase bit rate. The resulting signal will be DSBSC (double-sideband, suppressed-carrier) result. The amplitude nulls provide the information to adjust a local clock to the correct phase to mark bit intervals. It is estimated that less than 16 pulses will be required to bring the bit clock within $1/32^{\text{nd}}$ of a bit interval.

With bit clock, there is then sufficient information present at the I and Q linear outputs to demodulate the signal.

Bit Clock Accuracy

Since the bit clock rate is known *a priori*, the clocks in the system should be accurate enough so that an adjustment made on the burst preamble is good enough to coast for a few thousand octets before the timing needs to be refreshed.

A reasonable opening specification for a bit clock crystal accuracy is 10 ppm at the station and 2.5 PPM at a powered access point controller.

Differential Data Recovery

Data recovery depends upon knowing that the current sample corresponds to either 180° or 0° relative to the previous sample. The "D" in the modulation definition means that the information is in the current phase relative to the phase of the previous symbol.

The sampling time is derived from the recovered bit clock. The knowledge of the angle of each sample is gained from the x and y intercept values. This process occurs independently and concurrently for the I and Q phase outputs. Detail beyond this point is implementation specific.

This demodulation is almost the same as coherent. Near threshold, there is noise in the reference that is not present with strictly coherent demodulation. The threshold is perhaps 1 dB higher than for the noise-free reference. Pure coherent modulation is expected to be 3 dB better than non-coherent because half of the noise is ignored. It should be appreciated that the basic noise bandwidth of the coherent modulation is lower than is usual with non-coherent demodulators (e.g., discriminators and envelope detectors), and this is not considered in the 3 dB difference stated. The main reason is that the low pass filters associated with the vector demodulator can be much more tightly fitted to the signal than for the pre-detection filtering with non-coherent.

Radio Design

A block diagram of a possible design for a direct conversion NII band radio would contain the following elements:

- 5 GHz ASIC containing T-R switch, LNA and PA
- Receive vector demodulator ASIC
- Transmit vector modulator ASIC
- Receive baseband dual channel video amplifier with AGC ASIC
- Receive baseband signal processor including
 - Bit clock recovery and local generator
 - Vector demodulation circuit
 - Data output regenerator and valid indicator
 - Embedded channel decoder/dewhitener
- Transmit data input signal conditioner
 - Dual active FIR or Bessel lowpass filters
 - Embedded channel coder/whitener

It should be noted that the function describe in *Differential Data Recovery* above is contained in the *receive baseband signal processor*.

It is possible to use a single vector mixer with T-R switching instead of the two separate listed above. It is not presently clear that there is a single 5 GHz mixer component. The circuit can be built from two single mixer IC's, a quadrature hybrid and $6/4^{\text{th}}$ hybrid.

The area of this radio-processor unit would be less than that of a two-patch antenna. It is imagined as hip-mounted with the long dimension vertical.

Standards Implications

Users will want to know what service range can be expected from the system. It will be important to have consistent receiver performance between vendors to support this expectation. Though few users will understand this, it is also necessary to know the co-channel and adjacent channel interference tolerance. If the standard does not address these points, the result can vary widely between vendors.

Obviously, all features of the air-interface including channel plan should be part of the standard.

Range and Receiver Performance

In the case of a radio system, range is almost one of the first questions. Historically, radio has been defined by the transmitted signal, alone. The range question is quite dependent on the receiver and the implementation of the demodulation function in the receiver..

With antennas at a given spacing, the power margin could be measured (if transmitter power output can be controlled and calibrated). This would be a useful specification that would include receiver performance. This specification could be set to discourage non-coherent detection methods.

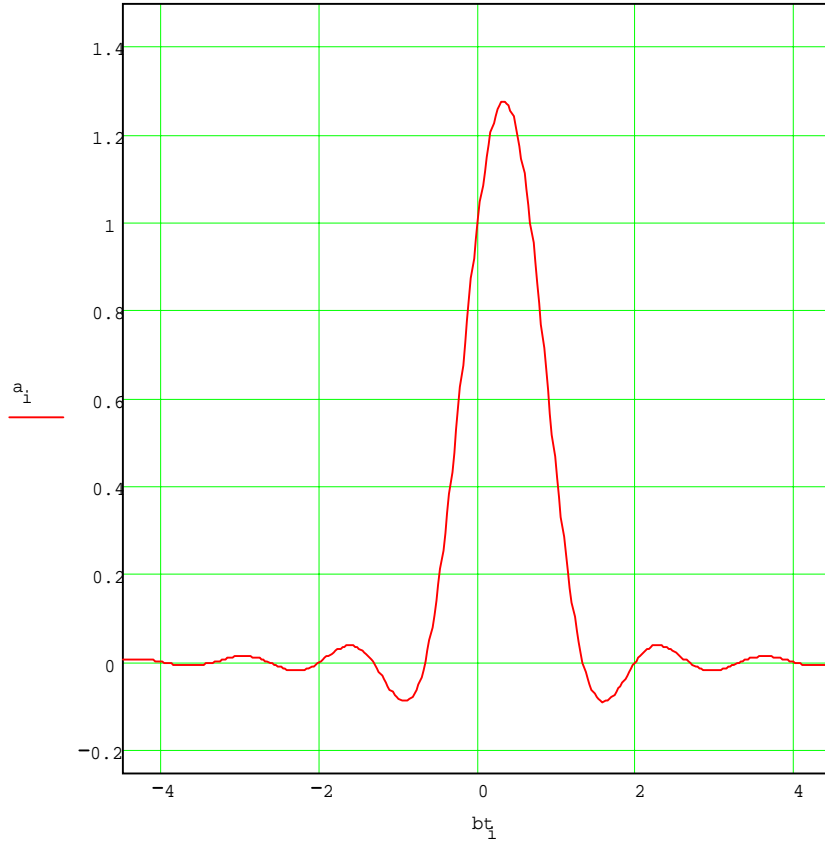
Transmit Spectrum Shape and Channelization

The FCC Section 15.4 rules specify -27 dB down as the channel edge. There is no specification about the utilization of the space within the channel edges. For a 20 Mbps medium transfer rate, a 14 MHz nose bandwidth might result—easily with FIR filtering, and harder to do with Bessel filtering.

A possible channel scheme would be five 20 MHz channels with a footnote: Usable only with appropriate control of OOB emissions below 5.150 GHz. In addition, four interleaved channels should be defined with center frequencies at the edge boundaries of the first five channels and with the lowest of these footnoted in the same way. The interleaved channels could be quite useful against marginal interference from reuse at a distance. There is a use pattern possible for nine channels which is much better than with four channels.

(END text—Figures appear on the following pages)

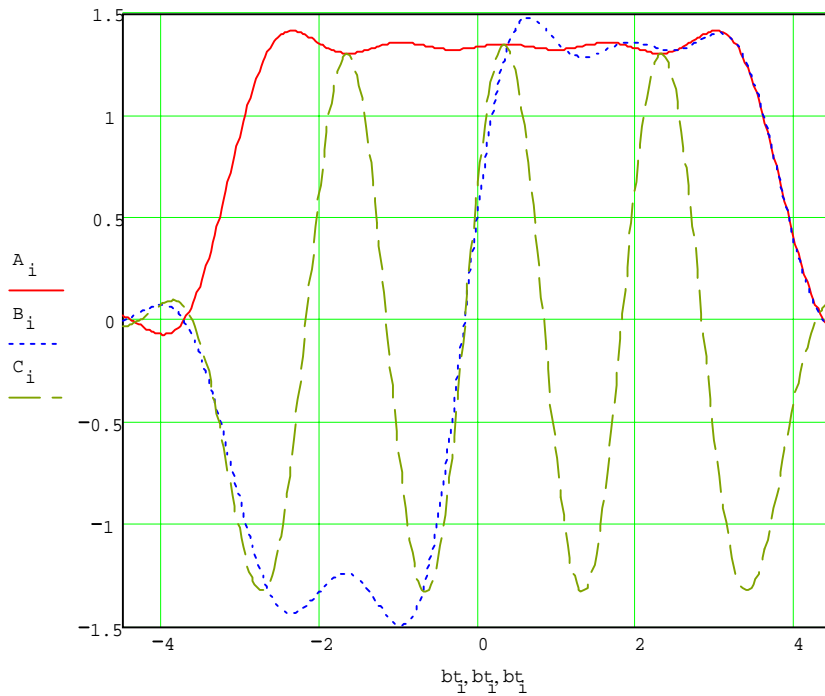
Figure 1
Isolated Pulse
Shape
Formed by FIR
Filter



Single Isolated 2/3rds Width Duobinary Pulse for NRZST

Figure 2
Data Pulse Shape
for 8 Consecutive
Bits in Four
Patterns

Note: Ripple shown



Bit Patterns 1111111, 0001111 and 0101010

ATTACHMENT COMPARING 802.11x VS. TIBURON

Comparison of 802.11x Standards With 802.15 “Tiburon” Proposal

It is now assumed that the radio aspects described in this document become the choice of 802.15. This radio bears the acronym “Tiburon” in the description below. Shown in Table I are the key attributes of several now-defined short-reach radio systems. The estimates for Tiburon do not assume use of FIR filtering.

Table I—Relative Function of Main Short-reach Radio Systems

<i>Property</i>	<i>802.11ⁱ existing</i>	<i>BlueToothⁱⁱ</i>	<i>802.11b high-rate</i>	<i>Hiper- LAN/2</i>	<i>802.11a high-rate</i>	<i>TIBURON 3 System</i>
PHY band	2.4 GHz ISM	2.4 GHz ISM	2.4 GHz ISM	5.470-5.725 GHz ETSI	5.15-5.35 GHz NII	5.15-5.35 GHz NII
Modulation	MSK	GMSK	Vector	OFDM ⁱⁱⁱ	OFDM	OQPSK(m)
Data speed	1.0/2.0 Mbps	0.8 Mbps	5.5/11 Mbps	12/18 Mbps QPSK	12/18 Mbps QPSK	8/16 Mbps
RF chnls	25(fh), 3(ss)	Na	3 (fdm)	19 (eu)	8 (usa)	8 (fdm)
Protocol	CSMA/CA		CSMA/CA	Cntrl Ctl ATM cell relay	CSMA/CA	Cntrl Ctl payload relay
Fwd error corr	None	None	Yes	½ or ¾ conv	½ or ¾ conv	None
Dly spread tol	na	na	150 ns	250 ns	250 ns	60 ns
Equalizer	No	No	Yes	No	No	No
Xmt pwr	+24 dBm	+10 dBm, lower EIRP	+24 dBm	1 W EIRP	.25/1 W EIRP	+12 dBm max EIRP
Size w/o btry	PC card	1 in ³	PC card	na	Na	<2 in ³
Battery drain	Med	Low	Med	High	High	Low
Acquire time	>25 µsec (?)	(?)	>20 µsec (?)	20 µsec	20 µsec	2.5 µsec
Range est	100 m (serv) 300 m (intfc)	10 m	300 m	>200 m	>200 m	25 m (small) 75 m (full)
Multi-rate	Yes (adap)	No	Yes (adap)	Yes (adap)	Yes (adap)	Yes (cnfg)

Comparison Based on Characteristics

The properties needed by 802.15 HRSG are low:

Cost
Weight
Battery drain

Acquisition time
Tx-Rx turn around
Antenna loss

All of these are needed together and at near state of the art levels. 802.11x is not the better choice on any one of these points or all taken together. This assertion will be supported later below.

Overcoverage

In addition, 802.11x has fundamental difficulties for the 802.15 HRSG application, the most important of which is the excessive range at which interference is generated. Over coverage will prevent the frequency from being reused short of a great distance. Overcoverage is inherent in 2.4 GHz working at the highest allowed power.

At 5 GHz, the interference-to-service range ratio is the worst for the higher speeds of OFDM. This modulation should only be considered for the 4-level mode of 12/18 Mbps where the greatest frequency reuse is attainable. The higher capabilities are advertising points.

Differentiation on Frequency Band and Antenna Directivity

The first partition is the difference between operating in the 2.45 and 5.25 GHz unlicensed bands. The lower frequency band is rapidly filling with many users. These uses are mostly LBT (listen-before-talk) access control or just send. Because the interference range of these higher power radios and low-directivity antennas, interference is easily projected in most directions up to 1000'.

The large interference range greatly reduces possible frequency reuse.

Operating at 5.25 GHz, antennas of narrower beam directivity are smaller and more efficient. This reduces the area of the interference presence and *increases frequency reuse*. Directive antennas (much smaller at 5.25 GHz) are essential for reducing delay spread that impairs high transfer rates. Also, the need for equalizers and FEC is abated.

All factors considered, operating at 5.25 GHz with a lower transmitter power is an excellent choice for minimizing battery drain and cost. There is no presently known advocacy of a 5 GHz radio fitting the low cost, short range criteria that Bluetooth has targeted at 2.4 GHz. What is now known and demonstrated is that a *5 GHz radio can be low cost and functionally effective*.

Coverage and Path Reliability Considerations

The proposed and **not accepted** (but better) 802.11a PHYsical medium mitigated excess delay spread with an FEC, a decision feedback equalizer and a single carrier. The **accepted** 802.11a and HiperLAN/2 used OFDM and a slowed symbol rate (52 parallel carriers). 802.11b use a longer symbol defined by channel coding. The resulting tolerance (300 nanoseconds) obtained from standard OFDM solutions is sufficient for larger meeting rooms and mid-size auditoriums.

The TIBURON approach will cover the large areas with more access points, shorter range and much more aggregate capacity from more intensive frequency reuse. This is *economically advantageous* because of low access point radio-antenna cost and size, and because the option of linking access points to a common hub with either category 5 cable or radio repeaters is available.

The primary limit on path length at high data rates comes from multi-path delay dispersion. For quick estimating, the delay spread is 0.5 times the path length assuming that the antenna at one end has a beam width of 90° or less. The velocity of light is about 1 nanosecond/foot so for a 200 foot path length a delay spread tolerance of 100 nanoseconds is either desirable or essential. If the access point is sectorized, and then for a given maximum path length, substantial reductions in delay spread can be achieved. The narrower antenna beam-widths admit fewer redundant paths.

If there is redundant radio coverage from a second access point to provide path diversity, the necessary reliability can be achieved at a yet greater range. This is a system plan providing path diversity rather than with multiple radios in the user station. These techniques can achieve the same results as equipment with greater delay spread tolerance and non-directive antennas.

Capacity and Area Coverage

For indoor systems, it presently looks economically helpful for the radio signals to go through walls with one access point serving many rooms. But this will change. It will be seen that each conference or meeting room requires its own autonomous system that can operate independently from those around it. The ability to provide numerous high-capacity systems in contiguous coverage's will make the proposed system an effective alternative.

OFDM PHY Summary

Technically, HiperLAN/2 is not an effective competitor because of different frequency band not available in USA. It is probable that it will be offered in a slightly modified form on the USA NII band at some future date. Possible protocols to build out the basic ATM cell transport are now being discussed in the engineering forums and publications. HiperLAN/2 can carry video channels.

802.11a is OFDM at 5 GHz, but it is tied to the 802.11 protocol which does not support connection-type services in general, and live video in particular.

A fundamental limitation of OFDM is that the slow symbol rate inherently creates a minimum size transfer of $20 \mu\text{sec} + N \times 96 \text{ bits}$ (for QPSK carriers). It is inherent that many transfers are short protocol messages. While these can be aggregated for a downlink, there is little that can be done to avoid acquisition time overhead for short messages from individual user stations. An ACK is an example of a common short message sent up from stations. The acquisition time of 20 $\mu\text{seconds}$ seems negligible, but it is the time required to transfer 360 bits (at 18 Mbps). The proportion of channel time used for payload is very low for short messages.

The OFDM radio requires a very linear radio transmitter amplifier to avoid spectrum regrowth from intermodulation between the carriers. The backoff required from the $P_{1\text{dB}}$ is -7 dB or more. This is a serious handicap in achieving low battery drain when compared with constant-envelope, single-carrier systems requiring no backoff at all.

The amount of backoff required is increased by the statistical possibility of voltage addition of all of the carriers at once—34 db above average value. While this event is rare, addition to a value

10 db above average is not. When the peak value is beyond the linear range of the transmit PA, “splatter” noise is generated out-of-band capable of causing unnecessary interference in adjacent channels.

The OFDM PHY is based on powerful, fast digital signal processors which only a few Companies can supply. This is a particular tough problem if low battery-drain is a further requirement. While many remarkable things can be done, many will not be available soon at a reasonable cost. A playing model* of an OFDM modem used separate 8 x 10” circuit boards in which the DSP was a small part.

Summary Negatives on OFDM (HiperLAN/2 and IEEE 802.11a)

Relative to the OFDM PHY, this proposed radio is technically much simpler. It has

less range,

less lost channel time for overhead (shorter acquisition time),

much less factory cost,

much smaller size,

much less battery drain, and

a potentially higher data capacity in megabits per acre (hectare) per MHz.

A system of this type may have more access points (but not necessarily more cost) per acre.

Further competitive advantages are:

much lower manufacturing and development cost and time to execute,

easy adaptation to customer specified rate, range, interface and packaging,

less lead time from order to delivery.

The intent of this radio design is to have a core design which can be supplied to meet specific needs without the “bloat” that is frequently found in designs intended for multiple applications.

* At the OFDM Interest Group Meeting; Santa Clara Marriott; Dec 2, 1999—WiLAN, Inc.

References:

ⁱ URL for IEEE802.11: <http://grouper.ieee.org/groups/802/11/index.html>

ⁱⁱ URL for Bluetooth: <http://www.bluetooth.com/v2/default.asp>

ⁱⁱⁱ URL for European Wireless OFDM: <http://www.imec.be/wlan/Welcome.html>