IEEE 802.11

802 LAN Access Method for Wireless Physical Medium

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TITLE: **RADIO PHY LAYER FOR USE WITH MEDIUM INDEPENDENT MAC**

SUMMARY

For success in timely 802 LAN standards definitions and product development, it is essential to have clean layer definitions in which functions are properly positioned. There is a tendency to arbitrarily dismiss the ideal of interchangeable physical mediums working with a common access method (e.g.; by using channelized radio systems for LAN.). Now described is a single channel radio PHY which is interchangeable at the MAC interface with broadcast optical or multi-drop pair mediums.

This paper includes an update of material first presented in IEEE 802.11/91-98 and 91-99, and a consolidation with 802.11-93/6 to form a **current definition of the radio frequency air signal**.

A concise description of the NRZ-ST baseband signal is given. A block diagram of the PHY layer is presented showing the use of a medium independent MAC interface.

A three part PHY layer is described:

1) **up-down conversion** between NRZ-ST chipping rate baseband and an AM modulated radio frequency, and
2) **baseband signal processing** where the receiver correlates analog noise-mixed waveforms to logic-level and clock free of noise and jitter; and where the transmit function generates the necessary band-limited partial response transmitted signal at the chipping rate.
3) a **PHY services sub-layer** where logical functions apart from signal modulation and demodulation are performed.

The **air interface** uses a direct sequence modulation where the chipping rate is chosen solely to mitigate the effects of time dispersion in the medium and Rayleigh fading. The following example parameters were chosen:

Frequency band:	**5.7250-5.8375 GHz**
Data transfer rate:	16 Mbits/sec
Symbol length:	7 chips
Chipping rate:	56 Mchips/sec
Bits per symbol:	2
Radio bandwidth:	66 MHz
Chip modulation:	POLAR AM (PSK)

The method is independent of operating frequency and data transfer rate insofar as the limitations of technical and transmission considerations. The occupied bandwidth for any 802 accepted data rate is linearly scalable. The expected radio range is also inversely scalable (but not linearly).

RADIO PHY LAYER FOR USE WITH MEDIUM INDEPENDENT MAC

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RADIO PHY LAYER FOR USE WITH MEDIUM INDEPENDENT MAC

BACKGROUND

To produce a standard, and to partition tasks among the many specialists required to do the work, there must be clean definitions separating the essential functions. When there is (radio) channelization in the PHY, such a definition is much less clean and probably exclusionary to alternate forms of physical medium. In particular, wireless optical and telephone pair mediums should also be supported.

Previous contributions (802.11-91/19, 91/95) described an access method based on the use of messages for all functions. The physical medium assumed was radio with overlapping coverages, but **using only one maximized rate radio channel within one system.** The reuse problem was addressed by sequential operation of interfering coverages. The administration of the timing of transmissions in different coverages was governed by algorithms in an intelligent hub controller ("scheduling server") common to a number of access-points.

First proposed two years ago, this remains a simpler way to design a system with 100% area coverage than by using multiple radio channels.

A necessary part of such a system is the appropriate PHY layer for radio which is now addressed. The definition of the air-interface and the MAC interface on each side of the PHY layer is important. Theses interfaces are now presented using mostly material already presented, but updated with what has been learned from discussions since the original proposals and with some new details to enable better implementation.

These interface choices, which will become part of the standard, cannot be understood without also weighing the implementation consequences. Though the implementation possibilities are unlikely to be part of the standard, they are important to estimating usefulness and marketability factors which motivate the investment necessary to develop the products.

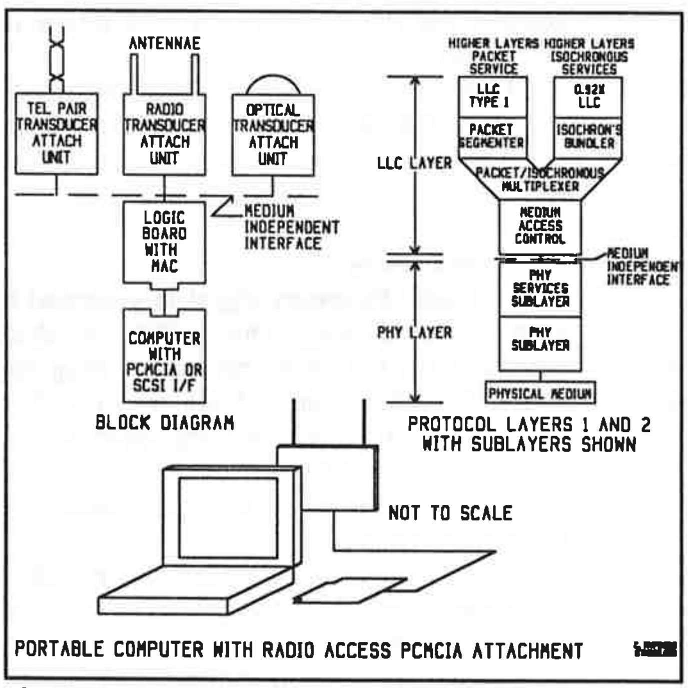

Figure 1 Wireless (radio) Station Layering.

DESCRIPTION OF THE PHY LAYER

The position of PHY in a Station is shown adjoining in Figure 1. The present concerns are:

1) the definitions of the interfaces above and below the PHY layer, and
2) the functional content of the PHY sub-layers some of which may require definition in the standard.

The concept of this plan is that the antenna or access-point can be located where it must be to perform its function, and then linked to the higher levels with a baseband signal that can be transmitted economically over a considerable distance if necessary. Sufficient electronics is included to make the antenna assembly into a transducer from the radio medium to telephone pairs with a baseband NRZ signal.

In Figure 1, the PHY is entirely contained in the radio attachment (back of display), and the MAC (and LLC) in the PC-MCIA card.

I -- FOR VARIOUS SYMBOL LENGTHS AND DATA RATES, BANDWIDTH AND CHIP LENGTH

REF #	SYM LEN CHIPS	DATA MB/S 1B/SYM	DATA MB/S 2B/SYM	CHIP MC/S	NOM BW MHZ	CHIP LEN NSEC	SYM LEN NSEC	CHIP LEN METERS	SYMBOL LENGTH METERS
1	7	2	4	14	16	71.4	500	21.4	150
2	7	4	8	28	33	35.7	250	10.7	75
3	7	8	16	56	66	17.9	125	5.36	37.5
4	7	12	24	84	99	11.9	83	3.57	25
5	7	16	32	112	132	8.93	63	2.68	19
6	11	2	4	22	26	45.5	500	13.6	150
7	11	4	8	44	52	22.7	250	6.82	75
8	11	8	16	88	104	11.4	125	3.41	37.5
9	31	2	4	62	73	16.1	500	4,84	150

THE AIR INTERFACE

The initial probable operating frequency band is the US Part 15 ISM band:

5.7250-5.8375 GHz

This band is 112.5 MHz wide sufficient for data rates of 24 Mbits/sec with the methods proposed.

CHIPPING RATE

Using a direct sequence modulation, the chipping rate is chosen solely to mitigate the effects of time dispersion in the medium and Rayleigh fading as described in 802.11-93/6. The above table is abridged from that reference, and it lists some of the possibilities for various symbol lengths.

As an example, line #3 is chosen to provide the following properties:

Data transfer rate:	16 Mbits/sec
Symbol length:	7 chips
Chipping rate:	56 Mchips/sec
Bits per symbol:	2
Radio bandwidth:	66 MHz
Chip modulation:	POLAR AM (PSK)

Quadrature phase transmission is not used, because of the probability of degradation in the medium of the isolation between phases and for other reasons. It is probable that this matter will be decided differently after there is more system experience. This change in the modulation might be part of the evolution to transfer rates much higher than 16 Mbits/sec.

Two bits of information are derived from each 7-chip symbol transmitted requiring four patterns for data in addition to those used for synchronization.

The ratio of obtainable data rate to occupied spectrum is approximately:

Mbits/sec (data rate) = 0.25 x MHz (width)

Using quadrature phase, the rate would be doubled and the resistance to time dispersion diminished.

Two data modes are provided: NORMAL and FALLBACK. The fallback mode is half rate relative to normal using only the synch symbol.

RF MODULATION

The radio frequency signal is generated by linearly multiplying the NRZ baseband waveform by the operating carrier frequency where the polar form of NRZ is +1 and -1. The carrier frequency is suppressed in this operation. As will be later described, the NRZ is shaped to provide a minimum bandwidth modulating signal.

The result is described as amplitude modulation since the operation must be linear. The representation of +1 and -1 in AM is the same amplitude for both values but of opposite phase. The appearance of the signal is identical to that of binary phase shift keying excepting for a lesser occupied bandwidth.

BASEBAND WAVEFORM FOR CHIPPING

The baseband NRZ-ST signal is described in **Attachment B**. It is NRZ with smoothed transitions.

There are two cases where NRZ-ST is used:

1) As the chipping waveform on the RF carrier at the chipping rate.
2) As the bit stream transfer modulation between the MAC and the PHY when this interface is exposed and uses a length of unshielded twisted pair transmission.

The following discussion relates to the radio frequency use: 1) above.

For comparison, note that the first zero for random-data square-wave baseband NRZ is at the bit rate frequency.

1st zero frequency:	75% of bit rate
95% of power below:	60% of bit rate
Sidelobes above 1st zero:	<-33 dBc

Above the first zero, the maximum level of the side lobes was 36 dB or more down in experimental models with FIR window size of 5 bits. The degree of reduction depends upon the window size in the FIR generating filter and in the precision of the sample and assembly execution.

The radio frequency spectrum will be the spectrum of the modulating signal both sides of the carrier frequency when the radio system is linear. Non-linearities will create additional radiated sidebands in the transmitter and increased inter-symbol interference in the receiver.

TRANSMITTED REFERENCE CARRIER

Radio frequency reference carrier is transmitted as part of the signal so that the demodulating carrier at the receiver may be more quickly recovered than if it were synthesized. The radio front end may select this carrier or lock to it to recover the baseband signal. Technical parameters of the reference carrier are:

Phase relative to data:	quadrature
Allocated power level:	33% of total
Modulation:	none

These proportions allow the reference carrier to be recovered in the receiver by selection with a center-frequency passband filter which is much narrower than the passband of the chipping rate.

MAC-PHY INTERFACE

There are two MAC-PHY exposed interfaces:

1) Station interface = four-pair balanced logic level for distances up to 1 meter.
2) Access-point interface = two-pair balanced NRZST data and multiplexed control for telephone pairs up to 200 meters at 16 Mbits/sec.

The PHY is powered from the logic side in all cases through the common interface. The signals and information crossing this interface include the following:

a) transmit data	pair
b) transmit clock	pair
c) transmit pending and ON	clk mux
d) not clear to send	clk mux
e) transmit power set	data mux
f) receive data	pair
g) receive data clock	pair
h) receive data valid	clk mux
i) receive signal level	data mux
j) power	phantom
k) sleep mode control	data mux
l) remote loopback from radio side	data mux
m) remote loopback from logic side	data mux
n) fallback mode	data mux

Detail on the definition, operation and multiplexing of these functions is shown as part of the description of **PHY Services Sub-layer in Attachment A.**

Sleep mode messages are decoded in the MAC and returned to the PHY as control commands in stations.

Via this interface, the vocabulary of processable management messages is a small set including the above functions and such others as may be needed for maintenance and fault isolation. Management communication is multiplexed on the data and clock lines.

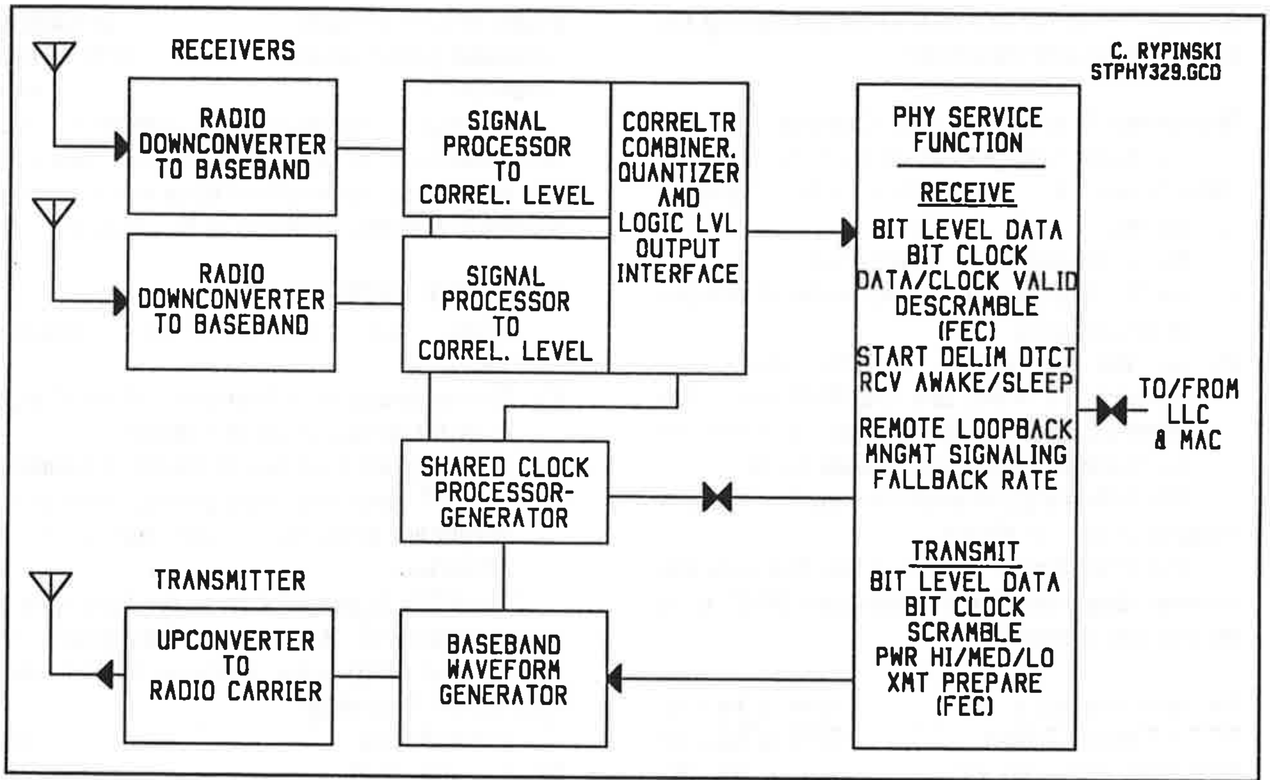

Figure 2 Block Diagram--PHY Layer Detail Function for Radio Wireless Station.

THE PHY LAYER FUNCTIONS

The PHY is made up of the following elements:

1) Antenna and radio frequency up-down converter to/from analog baseband. This is the only frequency dependent component in the PHY.
2) Baseband signal processor analog to/from logic level. This component is specific to the modulation and the data transfer rate.
3) PHY services including all logic functions necessary to make different PHYs interchangeable at the MAC interface. PHY services may include baseband signal conditioning for transmission over a length of two-pair cable.

ANTENNA AND RADIO FREQUENCY UP-DOWN CONVERTER

The possible operating frequencies for this front end are from 1.8 to 6.0 GHz, and the signal bandwidths from 20 to 80 MHz.

It is necessary to avoid or minimize cable length between the antenna and the radio front-end because of high losses and more complex matching and reflection problems. It may also be convenient to have separate antennas for transmit and receive rather than more complex duplexers and T-R switching.

About 25% of the radio receiver gain may be in this unit. Much more is not permissible because of automatic gain control and dynamic range considerations.

The receiver output is signal and noise at baseband with the bandwidth required to support the chipping rate in the medium.

SIGNAL PROCESSOR

The transmit portion of the signal processor converts the logic level data and clock to chip-patterned symbols, and then to baseband NRZ-ST to modulate the transmit up-converter.

The receive part of the signal processor accepts the analog chipping pulses and detects synch and data symbol patterns. The output noise bandwidth of the correlator function is the single-sideband width of the data stream which for the chipping rate selected is 1/14th of the input noise bandwidth. After correlation, the information is converted to a logic level serial bit stream.

The receive part of the signal processor deals with the variations in signal level and with recovery of chip and symbol clock.

Signal Level Adaptation

It is important that a large part of the automatic gain control function depend upon sensing the desired signal after correlation. The observed level then is usable for a signal level indication responding only to like-type signals rather than random-type interferers. A gain control signal might be returned to the radio down converter. Other techniques, in addition to feedback gain control, could also be used to diminish the effects of variable signal level.

Clock Acquisition

This must be accomplished very quickly after the appearance of a valid signal. For this purpose it is assumed that signal preamble is 16 bits of synch and a 7-bit start delimiter at binary level. It is expected that recovered bit clock will be valid within 5 bits of usable preamble

A system assumption must be that all stations have accurate clocks with near identical rates. The acquisition adjustment is then one of phase and not frequency. The necessary accuracy is that there is only a fraction of a chip run-out within one burst transmission.

Quantizer and Combiner

The accuracy and reliability of the receive function is significantly improved by a space diversity function. Two receivers and two antennas independently reach decisions on the value of a received symbol. The two results are linearly combined with each component weighted by the a function of the observed signal level.

Combining at baseband enables summing that is independent of RF phase, but does depend on approximate chip alignment.

Using a comparator, the result can be quantized to logic level as 2-bits parallel.

Fallback Mode

The receive part of the signal processor is also capable of a separately but not simultaneously detecting a half rate signal using only the synch pattern. This output is provided alternately to the PHY Services sub-layer, along with the indication that this is the current mode.

The transmit part can generate either type signal on command.

The transmit signal processor sends at a rate determined by the chip clock. Halving the rate by using only two instead of four symbol values has no effect on this processor.

PHY SERVICES SUB-LAYER

This sub-layer and its function are described in much greater detail in **Attachment A.**

The function of the PHY Services Sub-layer is to provide the convergence necessary to make all PHYs look alike to the MAC. In addition, all logic functions which are necessary for the PHY operation are positioned here. The interface between the signal processor and the PHY services sub-layer is the demarcation between analog modem and logical circuit function.

The functions the on signal processor side may be specific to the particular PHY, but the functions on the MAC interface side must be common to all PHYs.

This sub-layer has a very limited capacity to process the data stream passing through it. Specifically, it can recognize the start and end delimiters and it can encode and decode one octet in the frame space used by the predetermined preamble before the start delimiter or following the end delimiter. It is this capability that is used for transfer of management information and control particularly including loopback, sleepmode, power control and received signal level

SCRAMBLERS AND FEC

Scrambling and/or forward error correction (FEC) should be in the PHY Services Sub-layer if for the radio PHY, but would be different or absent for other mediums.

Though these functions appear in the PHY block diagram, **it is concluded that neither scrambling or FEC is needed for the radio path, but that the scrambler would be the simplest solution for the long telephone pair linking a remote PHY to a central hub.**

The primary reason for using scramblers is to mitigate dc effects from singular bit patterns when the medium has zero transmission at dc and possibly insufficient low frequency response. Another antidote is a dc restorer circuit which works quite well when the bit mix is near random and there is too not much noise in the signal.

Scramblers have been required for modulations of highly compressed bandwidth to enable clock recovery from the guaranteed presence of transitions. This is not relevant to the present case.

The benefit of FEC comes in raising the quality of a good channel to excellent at a price in redundancy. The problem of wireless LAN PHY is raising a rotten channel to good.

AIR INTERFACE

Because the 7-bit symbols used are near square codes (near equal 1's and 0's) there is no low frequency problem regardless of the bit pattern, and therefore no scrambler is needed.

On the basis of the following reasoning, it is also concluded that FEC would not provide sufficient benefits to offset its cost in delay and power drain. Furthe, the means of spreading and detection is a strong form of forward error correction.

When only 6 patterns out of 128 are used, there is a strong error detection code when the framing function is also strong. The result is quite different looking for one of 6 patterns that is either recognized logically or with linear summing.

A logical pattern form of error correction at best would be very limited using a short symbol.

The summing with analog combining means that each element is weighted according to its amplitude. A chip which is of the opposite sign from what it should be but of low amplitude will not by itself materially degrade the result. A majority of chips would have to be wrong and have an aggregate power content exceeding those that were right. It is believed that the modulation and chipping described is a power forward error correcting means for this context.

It might be useful to add a conventional FEC wrapper which could surely raise 10^{-4} BER to 10^{-7} at a cost of 30 to 50% added overhead and some further tranfer delay. The first point to consider is that BER is not meaningful in this context. The criteria is the proportion of error-free messages out of those transmitted

Errors are more likely to be clustered as a result of some temporary impairment of the transmission path. Simple BER assumes randomly distributed errors. If a message is flawed, it should be retransmitted possibly using a different alternative in the medium. If a message is lost because someone walks past the antenna, that is better fixed with retry than FEC.

FEC does not appear sufficiently beneficial in this context.

PAIR INTERFACE

The pair interface is transporting at the bit rate rather than the chip rate. The bit is polar modulated with binary values +1 and -1. A sustained state of one binary value will produce dc or low frequency components.

The copper pair does indeed transmit dc unless someone puts a transformer (repeat coil) in the path or shunts it with an inductor to get a center-tap for the phantom.

If power is transmitted at dc, then scrambled data is desirable. If power is transmitted at ac, then there is a possibility of retaining the usefulness of the dc path.

ATTACHMENT A
PHY SERVICES SUB-LAYER

BACKGROUND

It is believed imperative that there be a PHY Services Sub-layer in order to isolate the design of the 802.11 MAC from excessive transmission medium dependence. The most acute matters are management of channel selection, transmitter power control, threshold settings and use of observed received signal level. There are lesser matters related to fault isolation. In this area the number of variants is so large that the probability of an acceptable conclusion is very small.

The presently assumed radio transmission medium is minimal in these areas, yet there is considerable function for this sub-layer.

Any implementation will require the design of this sub-layer in order to separate the design of the analog and digital parts of the PHY. The need for this sub-layer is now demonstrated by pointing out the specific functions which it must include.

THE MAC-PHY INTERFACE

The presumed system plan requires physical separation between the MAC and the PHY creating a further intermediate transmission medium (like the AUI drop cable in 802.3). While this interface could be left to proprietary solutions, this direction could seriously degrade the effectiveness of the Standard.

There is an assumption that this interface must be defined so that the radio part of the system can be separately supplied from the remainder of the function. Some the details addressed are present to indicate what must be defined for a multi-vendor environment.

The services sub-layer adapts to this interface.

The station interface is seen as 4-pairs where 2-Pair are transmitting and 2-pair are receiving. The access-point interface is seen as 2-pair used alternately for send and receive. One of the 2-pair is used for data and the other for clock.

The multiplexing of data, clock, power and management on a small number of conductors is an important further function of the PHY Services Sub-layer. Good choices are necessary to minimize the cost and power drain of this function.

PHY SERVICES SUB-LAYER

The main function of this sub-layer is to provide convergence to make all PHYs look alike to the MAC. In addition, all logic functions, which are necessary for the PHY operation are in this sub-layer. Competent definition of this sub-layer will simplify the definition of the MAC.

MANAGEMENT COMMUNICATION

All management communication must reach the PHY via the MAC. This requires a path and a vocabulary to be defined which is as rapid as the normal data transfers. A bidirectional mode is now defined obtained by replacing the 16 bits of preamble before the message start delimiter with 16 bits formatted: 8-bits normal preamble and 8-bits of management message. The start delimiter that follows is recognized so that only the preceding 8-bits are interpreted.

The preamble and delimiter provide enough message capacity for power control, signal level reporting, loopback and parameter setting.

Presently, it appears sufficient for management information to appear as a prefix, but if needed, the same information could be suffixed after an end delimiter for transmission.

In addition some management functions are multiplexed on the clock and power paths as later detailed.

FORMATTING AND FRAMING

The received signal comes out of the signal processor as 2-bits parallel. The transmitted signal is transferred to the signal processor with spreading code already applied. These and other functions are performed in the PHY Services Sub-layer.

Bit-Symbol-Chip Formatting

The output of the receive signal processor is chip rate clock and symbol value. The services sub-layer must convert this to bit rate clock and a serial bit stream.

The services sub-layer receives a serial bit stream and clock from the MAC which must be converted into bit or synch symbol values. This forms the serial bit-stream at the chip rate which is presented to the transmit signal processor.

Transmit and Receive Frame Format

The preamble preceding the start delimiter is formed in the sub-layer for transmitting and stripped and replaced for receiving. This message space is then use to pass management information between MAC and PHY.

CLOCK AND MULTIPLEXED MANAGEMENT

The services sub-layer converts received chip and symbol clock to bit clock. The reverse occurs for transmitted messages.

The MAC can be defined to start a transmit cycle with transmitted clock in parallel with the data. When the sub-layer receives clock, it assumes that the transmitter will be turned ON soon after. The first clock pulse received is assumed valid and used to clock the data shift register of length two octets.

Presence and absence of the clock signal is the transmit on-off function.

DATA AND MULTIPLEXED MANAGEMENT

Data from the MAC is clocked into the two octet shift register creating a delay before transmission sufficient to evaluate the effect of any management message. The eight bits preceding the start delimiter may contain management information.

Clock Line Signal

Clock is transmitted as a sine wave at half of the data rate (e.g.; 8 MHz for 16 Mbits/sec). Clock will be present from the PHY only when valid data is present. The zero crossing of the sine wave will be aligned with the preferred sampling instant of the data.

If the detection bandwidth for this sine wave is 4 to 12 MHz, it may be assumed that it will take 125 nanoseconds (at 16 Mbits/sec) before the amplitude will be close to the final value, an interval equal to one cycle or two bits.

The presence of clock on the line is the first indication that data will be received, and its absence is a backup end delimiter indication.

In no case, does the PHY recognize or process data between the delimiters

Physical Medium Delimiting

PHY layer delimiting occurs on the basis of chip patterns on the radio side and bit patterns on the MAC side. They are entirely separate.

Recognition of the <u>Start delimiting</u> symbol in the PHY layer is a useful function. The use of that information might be:

1) To inform following logic to wake-up and process.
2) To mark the beginning of the transferred data message.

<u>End delimiting</u> in the MAC is primarily dependent on a MSG TYPE or a LENgth field in a header. This must be backed up by a default end delimiter that is loss of signal indication from the PHY implemented as a transition out of the data/clock valid state and indication.

Certain types of abnormal relationships in the correlator can be interpreted as loss of valid signal for this purpose. This function cannot be performed reliably by an envelope carrier detector in the radio.

The 7-bit <u>MAC start and end delimiter</u> are detectable by the PHY services function, and are also used to separate preceding and following management messages from transferred frames.

POWER CONTROL AND SIGNAL LEVEL DETECTION

The speed with which signal level and transmit power level need to be moved is similar to that of the data. It multiplexed on the data pair transmitted in the management field.

<u>Received Signal Level</u> is appended after the end delimiter at the end of each received transmission. The value is entered by the PHY services sub-layer.

Transmitter Power Reduction Command is a field in a management message received by the PHY from the MAC as a prefix on the message to be transmitted. Transmit power is always full unless a specific management message is received indicating a reduction.

LOOPBACK AND FAULT ISOLATION

Polling is the basic evidence that all parts of the system are working. The station MAC should send upward an "infrastructure present" indication if invitation or polling messages are heard.

A station that recognizes the presence of infrastructure knows that a great deal of the station is operating including all of the receiving system. A station that cannot sign-on has a fault that cannot be located without further testing. Since the station, normally, cannot send and receive at the same time, the transmitter cannot be tested by radio frequency loopback. Whether design-in of this capability is reasonable in cost remains to be determined.

As an alternative, it is possible to loopback from the PHY services sub-layer which would show that the cable between MAC and PHY was good. It is possible to have an RF sniffer that reports transmitter power output above a threshold. Any of these result in additional function which the PHY services sub-layer must support.

In a station, local loopback is initiated by a management message from the MAC via the management preamble. The services sub-layer is cable of storing 64 octets received either from the transmit logic or from a receiver capable of local monitoring, and the sub-layer can repeat back these octets in the same form as any other received message.

In a station, remote loopback is commanded by a received message which is interpreted in the MAC. The reply is formed in the MAC and returned as any other transmitted message.

In an access-point, there is no remote loopback. There is local loopback at the PHY Services Sub-layer which uses the same 64 octet storage as defined for local loopback at the station. Local loopback passing through the radio is well done using a test station with a store and forward at the sub-layer. Alternatively, the radio may be rigged for duplex monitoring.

INTERFACE SIGNAL CONDITIONING

Some sort of conditioning is necessary on the data and clock signals for copper wire transmission of 12" from the PC-MCIA card to the radio, and from an access-point to an intelligent hub within the infrastructure.

In the station interface, the cable will be short introducing little delay distortion at the bit rate, however balanced transmission line must be used to limit radiation and pickup. In addition, logic level rise and fall times must be limited by filtering, and then the pulse distortion from the filtering should be at least mildly compensated. The level of these signals may be considerably lower than that of conventional line drivers to minimize battery drain and radiation.

The access-point interface must be more elaborate because of the reduced number of pairs.

Data at the bit rate will be transmitted in NRZ-ST pulse shaping with compensation for up to 150 meters of pair.

INTERFACE POWER SUPPLY

Primary power is sent from the MAC to the PHY over the "phantom" of the two pairs. Each of the 2-pair is used in parallel or longitudinal mode for one side of the power. This results in ohmic loss that is one-half of what it would be for one pair alone.

The station interface would have a total of 4-wires for power so that multiple voltages could be transferred including those which are absent in sleep mode.

The access-point interface would transfer power at 24 Vac or Vdc to be determined. The access-point PHY services layer would have to convert the received level to operating supply voltages.

ATTACHMENT B
NRZ-ST -- NON-RETURN TO ZERO - SMOOTH TRANSITION MODULATION

BACKGROUND AND NOTES

Historically, many digital modulations have been keyed sine wave switched in amplitude, frequency or phase. The discontinuity at the switching instant produces sidebands at multiples of the switching rate which must be transmitted in correct time and amplitude to recover the original waveform. Filtering of these extra sidebands results in severe or fatal intersymbol interference first because of the loss of the information, and then because of time delay distortion of the filter. The confinement of the spectrum of a binary signal by filtering is either not possible or difficult to implement with compromised requirements.

The alternative approach is to generate a low spectrum signal in the first place that does not require filtering. This is possible because of the great improvement in the understanding of time and frequency domain inter-relationships brougth about through transfrom mathematics. The most fundamental difference is that the generated pulse for each bit of information must be defined over several bit intervals before and after the current bit. Since the desired span is infinite, the engineering compromise is finite.

In relation to 802.11, there are two applications of this art: 1) chipping rate modulation to minimize the out-of-band spectrum of the radio signal, and 2) the baseband bit rate transmission over telephone pairs between an intelligent hub and radio access-point distributed throughout the premises. The basic pulse shapes are the same for both.

Starting with the impulse response of the medium, it is possible to modify the generated pulse to compensate predictable delay and amplitude distortion from selective filters and marginal low frequency transmission response.

TRANSMISSION PATH COMPENSATION

There are material differences between these two applications in compensation for the transmission medium.

The compensation process is not addressed in this paper since it is not essential to the chipping rate transmission problem. In this case it is an improvement that will enable the receive front end filter to be somewhat narrower than without it.

Compensation for the telephone pair case is outside of the present scope of the 802.11 Standard since there is not yet recognition that this medium has relevance.

IEEE 802.9 TWISTED PAIR MEDIUM

This paper has been derived from work done to address telephone twisted pair transmission at high megabit rates for IEEE 802.9 and reported in Document No. IEEE 802.9-90/7 offered on January 11, 1990. The conceptual work on implementation with FIR pulse generation is that of G. L. Somer.

The main differences between an 802.9 and an 802.11 application are:

- In 802.9, the medium is two-ended, and the transmit signal is ON at all times.
  In 802.11, there is a shared medium where a user is only ON for a message burst.
- In 802.9, clock is acquired only when a station is turned ON.
  In 802.11, clock must be reacquired very quickly at the start of each burst.
- In 802.9, signal level has a limited possible dynamic range, and it is near constant over long periods of time.
  In 802.11 at access-points, each burst has a level unrelated to the prior transmission and may vary over a large dynamic range.

The mediums are similar in that there is impulse noise and interference from other simultaneous users (due to crosstalk in the cable for 802.9). A more subtle similarity is that intersymbol interference may be introduced by band-limiting filters.

The math of pulse-shaping, combining and spectrum limiting is identical.

GENERAL DESCRIPTION

The technology employed is concerned with optimization of transmitted pulse shape to minimize out-of-band spectrum and intersymbol crosstalk. At baseband, the advantage over square wave modulation is now described. For comparison, note that the first zero for random-data square-wave baseband NRZ is at the bit rate frequency. For NRZ-ST, the ratios are:

1st zero frequency:	75% of bit rate
95% of power below:	60% of bit rate
Sidelobes above 1st zero:	<-33 dBc

Above the first zero, the maximum level of the side lobes was 36 dB or more down in experimental models with FIR window size of 5 bits. The degree of reduction depends upon the window size in the FIR generating filter and in the precision of the sample and assembly execution.

Binary Baseband Signal from Consecutive Overlapping Pulses

The transmitted signal is generated by overlapping pulses of the same or opposite polarities. The pulse shape must have the property of adding to a near constant value when repeated and added at the desired pulse rate.

An illustrative example is shown in Figure 1. A triangular pulse with a width at the base equal to twice the period of the pulse rate has the necessary additive and overlap properties. Information is coded by using one of two polarities for each pulse. The sum of overlapping pulses of the same polarity is a straight line as shown. A further coding step is to define a transition as binary 0 and steady state as binary one.

The chosen shape, described later, is a compressed duobinary pulse spread over two bit intervals (rather than three), which is favorable for transmission in a bandlimited medium and which has the necessary additive property. When the polarity of consecutive pulses is opposite, the line signal makes the transition from one polarity to the other with a near sinusoidal shape.

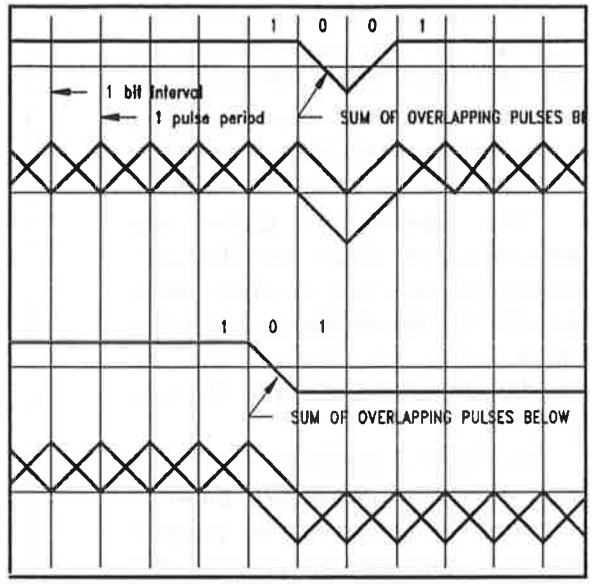

Figure 1 Formation of NRZI Signal with Overlapping Triangular Pulses

The pulses are differentially precoded so that the information is carried in the polarity of the current pulse relative to the previous pulse.

It should be noted that a polar NRZ may have a significant dc component in the signal depending upon bit-pattern history.

Pulse Shape for Distortion Free Medium

Each pulse, optimized for the distortionless medium, is the compressed duobinary pulse given by equation [2] below.

$T^2 \sin(\pi t/T) / \pi t(T-t)$ [1]
duobinary

$(2T/3)^2 \sin(3\pi t/2T) / \pi t((2T/3)-t)$ [2]
compressed duobinary

This pulse shape, plotted in MathCad, is shown in Figure 2 on the following page. The width of the main lobe of this pulse is spread over two bit intervals (as given by equation [2] above, rather than the three intervals of well-known duobinary pulses, as given by equation [1].

This pulse shape is also the desired receiver pulse shape at the point of baseband demodulation after passing through the receiver bandpass filtering.

Consecutive pulses of the same sign add to a near constant dc level provided the detail of the low amplitude parts of the pulse extending a few bit intervals before and after the main lobe are taken into account.

The capacity to define and generate a pulse shape extending over several bit intervals is what makes possible the use of this type of pulse shape many of which must be overlaid in accordance with the data pattern.

In Figure 2 adjoining below, the sum of seven consecutive pulse is shown for three cases: no polarity reversals, one polarity reversal and alternating polarity revesals. There are amplitude ripples before and after each transition. If these were limited out, the frequency spectrum of the transmitted signal would be widened. The reproduction of these shapes creates the radio linearity requirement.

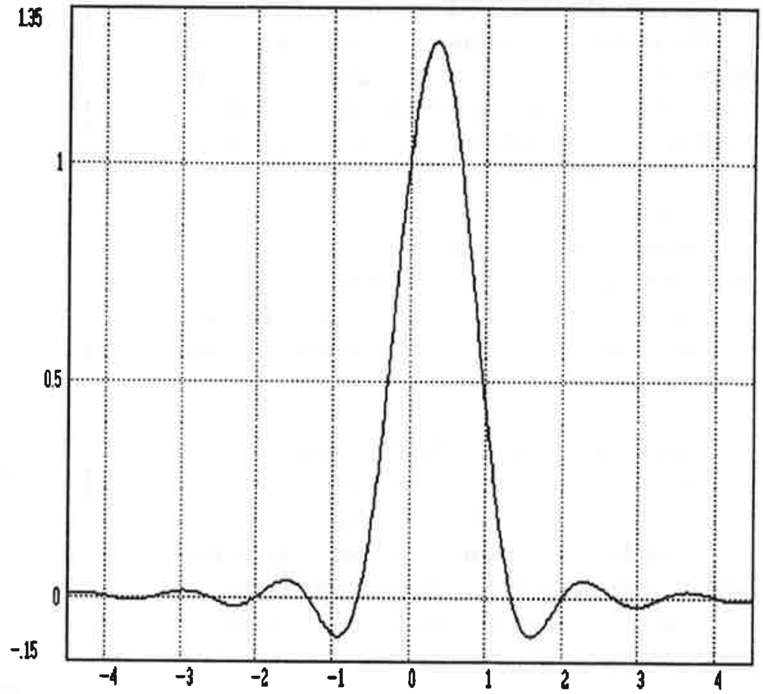

Figure 2 Isolated Pulse for Compressed Duobinary Shape.

Finite Impulse Response (FIR) Pulse Shape Formation

There is existing art on generating certain types of wave shapes using a "finite impulse response" filter. This technique has been used where the pulse shape generated depends on the value of preceding and following bits as well as the current bits.

There is a window consideration. In theory, it is necessary to consider all values between + and - infinity, however a judgment must be made as to how wide the time window needs to be for satisfactory results. This value is usually 1 to 3 bits before and after the current bit.

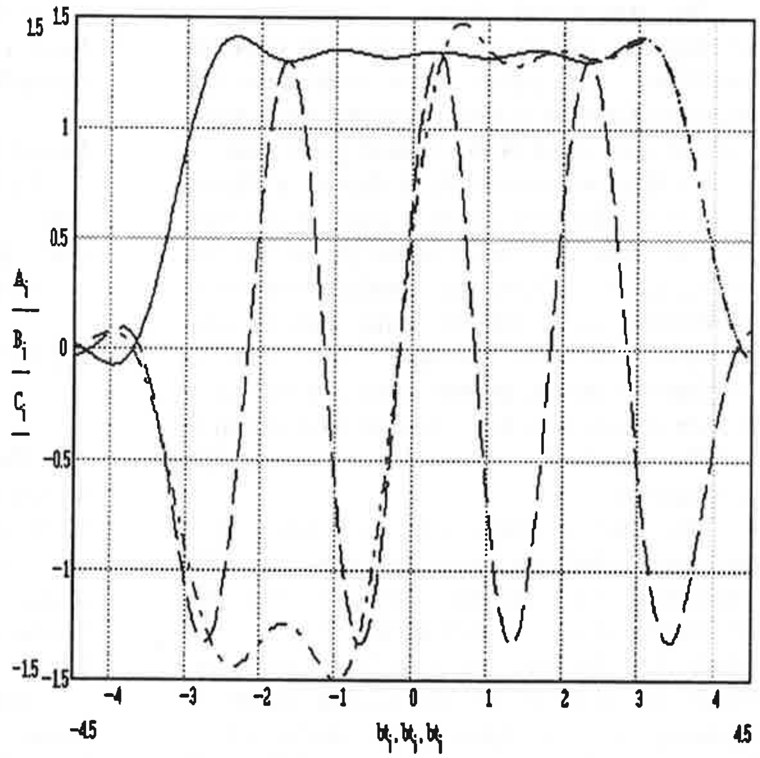

Figure 3 Sum of Seven Consecutive Pulses for Three Patterns of Polarity Reversal.