IEEE 802.11
Wireless Access Method and Physical Specification

title: **PROPOSAL FOR 2 Mbit/s DSSS PHY**

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1. INTRODUCTION

This contribution is intended to provide a proposal for the definition of the IEEE 802.11 DSSS PHY standard. The proposal is based on existing technology that is available today.
The document is more than just a specification, it will also describe the reasons and the benefits of certain design choices. The specification framework can be found in the appendix.
The Physical layer that is presented here has the following characteristics:
- Each channel has a bitrate of 2 Mbit/s.
- Multichannel: three channels are defined in the 2.4 GHz ISM band and one channel can be defined in the 915 MHz ISM band.

2. REQUIREMENTS

The basic requirement for the physical layer that is to be standardised by the IEEE is compliance with 802.11 PAR. For the PHY this means that the bitrate has to be between 1 and 20 Mbit/s. Secondly the PHY has to be in compliance with Regulatory Agencies for unlicensed operation.
An outline of other requirements is listed below:
. Operation in a multinetwork environment (multiple co-located networks)
. Suitable for low power, cost effective and small size implementations
. Targeted environments: indoor offices, retail, industrial, medical.
. Robust operation with all kinds of interferers.
. High medium reuse efficiency.

3. SYSTEM CONSIDERATIONS

Operation in a radio environment makes the system different from a cable environment in many aspects. The most important considerations for defining a Radio system are listed:

- CARRIER SENSING

  Compared to a 802.3 Ethernet LAN with CSMA/CD the collision detection in a radio environment is not possible. Therefor the emphasis is on the avoidance of collisions. The most promising MAC protocols are based on a Listen Before Talk function. Before a frame can be sent into the air, the receiver must examine if there is something received above a certain threshold level: the carrier sense (CS) function. Fast carrier sensing is crucial for the performance of a Radio network. The sooner it is known that an other station started transmission the lower the probability for a collision, the so called collision window must be as short as possible. The length of the carrier sense delay effects heavily the 'normalised propagation' delay (this is the ratio carrier sense delay/packet transmission time) in a CSMA environment (see a.o. doc IEEE P802.11/91-67). As known the normalised propagation delay is a parameter for the CSMA performance.

- COVERAGE

  The covered range depends on environment, interference situation, receiver sensitivity, regulatory power limits and the outage requirements. High receiver sensibility and diversity provisions are utilised to provide a maximum coverage range. The actual coverage range depends on:

  - Path loss characteristics.

    Attenuation coefficients of n=2 up to to 6 can be expected.

  - Multipath.

    The radio system must be designed such that it is robust against delay spread. In normal indoor environments delay spread figures up to 200 ns occur.

  - Fading.

    Radio systems suffer from fading and shadowing. The fading margin that is to be taken into account can be improved significantly by applying an antenna diversity scheme.

  - Interferers.

    In a radio environment there are all kinds of interferers. If there is a neighbouring system on the same frequency a receiver must be capable to capture a frame of its own network to overcome this co-channel interference. Other interferers are e.g. narrow band interferers. The carrier sense function should not be sensitive for interference sources. The characteristics of the system must be chosen such that it is robust against interferers.

- POWER CONTROL

  Radio systems transmitting on the same frequencies do not have the physical separation like cables. To use the medium as optimally as possible special arrangements must be designed in order to optimise the reuse of the medium. If two transmitters are sending to

two different receivers at the same time, the interference at the receiver of the wanted signal by the not wanted is determined by the power with which the signals are sent and the attenuation of the two signals. Medium reuse (or parallel transmission) can be optimised by having the arrangement that no transmitter is emitting more power than necessary for reliable reception by the receiver. The optimal amount of power can change and depends on mobility. The control of this power is a dynamic function that differs per destination or that can have a system dependent limit. This proposal contains provisions to support Dynamic Power Control.
If a station is sending with less power than inherently the threshold for carrier sensing must be adapted. In this case the threshold can be less sensitive to prevent that a station defers for another transmitter, while this was not necessary.

4. MAJOR CHARACTERISTICS

The major characteristics for the Direct Sequence Spread Spectrum PHY are listed below:

- FREQUENCY BAND
The system is designed to provide multiple channels in the 2.4 GHz ISM band. Also a single channel can be supported in the 915 MHz ISM band.

- SPREADING SEQUENCE
An 11-chip Barker sequence is proposed for spreading. Spreading with a factor 11 is conformant to the FCC requirement for a processing gain of 10 dB. In addition the sequence has very good odd and even autocorrelation properties. It makes the system robust against interferers.

- SYMBOL RATE
The symbol rate is 1 MBaud. Together with the 11-chip spreading sequence this 11 Mchip/s system shows good robustness against delay spread.

- MODULATION
The modulation method is differential QPSK. The four phases define 2 bit per symbol resulting in a bitrate of 2 Mbit/s. QPSK has been analysed as very efficient with regard to medium reuse and modulation bandwidth (doc IEEE 802.11/91-22) . With differential schemes the need for accurate carrier tracking is less than with coherent detection.

- CARRIER SENSING
The system should have a fast carrier sense capability. Carrier detection must be more sensitive than the receiver sensitivity. This is needed to limit co-channel interference in an overlapping environment.

- CARRIER OFFSET TRACKING
The system is capable to determine and track the carrier offset caused by a frequency difference between the Local Oscillators of the transmitter and receiver. The system is

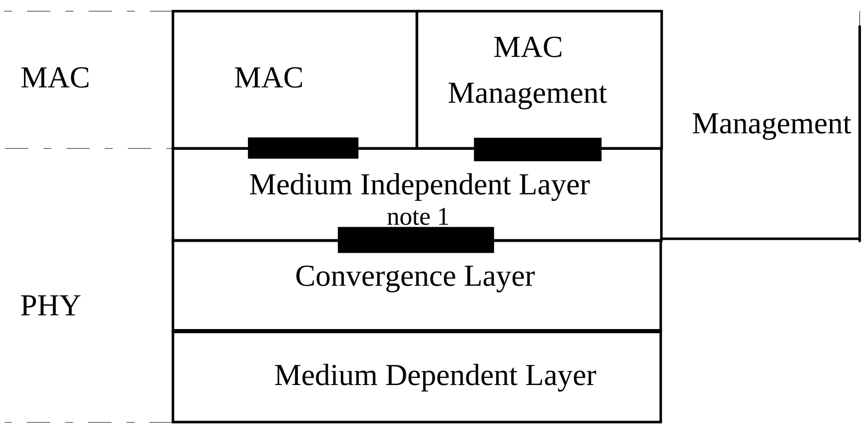
designed to allow the use of 50 ppm crystal accuracy for operation in the 2.4 GHz band to allow low cost implementation.

- CAPTURE CAPABILITY

While receiving a frame from one transmitter, the receiver should be capable to capture a frame from another transmitter if the level of this second frame is above the minimum capture ratio. A minimum capture ratio of 8 dB is feasible.

5. OVERVIEW

The proposed Physical Layer will be one of the multiple PHY's that will be part of the IEEE 802.11 standard. This document will concentrate on the Medium Dependent Layer (see figure 1).



Note 1 -Optional exposed DTE/DCE interface

fig 1: General overview of the 802.11 MAC and PHY Layer.

Figure 2 shows the functional blocks of the PHY.
Different functional blocks can be identified in the PHY. The TX block performs all the analog and /or digital signal processing transmitter functions. It includes a TX control block that controls the sequence of all these functions: e.g. start of transmission, generation of the training sequence etc. It interfaces to the MAC.
The same blocks can be distinguished in the receiver part. In addition to the RX and TX control blocks a management block is defined. All static and per packet handling are controlled here. Examples are TX level, RX threshold or bitrate. The management block is interfaced to the MAC through the Mngt I/F
Finally there is an antenna interface. This I/F connects the TX or RX to the antenna.

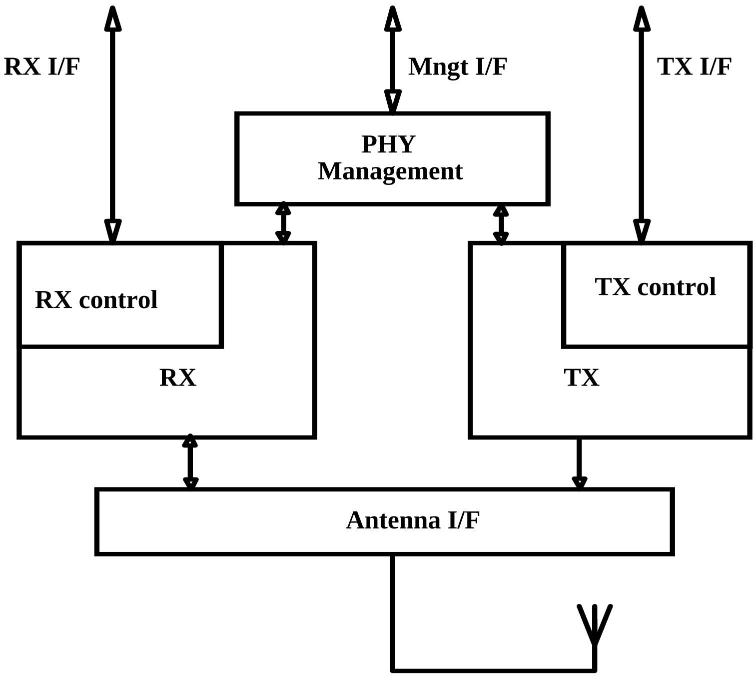


Figure 2 Basic Blocks in the PHY and the Interfaces.

6. THE TRANSMITTER AND RECEIVER BLOCK DIAGRAMS

This chapter gives the functional blocks that allow the description of the important characteristics of transmitter and receiver. They are described in a generic model; it is not the intention to specify the implementation of transmitter or receiver.

6.1. THE TRANSMIT PATH

Prior to the MAC-frame a PHY-preamble (training sequence) for the training and synchronisation of the receiver is generated (See Training requirements).
The MAC-frame is scrambled. The FCC requires this if the spreading code length is less than 127. The now formed bit stream is input of the differential encoder. Dibits are formed from the data bits and mapped to I (in phase) and Q (quadrature) signals in the differential encoder. Differential encoding is chosen, which makes the requirements for carrier recovery in the receiver less stringent.

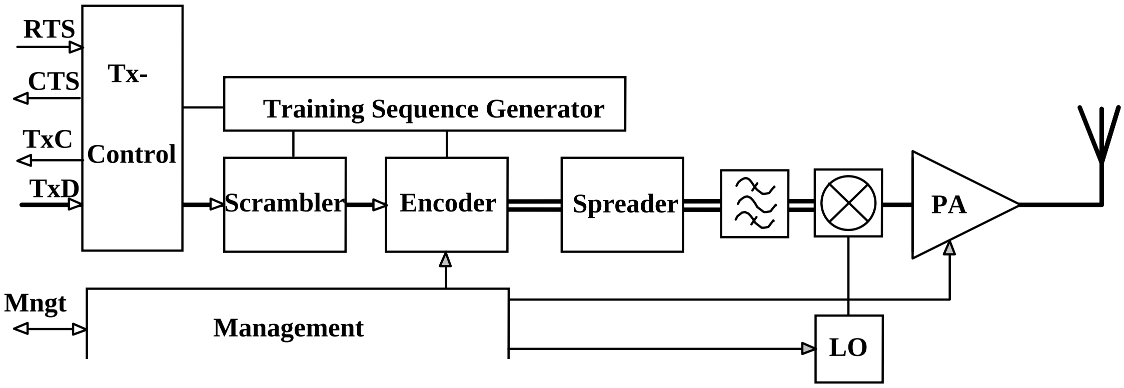


Figure 3. Transmitter functional block diagram.

The resulting I and Q data signals are still symbol based. In the next step spreading is introduced: The I and Q signals are both replaced by a sequence of 11 chips. In both paths a +1 is replaced directly by the sequence, a -1 is replaced by the sign-inverted sequence. The I and Q output signals of the spreading block have a chiprate of 11 Mchips/s. Now the I and Q signal are filtered and upconverted to the RF-band. This can be the 915 MHz band or the 2.4 GHz band. The resulting RF signal is amplified by the power amplifier (PA) before it is send out by the antenna.

6.2. THE RECEIVE PATH

The functionality of the receiver and the associated requirements for the PHY preamble generated in the transmitter are described with reference to the following block diagram.

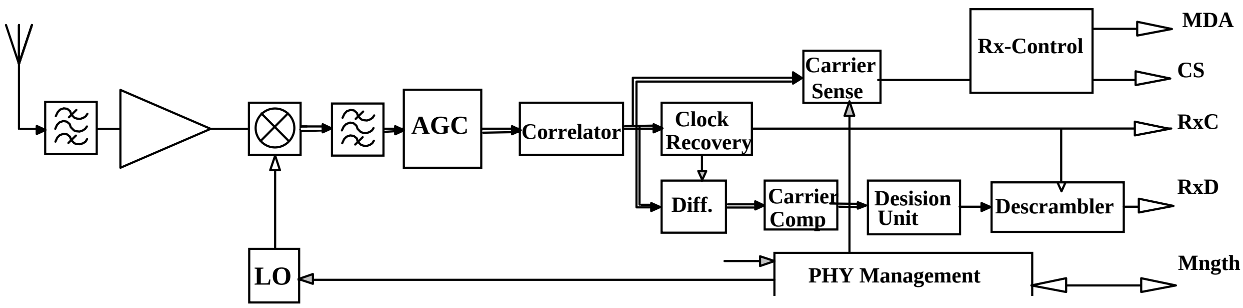


Figure 4. Receiver functional block diagram

After bandpass filtering the modulated RF signal is fed to the downconverter which delivers the I and Q baseband signals. The baseband signals are filtered and gain controlled. The AGC should take care of a huge dynamic range.
Both I and Q signals are fed into the correlators and correlated with the 11 bit sequence. The correlator is followed by a timing recovery circuit. The function is to find and track the peak in the combined output of the I and Q correlator. The peak position defines the symbol timing. Tracking is necessary to compensate for TX and RX clock differences.
Because of the use of differential encoding two correlator output peak signals undergo in the differentiator a phase difference determination. This phase difference is translated in the databits. However, caused by a frequency difference of the local oscillators (LO) of the transmitter and the receiver an additional phase turn is introduced for each symbol. The carrier compensation circuit should take care of this. If the carrier compensation circuit is capable of determine average phase turns per symbol of about 90 degrees (this is 250 KHz in a 1 MBaud system). This means for the 2.4 GHz crystals an accuracy of 50 ppm for both TX and RX. In addition this circuit must track the carrier offset during the reception of a frame because of LO jitter.
Finally the phase jumps are fed into the decision unit to retrieve the bits. This bit stream is descrambled in the descrambler block. The descrambler must be synchronised (or initialised).
As described above an important receiver function is a reliable carrier sense function. The best place to perform carrier sensing is behind the correlator, where a data signal can be distinguished from any other signal and a signal quality measurement can be performed.

For each incoming frame different circuits have to be trained. Therefor a training sequence (preamble) has to be defined which is generated by the transmitter. In this training also the decision is to be made which antenna is to be selected.
In the next paragraph the requirements for the training will be described.

7. TRAINING REQUIREMENTS

The above described blocks that need training are:

- AGC
- Timing recovery
- Carrier compensation
- Descrambler

The following characteristics of the receiver define the requirements for the training sequence (preamble):

- Fast carrier sensing
- Antenna selection
- Carrier offset training
- Descrambler training
- Capturing capability

They are described in the next paragraphs.

7.1. FAST CARRIER SENSING

For fast carrier sensing the following functions must be performed on the incoming training sequence:
- Automatic Gain Control. This can be done either in the analog RF part or in the baseband signal processing part or both. The required performance of the AGC function is dependent on the rest of the receiver . Initially the adaptation of the AGC can be relatively fast. (Once the training is done, the AGC adaptation must be slower to avoid AM distortion)
- Carrier sensing indicates that a valid input frame is present. Validity is checked by correlating the input frame with the spreading sequence in the correlator. If there is a clear peak in the correlator output compared to other values in the symbol, this indicates a valid frame. The proposed carrier sensing approach has the big advantage that the receiver will not react on an incoming noise signal or (non co-channnel) interferer.
- The peak can be fast identified and with high reliability if the rectified output samples of the correlator is integrated based on a modulo symbol time (sample 12 is added to sample 1, sample 13 added to sample 2, etc.)
- In the carrier detection circuit the height of the peak is compared to the other samples within the symbol. The ratio can be used as a measure for the quality of the incoming signal (SQ).

Carrier sense time is dependent on the performance of the above described functions.

7.2. ANTENNA SELECTION.

For antenna selection two scenarios can be employed:
- Parallel measurement at the antennas is performed (at the same time) and the best is selected. Parallel measurement need also parallel receivers (see figure 5).
- The alternative is consecutive measurement via the different antennas. Only one receiver path is needed, but each measurement needs time.

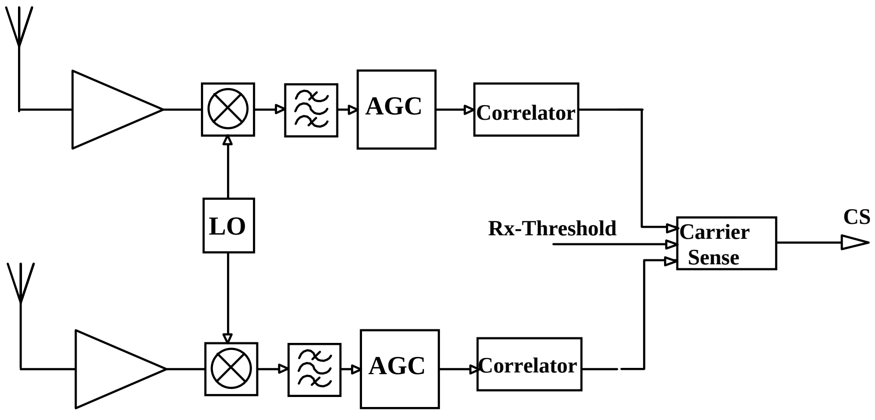


Figure 5. Parallel antenna diversity scheme.

The standard should allow for consecutive measurement, which is most cost effective and easy to implement. The consequence is that a longer training is required. This gives some extra overhead but it does however not effect the carrier sense delay. The throughput of the network is more dependent on the 'normalised propagation delay' .
The time to measure an antenna is about the same as the carrier sense time: the derived signal quality can be used for antenna selection. If we define this time as an antenna slot, multiple slots are required in the training sequence.
In a worst case scenario 5 antenna slots are needed (see figure 6) for the selection out of two antennas. In the first slot antenna 1 is measured. The carrier comes up somewhere after the start of the slot, such that on antenna 1 just no carrier is sensed. In the second slot antenna 2 is measured. This antenna is in a fade, so no carrier is sensed. In slot number 3 for the first time a carrier is sensed. At this time the receiver does not know yet that antenna 2 is in a fade, so antenna 2 is measured again in slot 4. Now the receiver take the decision that antenna 1 has the best signal. In slot 5 the final training of the receiver is performed on antenna 1.

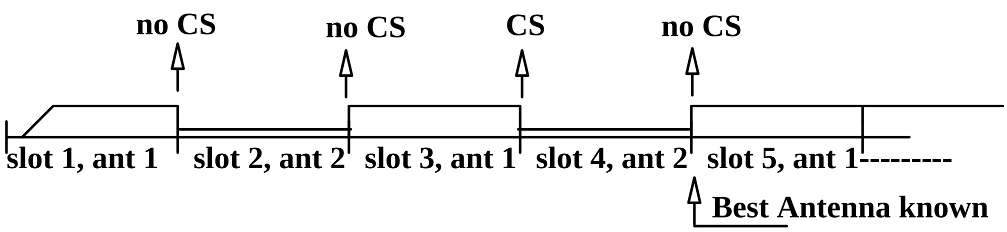


Figure 6. Worst case antenna measurement.

7.3. CARRIER OFFSET TRAINING AND TRACKING.

50 ppm accuracy is assumed for the frequency of the Local Oscillators of the transmitter and receiver. In the phase diagram in the receiver frequency difference can cause a phase turn per symbol of more then ±90 degrees in addition to the information carrying phase jumps.
For the differential modulation scheme, which is less sensitive to phase disturbance, this carrier offset must be measured and compensated to allow sufficient detection margin.
To initialise the carrier compensation block, the phase turn pr symbol must be measured with sufficient accuracy. This requires averaging of the measured additional phase turn to filter out the noise. The easiest way to measure it is to sent out a number of 'known' symbols (vectors) in the training . The receiver can average the deficiencies of the expected sequence and use that number for the initial setting of the carrier compensation circuit. After this the circuit is used to compensate further and to handle inaccuracy of the oscillators.
However the sequence must be detected and synchronised upon. Therefor the training sequence must have provisions that the start of this sequence can reliably be detected and thus a sequence delimiter is required.

7.4. DESCRAMBLER TRAINING

The descrambler must be synchronised on the incoming bit sequence. There are two ways to accomplish this.
- A descrambler has the capability for self-synchronisation. There is some time needed to do this: this is the length (number of delay elements) of the descrambler.
- The second way is to initialise the descrambler. If the transmitter scrambler is initialised with a fixed number, the descrambler can be initialised with the same value at the same point in the training sequence. If this point in the training is well defined then the time to self synchronise can be saved. Again a reliable delimiter is required.

7.5. CAPTURING CAPABILITY

It is possible that a receiver is involved in receiving a (weak) signal from a neighbouring network, while a transmitter of his own network starts transmission. In another situation two transmitter of the same network are colliding. If the receiver is training or already trained on the frame of the first transmitter there are three situations possible when the second transmitter starts his frame:
- The receive level of the second frame is far below the level of the first. The receiver should not react on this frame. There is a decrease of the SIR (signal interference ratio) but the first frame can still be well received.
- The receive levels of the frames are about the same. The SIR drops to a unacceptable level and both frames are disrupted.
- The receive level of the second frame is much higher. Reliable reception of the second frame is possible, while the first will be disrupted. The receiver must be capable to capture and thus train on this second frame.

The AGC has to adapt to the new frame. Also the timing must be adapted. The peak in the signal out of the correlator will be most probably on another position. The training sequence must be long enough to ensure that all applicable circuitry is adapted on the new frame before the phase compensation training can start. Detection of a reliable delimiter is here not only useful to synchronise the carrier offset training, but also to notify the receiver control that a capturing situation has occurred.

7.6. DELIMITER CONCEPT

In the above paragraph on training requirements it was stated that a delimiter in the training sequence is required. The requirement that must be put on the delimiter, is that detection is at least as reliable as the detection of the actual data. It is unacceptable that a frame is missed because a delimiter is not seen, while data could be reliable received. Basically there are two ways to implement such a delimiter.

The first way is to send out a sequence during the training that can be recognised by the receiver. It is not possible to use a bit stream to be recognised because the decision unit does not work yet.

The carrier offset is not yet compensated for. So it must be a special sequence of phase jumps that can be recognised and synchronised upon in spite of an unknown phase turn per symbol, caused by the LO difference.

Although it is possible to design such a sequence, it has some disadvantages. The sequence must be rather long to allow reliable detection and complex algorithms must be developed and implemented to recognise the sequence and to synchronise. E.g. at a sequence of phase jumps of zero degrees, which can be recognised by processing them differentially the receiver must exactly know where the sequence starts or ends, which can require backwards processing.

For this DSSS system we developed a Delimiter concept that is possible because of the spreading applied. The principal is to define data symbols and non-data symbols. The data symbols are spreaded with the normal spreading sequence, while the non-data symbols are spreaded with the same but in time reverse spreading sequence. It should be noted that this is not code multiplexing, because the data and non-data symbols are not used at the same moment. It is purely used for signalling or delimiting.

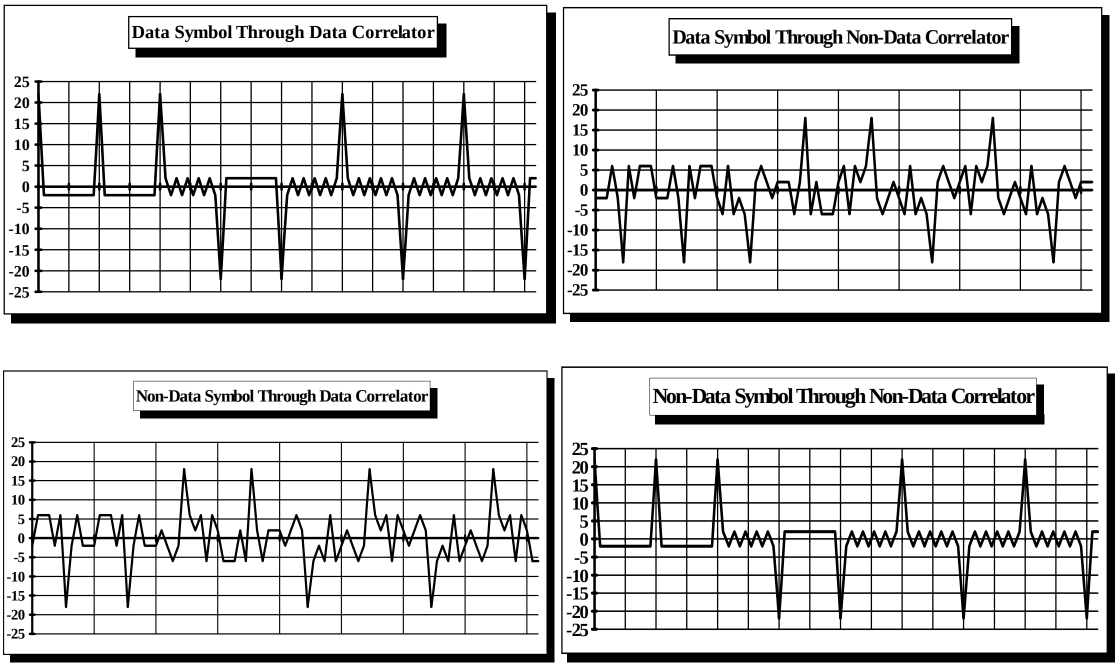


Figure 7. Correlator output on data and non-data.

Figure 7 shows how the data and non data symbols can be processed.
Two correlators are used: one for correlating the data sequence and one for correlating the non data sequence. If data symbols are sent there is (as described before) a peak at the output of the data correlator at the timing moment. The output of the non-data correlator is low at that moment. If there is a non-data symbol, the peak out of the data correlator at moment of timing

disappears, while at the non-data correlator there is a peak. By comparing the output of the two correlators a decision can be made on data or non-data. In essence there is no need for phase training, only the AGC and the timing must be properly set. The detection of the non-data symbol is reliable compared to data detection (about 4dB better).

By using more than one symbol for a delimiter also signalling is possible. The kind of delimiter is dependent on the (short) sequence of data (D) and non-data (ND).

We propose to define an START and END delimiter.
The concept has a lot of advantages:
- Allows faster and accurate carrier training.
- Eliminates the need for a descrambler sync period: initialisation at the exact moment, defined by the transmitter.
- Simplifies frame capturing. The receiver control function has nothing else to do then adjust the AGC and the timing and detect the start delimiter, after which all control functions can be notified that a capturing situation occurred and the new phase for carrier offset and the descrambler can be initialised.
- Exact (bit synchronous) notification to the MAC is possible where the MAC frame starts (the interface signal MDA, MAC Data Available is here defined.)
- The end delimiter allows for accurate "end of frame" detection, again bit synchronous. This has advantages for the CRC checking. End of frame detection is not dependent on Tx and Rx filters decay, or on the adjustment rate of the AGC.
- The end delimiter allows for efficient MAC implementation by optimising the access mechanism, due to the synchronisation that can be achieved in all receivers in the network.

7.7. NET-ID DEFINITION.

In a wired environment the separation between networks is guaranteed by the use of different (physically separated) cables. In a wireless environment virtual cable functionality is useful. To make it possible to filter between different networks in the wireless environment it is proposed to define a field at the end of the training sequence which contents is a Net- Identification (NID). The advantage of this approach is that if the receiver detects that the incoming frame is not of its own network (ESA), it can ignore the frame (e.g. by suppressing MDA).
An additional advantage is that the frame can not be read by a station not belonging to the network.

7.8. RECEIVER OVERVIEW

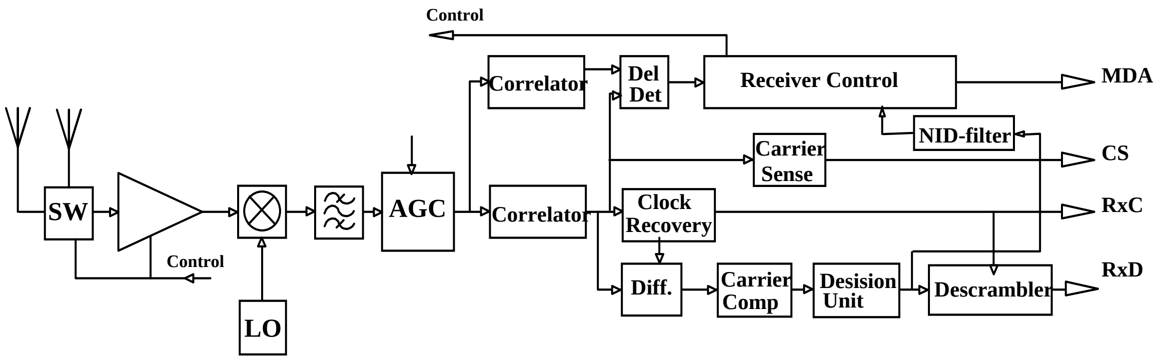


Figure 8. Receiver functional block diagram.

The above figure gives an overview of all the blocks of the receiver that are necessary to handle the training sequence is given. In this block diagram antenna diversity is performed by an antenna switch (SW), measurement of the performance of an antenna in the training sequence is done in consecutive antenna measurement slots. The field needed for the training (plus the rest of the frame) is given in figure 9.

SCRAMBLED PATTERN	**SD**	**CAR TRN**	**NID**	**MAC FRAME**	**ED**

Figure 9. Wireless frame format.

The scrambled pattern is for the training of the AGC and timing. It allows fast carrier sense and antenna selection.
The start delimiter (SD) delimits the carrier training pattern (CAR-TRN). It makes descrambler initialisation possible. Net-ID defines the network the frame belongs to. Finally the end delimiter (ED) delimits the end of the MAC frame.

8. SPECIFICATION FOR THE SIGNAL GENERATION

In this section the signal generation for the 2 Mbit/s DSSS PHY is specified. Signal generation is done in the transmitter, so refer to figure 4 for the block diagram of the specific functions. The function are:
- Scrambler
- Differential encoder
- Spreader
- Training sequence generator
- Modulator

8.1. SCRAMBLER

The information TxD, originating from the MAC at 2 Mbit/s is scrambled so as to remove steady state pattern information. Because the spreading factor is less than 127 the scrambler is required by the FCC (refer to doc FCC 90-233,9)
The scrambler uses the polynomial $1+x^{-4}+x^{-7}$ which randomises the data over a length of 127 bits.
The initial value of the scrambler is 0010000. This seed is loaded in the scrambler at the beginning of the preamble (training sequence) and at the beginning of the transmission of the MAC data.

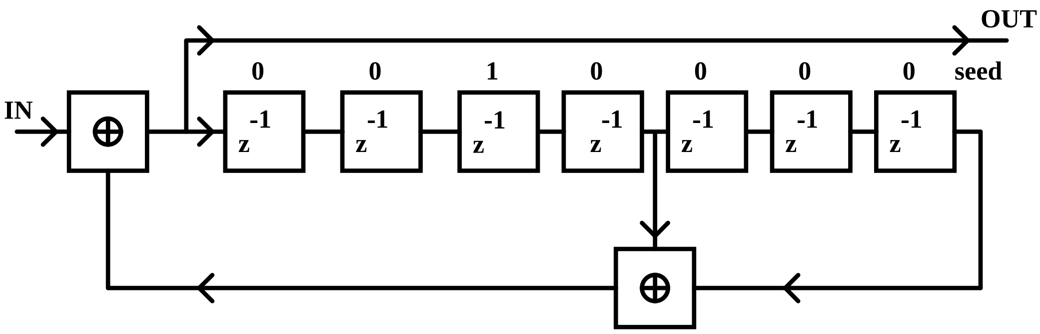


Figure 10 . Scrambler block diagram.

8.2. DIFFERENTIAL ENCODER

The modulation scheme proposed is DQPSK.
In the differential encoder every dibit is translated in phase jumps of a (I,Q) vector; the initial vector is $\pi/4$. The mapping is shown in table 1.

dibit pattern (d0,d1) (d0, first in time)	Phase jump
0, 0	0
0 ,1	$\pi/2$
1 ,1	π
1 ,0	$-\pi/2$

Table 1. Data dibit to differential phase mapping

Figure 11 shows the values for the (I,Q) vector.

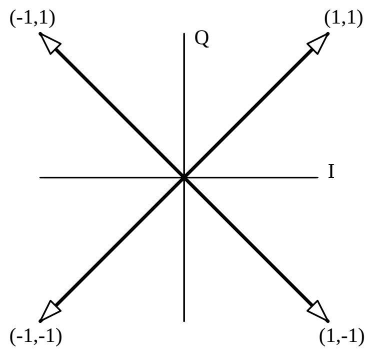


Figure 11. (I,Q) phase diagram.

There is a possibility for reduced rate (1Mbit/s) by sending only two phase jumps. A '0' maps to $\pi/2$, a '1' maps to $-\pi/2$.

8.3. SPREADER

In the spreader block each symbol (I and Q signals) is replaced by the spreader code. A '1' in the I or Q signal is replaced by the spreading code, a '-1' is replaced by the inverted spreading code.
For the Data symbols the spreading sequence that is used is the 11-chip BARKER sequence as shown in Figure 12a. For the Non-Data the sequence is time inverted. The first (left) chip is send first in time.

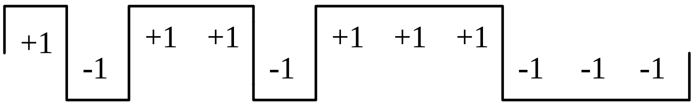


Figure 12a. 11-chip Barker sequence for Data symbols.

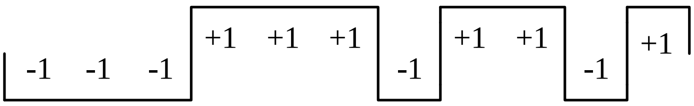


Figure 12b. 11-chip Barker sequence for Non-Data symbols.

The reasons to use the 11-chip Barker sequence are:

* The minimal spreading sequence to meet the FCC requirements for a processing gain of 10 dB.
* Very good even and odd (periodic and a-periodic) autocorrelation characteristics. See figure 13. The ratio peak/sidelob is always 11/1. For the odd autocorrelation the sidelobs are alternating ±1.

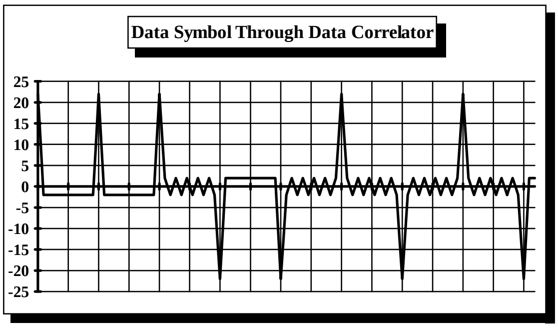


Figure 13.
Even and odd autocorrelation of the Barker sequence.

8.4. TRAINING SEQUENCE GENERATOR

In this block the preamble is generated for training and synchronising the receiver.

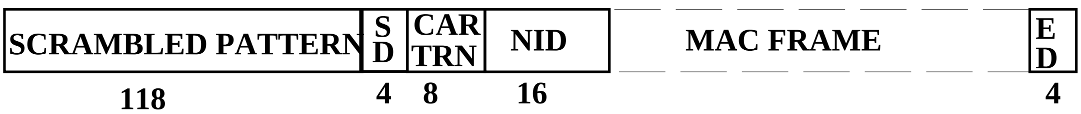


Figure 14. Wireless frame format.

The building blocks of a wireless frame are the preamble, the MAC frame and the end-delimiter (postamble).
The preamble is build up out of:

Scrambled pattern:
A 118 symbol long dibit sequence of dibits (0,1) (0,1) (0,1) ... is scrambled with the specified scrambler (initial value 0010000). The sequence has two phase jumps according to table 2. The initial phase vector is $\pi/4$

dibit pattern (d0,d1) (d0, first in time)	Phase jump
0, 0	$\pi/2$
0 ,1	$\pi/2$
1 ,1	$-\pi/2$
1 ,0	$-\pi/2$

Table 2. Data dibit to differential phase mapping in the scrambled pattern.

Start delimiter:
4 symbols are used for the start- (and end-) delimiter: (0,1) (0,1) (0,1) (0,1) . The sequence is not scrambled. Mapping is defined in table 1. Only the first symbol of the start delimiter is spreaded with the non-data sequence.
start-delimiter: ND D D D

In case of an end delimiter the first two symbols are spreaded with a non-data sequence. (note: the last two symbols are reserved for future use.)

Carrier offset training:
Eight symbols for the carrier offset training are transmitted. The dibit sequence used is
8 * (1,0) and is not scrambled. The mapping of table 1 is applied here, so the carrier offset is trained (averaged) on eight phase jumps of $-\pi/2$.

Net-ID:
The 16 bit Net-ID is transmitted after the carrier training at 1 bit per symbol for reliable detection. A '0' Net-ID-bit is encoded as dibit (0,1); a '1' Net-ID-bit as (1,0). The Net-ID will not be scrambled. The mapping is as in table 1.

End-delimiter:
The sequence for the end-delimiter is the same as the start-delimiter. The first two symbols are spreaded with the non-data sequence.
end-delimiter: ND ND D D

8.5. MODULATOR AND POWER AMPLIFIER

In this part the baseband signal is mixed up to the RF band, filtered and amplified. Spurious out of band emission are specified by the regulatory bodies (-20dB in the US).
The occupied channel bandwidth (spectrum shape) defines the number of parallel channels that are possible. In the 915 MHz ISM band one channel is possible, while in the 2.4 GHz ISM band three channels are possible with the proposed Tx characteristics:

data rate	2 Mbit/s
symbol rate	1 MBaud
chip rate	11 MChip/s
occupied bandwidth	-30 dBc @ Δf=11MHz
	-55 dBc @ Δf=22MHz

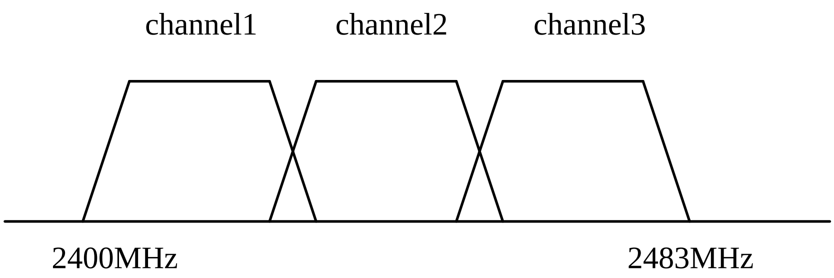


Figure 15: Three parallel channels in 2.4 GHz band.

The centerfrequencies of the channels in figure 15 are 2412, 2442, 2472 MHz.
The above defined occupied bandwidth defines the shape of the transmit filter.

The application of more channels in this band is still subject to investigations. One can think of 5 partly overlapping channels. Application is possible if there is some physical separation between adjacent channels, e.g. a thick wall. The application of higher requirements on the transmit spectrum (sharper filtering) must be studied.

9. MAC/PHY INTERFACE

The transmit and receiver control interface is such that it allows for accurate control of the access function by the MAC.

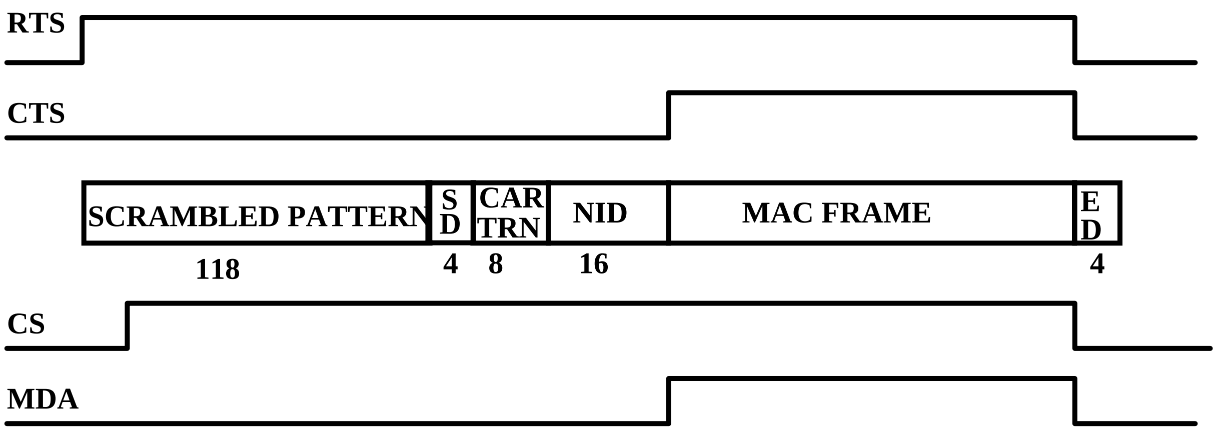


Figure 16 TX and RX control interface.

A simple 3 line interface can be used to provide for a per packet PHY management function, that allows full control of the PHY by the MAC. In addition it is used to set more static parameters in the PHY.
The following functionality is provided:

Dynamic (per packet) Control of:

- Tx Level
- Rx-Threshold
- Bitrate selection

Dynamic per packet status:

- Received-signal level
- Received signal quality
- Silence (background noise) level
- Bitrate received.

More Static parameters to be controlled are:

- NID selection
- Frequency Channel selection

APPENDIX A

This appendix is intended to provide a framework for the definition of the IEEE802.11 DSSS PHY standard.
The PHY is defined for the 2.4 GHz band, having three channels, but one channel can also be used in the 915 MHz ISM band.
The specification is put in table format like document 92/82 and 92/127 as long it is a living document. I changed the order of the items to make this specification more suitable for DSSS.

	Parameter	**Proposed Spec**	**Comments/Notes**
1	Frequency range	2.4 to 2.4835 GHz	Also the 915 MHz ISM band is usable
2	Number of parallel channels	3	defined by occupied channel bandwidth (8) and Frequency range (1)
3	Spreading sequence	11 chips	Barker sequence (1,-1,1,1,-1,1,1,1,-1,-1,-1)
4	Data rate	2 Mbps	Fall back rates can be defined
5	Symbol rate	1 MBaud	
6	Modulation	DQPSK	see also 22
7	Channel bandwidth	11 MHz	spreading factor 11 times symbol rate 1 MBaud
8	Occupied channel bandwidth (spectrum shape)	-30 dBc @ Δf=11Mhz -55 dBc @ Δf=22Mhz	Tx spectrum requirements
9	Spurious emissions out of band	-20 dB in US -60 dB/100KHz @1 to 10 GHz -66 dB/100KHz @30 MHz to 1 GHz	country dependent
10	Transmitted power level	Up to 1000 mW	FCC Part 15.247
11	Power control	Optional	steps of e.g. 2 dB downwards (in relation to carrier sense threshold upwards)
12	Receiver sensitivity	better than -70 dBm	at FER see point 23
13	Carrier sense threshold	selectable	adjustable at power control steps

14	Adjacent channel rejection	50-55dB	This defines the receiver filter characteristics
15	Max received signal power level	10 dBm	
16	Tx/Rx Frequency stability	≤ 50 ppm	this also defines the acceptance range of the receiver centre frequency
17	Clock accuracy	≤ 50 ppm	see 19
18	Preamble length	146 symbols (146µs)	used for: antenna selection clock recovery phase compensation delimiter detection
19	Clock recovery	Rx should follow Tx clock	at 2 times oversampling (22 MHz) choose largest at decorrelator output
20	Carrier response time	≤ 30 µs	Time to switch from receive mode (carrier sense mode) to start transmission plus the time to detect energy (by receiver)
21	Switching time Tx to Rx	faster then gap between messages	In a CSMA/CA like protocol a Inter Frame Space is defined. Rx function (carrier sensing) must be on before new frame may arrive.
22	Demodulation	Decorrelator, differential QPSK detection	Differential : robust against carrier frequency instability
23	FER (frame error rate)	5*10e-5	At frame length 576 bytes Power at Rx: -70dBm WGNoise power density of -156dBm/Hz (18 dB above thermal noise)
24	Dynamic capture ratio	8 dB	Frame in a frame reception capability
25	Channel availability	99.5%	probability of outage, defined for within coverage area and normal indoor channels
26	Antenna port impedance	50 ohms	

27	VSWR	Devices shall stand 0≤VSWR≤∞ with no damage Operational VSWR ≤2.5	within 2.4-2.5 band
28	Interface lines to convergence layer (when exposed)	RX data TX data RX/TX clock RTS/CTS CS MDA Control line Status line Ctl/Sta clock	Timing and levels TBD
29	Data Line/clock input/output jitter	TBD	Includes static and dynamic jitter (see 802.3 definition) dependent on MAC requirements
30	PHY-MAC Net management info/control variables	TX level RX threshold bitrate Rx level signal quality NID channel # etc.	The interface has to be defined by MAC and PHY group. See also document 92-127 point 41
31	Safety requirements	TDB	
32	DTE/DCE interface	TBD	
33	ACK protocol support	TBD	