

# 5 GHz, U-NII Band, L-PPM

## Preliminary Performance Data & Specifications

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This proposal has the following distinct attributes:

- Fundamentally DC-Power Efficient:
  1. The waveform is a pulse with a low duty cycle for the transmitter including the power amplifier.
  2. Requires very low back-off for the power amplifier.
- Mobility as the core focus: Battery-friendly, low-cost & low-power.
- Complies with FCC U-NII regulations (band-edge requirements).
- Non-coherent & non-complex receiver option & higher-performance receiver option (not included).
- Low complexity and low technology risk.
- Insensitive to phase-noise & carrier frequency accuracy.
- Demonstrated implementation evidence at 10 Mbps.

**General Description**

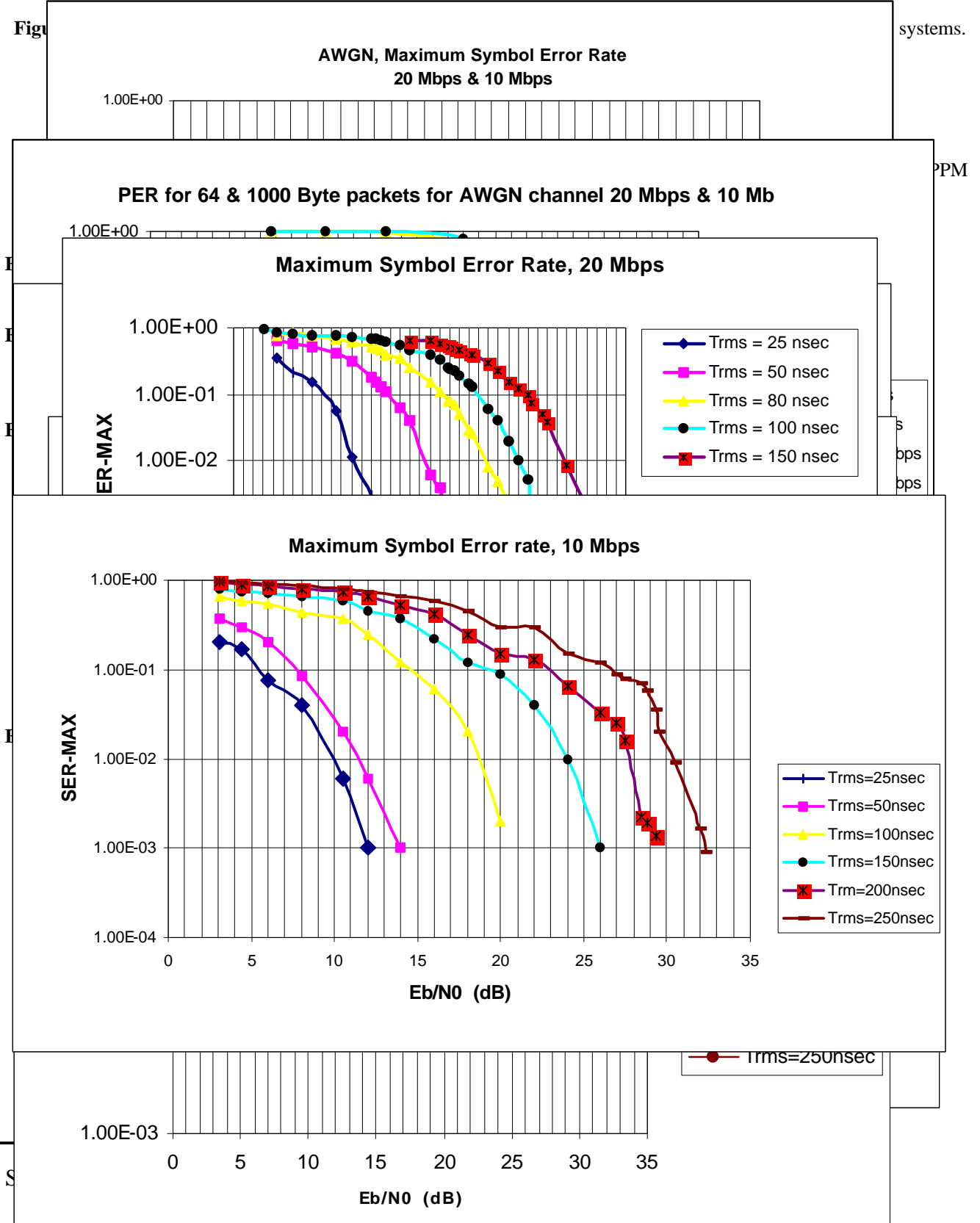
Parameter	Value(s)
Data Rates Supported	10 Mbps uncoded 20 Mbps, uncoded 23.88 Mbps, coded (optional)
Channel Spacing	30 MHz
Center Frequencies	<b>9-Channels Plan:</b> Lower: 5170 MHz 5200 MHz 5230 MHz  Middle: 5270 MHz 5300 MHz 5330 MHz  Upper: 5745 MHz 5775 MHz 5805 MHz
Power Levels	<b>9-Channels Plan:</b> Lower: 50 mW  Middle: 250 mW  Upper: 1000 mW
Sensitivities	-75 dBm at 10 Mbps -72 dBm at 20 Mbps -70 dBm at 23.88 Mbps
CCA threshold	-70 dBm
Clock Rate accuracy	100 ppm
Carrier Frequency accuracy	100 ppm
Waveform implementation accuracy specification method	Per Waveform Mask
Power Backoff in RF PA	0 to 1.5 dB back-off from P-1dBc for all rates
Implementation Complexity	The complexity of the RF transmitter, the RF receiver, and the baseband processor for L-PPM is rather low. The receiver is non-coherent and therefore quite simple. The baseband processor will be a single-chip Silicon integrated circuit implemented in either high-speed CMOS, or BiCMOS. The DC power consumption is quite efficient due to the pulsed nature of this system, with a low duty cycle. We believe this to be the simplest and most readily achievable approach as compared to the other five proposals.

**Per-Rate Feature Summary**

Parameter	Rate A	Rate B	Rate C
Data rate	10 Mbps	20 Mbps	23.88 Mbps
ECC method	uncoded	uncoded	Reed-Solomon (15,13)
Interleaving method	none	none	Depth 4
Suggested minimal sensitivity	-75 dBm	-72 dBm	-70 dBm
Suggested Co-Channel rejection	TBD	TBD	TBD
Suggested Adjacent Channel rejection (Suboptimal) (Matched IF Filter)	10 dB 15 dB	7 dB 12 dB	7 dB 11 dB
Suggested Alternate Channel rejection	35 dB	30 dB	30 dB
Implementation Accuracy	100 ppm center frequency 100 ppm clock frequency	100 ppm center frequency 100 ppm clock frequency	100 ppm center frequency 100 ppm clock frequency

Performance in Noise and Multipath

The following are the graphs of PER vs. Eb/N0, for AWGN, multipath and noise for 20 and 10 Mbps systems:



**Channel Coding (FEC + Interleaving) Performance:**

**Figure 9.** Channel coding performance summary.

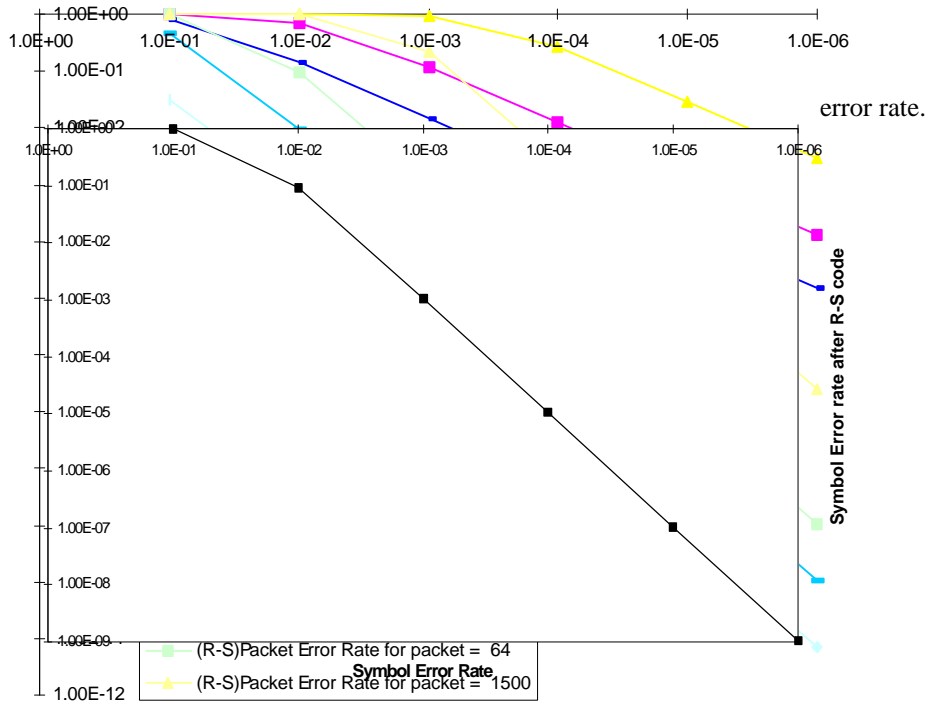
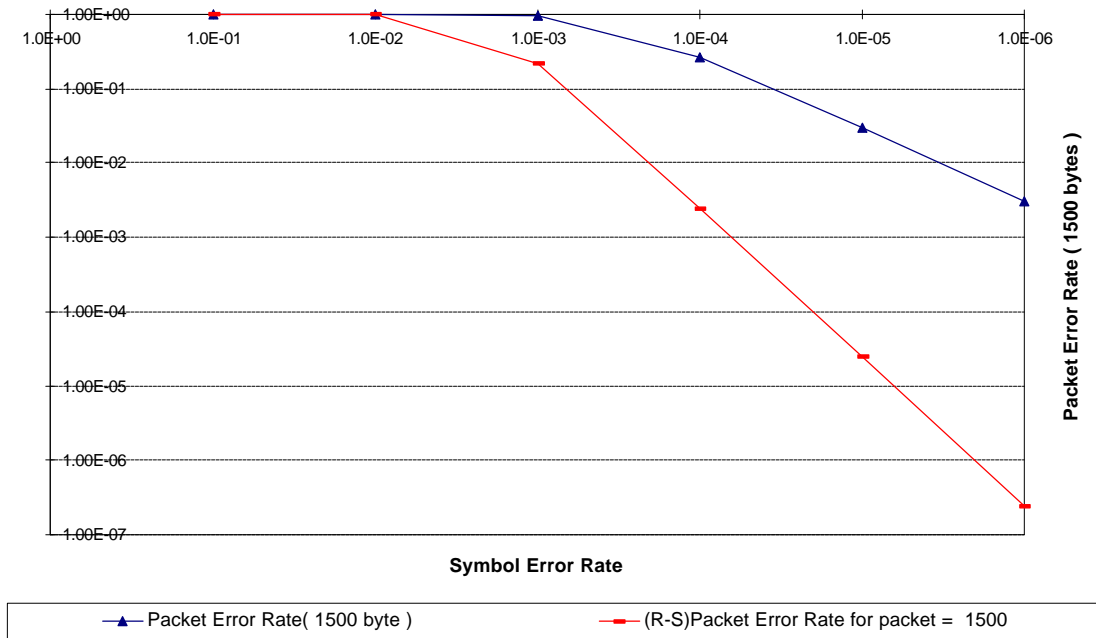
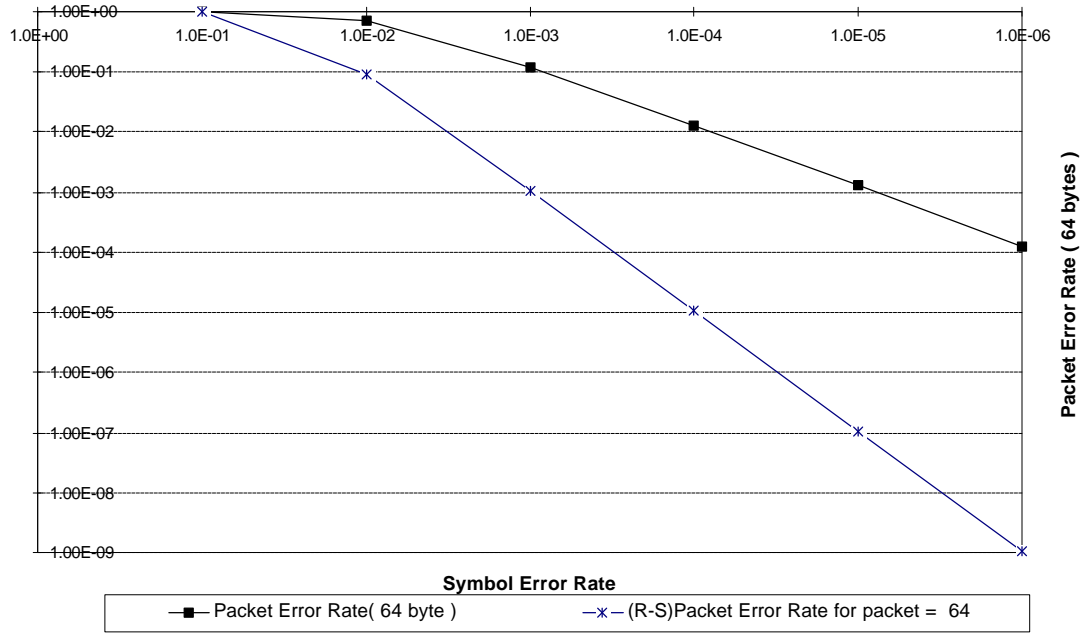


Figure 11. Effect of FEC and interleaving on 64-Byte packet error rate.



**Per-Rate Performance Summary**

Parameter	Rate A	Rate B	Rate C
Eb/No at PER=10%, AWGN, 64b	7.5 dB	7.5 dB	7.5 dB
Trms at PER=10%, noise free, 64b	200 nsec	150 nsec	120 nsec
Eb/No @ 20%, with Trms @ 10%, 64b**	See graphs	See graphs	See graphs
Eb/No at PER=10%, AWGN, 1000b	10 dB	10 dB	10 dB
Trms at PER=10%, noise free, 1000b	200 nsec	140 nsec	110 nsec
Eb/No @ 20%, with Trms @ 10%, 1000b**	See graphs	See graphs	See graphs
CCI immunity [dB]	TBD	TBD	TBD
ACI immunity [dB]	10 15	7 12	7 11
CW jammer immunity [dB]	TBD	TBD	TBD
Narrowband Gaussian noise immunity [dB]**	TBD	TBD	TBD
Phase noise tolerance, (BW=50 kHz), rad <sup>2</sup> [dBc] at which PER becomes 10%	Non-coherent system, phase-noise only critical for frequency stability	Non-coherent system, phase-noise only critical for frequency stability	Non-coherent system, phase-noise only critical for frequency stability

\*\* : Unclear about the definition of this parameter.

**Timing and Overhead related parameters**

Attach verbal explanation of the assumptions taken for each parameter

Attribute	Suggested Value
AslotTime	3 μsec
ACCATime	3 μsec -----
ArxTxTurnaroundTime	1 μsec
ATxPLCPDelay	0.5 μsec
ArxTxSwitchTime	μsec -----
AtxRampOnTime	700 nsec
ATxRFDelay	0.5 μsec
ASIFSTime	5 μsec
ARxRFDelay	2 μsec
ARxPLCPDelay	1 μsec
AMACProcessingDelay	1 μsec
AtxRampOffTime	1.5 μsec
ApreambleLength	12.8 μsec
APLCPHdrLength	4.8 μsec
AMPDUDurationFactor	64 bytes to 1514 bytes
AairPropagationTime	300 nsec (indoor)
ACWmin	Not applicable
ACWmax	Not applicable

# 5 GHz, U-NII Band, L-PPM

## Physical Layer Specification

### 1.1 Introduction

This document describes the physical layer proposed by RadioLAN Inc. for the 5 GHz, U-NII, L-PPM wireless LAN system.

#### 1.1.1 Physical Layer Functions

The L-PPM contains three functional entities: the physical medium dependent function, the physical layer convergence function, and the layer management function.

##### 1.1.1.1 Physical Layer Convergence Procedure Sublayer

In order to allow the MAC to operate with minimum dependence on the PMD sublayer, a physical layer convergence is defined. This layer simplifies the physical interface to the MAC services.

##### 1.1.1.2 Physical Medium Dependent Sublayer

The physical medium dependent sublayer provides a transmission to send or receive data between two or more nodes using 5 GHz U-NII band with 16-PPM modulation.

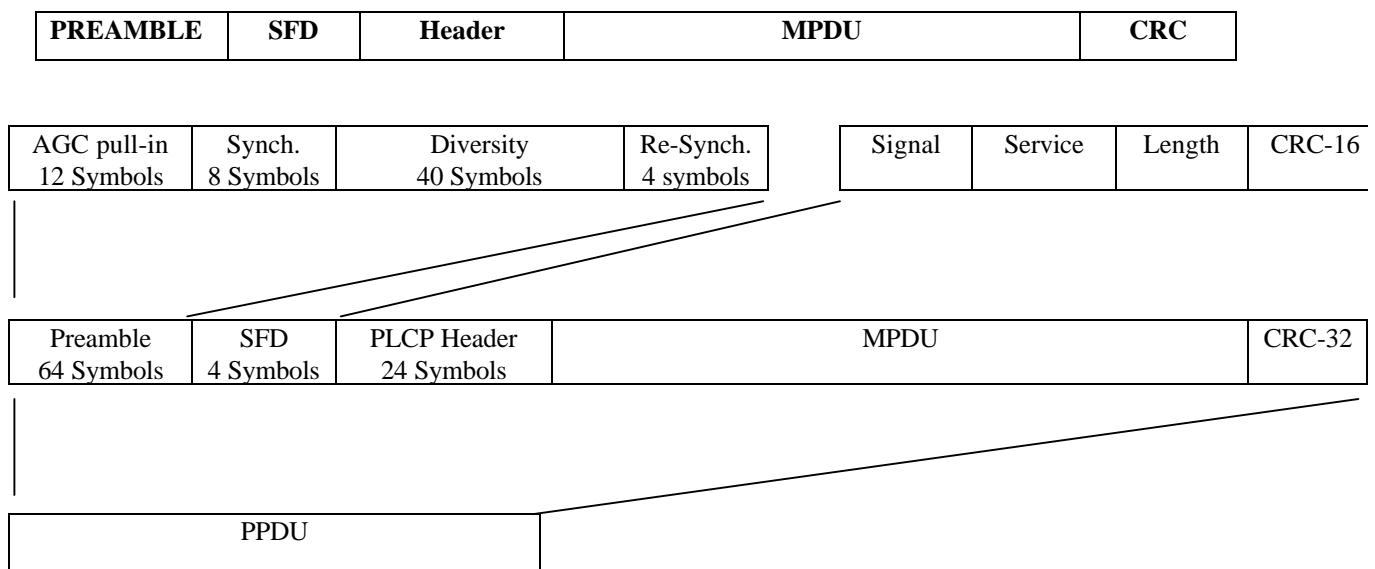
##### 1.1.1.3 Physical Layer Management Entity

The physical LME performs management of the local physical layer functions in conjunction with the MAC management entity.

### 1.2 L-PPM Physical Layer Convergence Procedure Sublayer

#### 1.2.1 Physical Layer Convergence Procedure Frame Format

The following figure shows the format of PPDU including the preamble, start frame delimiter, MPDU and CRC.





**Figure 13.** PLCP Frame Format

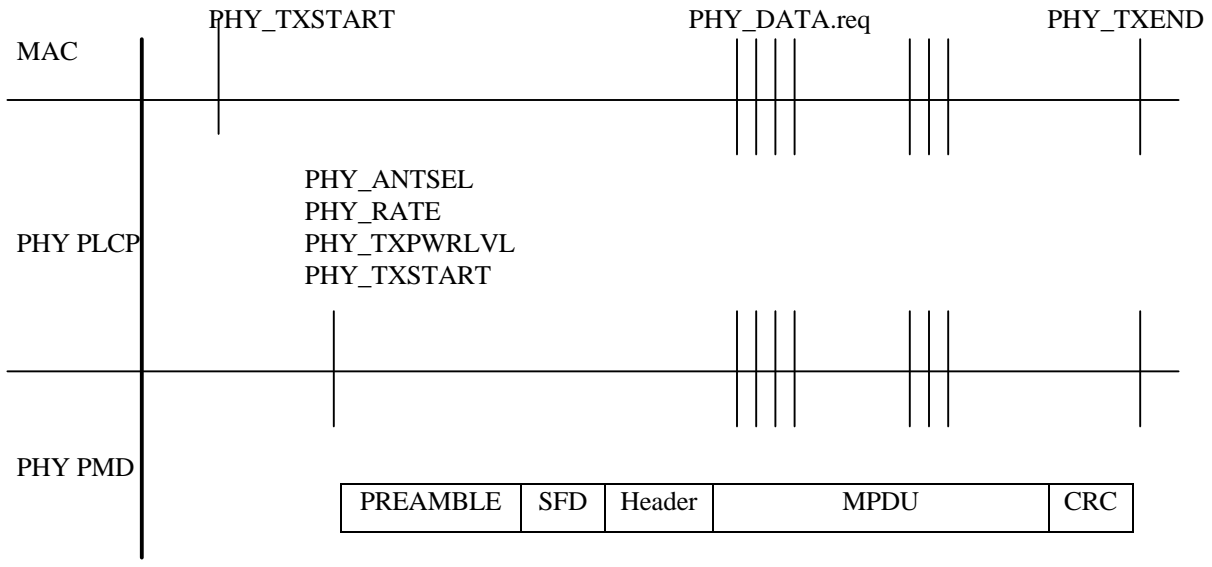
A preamble consisting of 64 symbols. It is provided so that the receiver can perform AGC, slot synchronization and diversity selection. The Start Frame Delimiter (SFD) indicates the beginning of the MPDU. The Signal field will indicate the data rate, the length field will indicate the MPDU length in bytes, and the CRC-16 is the CCITT CRC-16 for the signal, service and length.

The CRC-32 is a 32-bit CRC-32 with the following formula:

$$\text{CRC-32} = X^{32} + X^{26} + X^{23} + X^{22} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^5 + X^4 + X^2 + X + 1$$

### 1.2.2 PLCP Transmit Procedure

In order to transmit packet, the PHY\_TXSTART.request (ANT\_SEL) primitive is issued. The PHY will start transmit PLCP preamble using the antenna specified in the primitive. Once the PLCP preamble transmission is completed, data is exchanged between MAC and PHY by a series of PHY\_DATA.request primitives issued by the MAC. After the MPDU is sent, MAC issues PHY\_TXEND.request to terminate packet transmission. PHY entity will send out 32 bit CRC and return back to receive mode. The LSB is transmitted first.



**Figure 14.** PLCP Transmit Procedure

### 1.2.3 PLCP Receive Procedure

In order to receive data, PHY\_TXSTART.request must be disabled so that the PHY entity is in the receive state. Upon receiving the transmitted energy, the PHY\_ED.indicate is issued. The receiver will start waiting for preamble. The PHY should be able to synchronize on the preamble within 12-symbol time. The PHY sends out PHY\_CS.indicate to MAC after it receives preamble. If the diversity is enabled and bit error occurs within the RX\_DIV\_SAMPLE (4 bytes) period, the PHY should switch to the other antenna for packet reception.

If the SFD is received successfully, a PHY\_RXSTART.indicate will be issued. The received MPDU bits are assembled into octets and presented to the MAC using a series of PHY\_DATA.indicate(DATA) primitive exchanges. After the reception of the final bit of the last MPDU, the PHY issues PHY\_RXSTOP.indicate(RX\_ERROR). After the PHY\_RXSTOP.indicate, the PHY will issue PHY\_CCA.Indicate with a state value of IDLE.

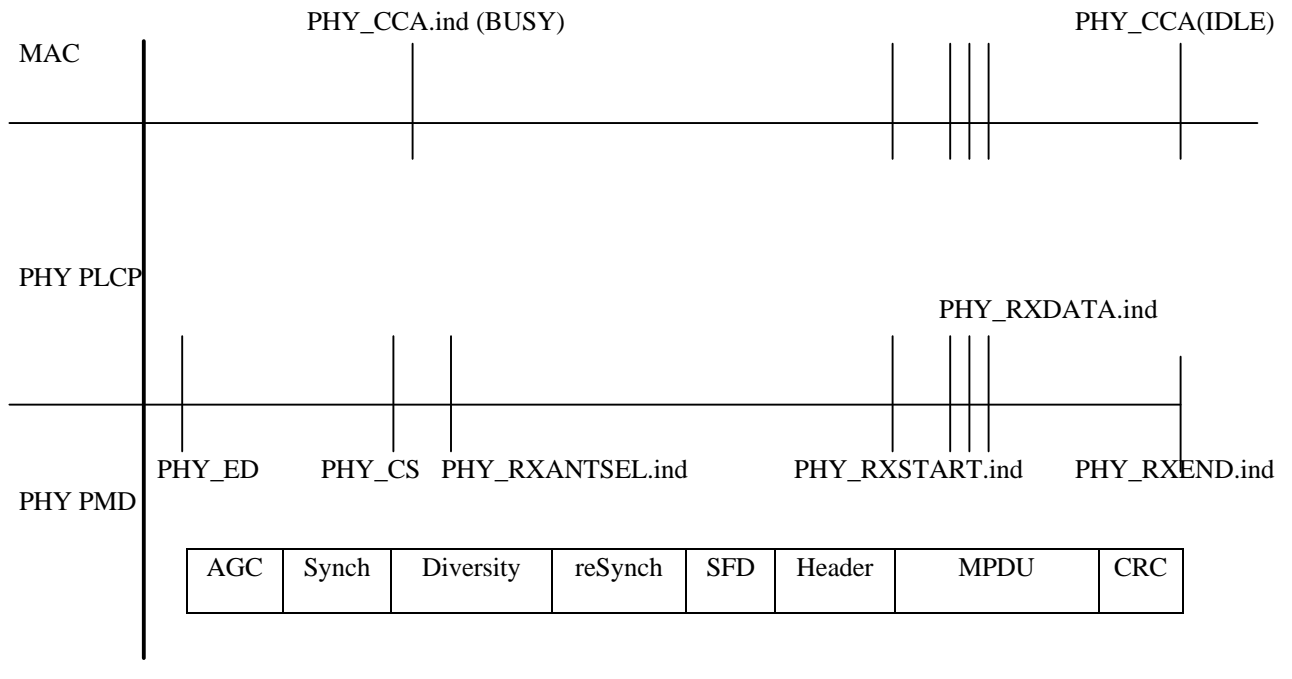


Figure 15. PLCP Receive Procedure

### 1.3 L-PPM Physical Layer Management Entity (LME)

#### 1.3.1 PLME\_SAP Detailed Service Specification

##### 1.3.1.1 PLME\_RESET.request

This primitive is a request by LME to reset the PHY.

##### 1.3.1.2 PLEM\_CHNL\_ID.request

This primitive is a request by LME to set the operational frequency of the PHY.

##### 1.3.1.3 PLME\_DIVERSITY.request

This primitive is a request by LME to enable or disable antenna diversity.

##### 1.3.1.4 PLME\_RX\_DIV\_SAMPLE.request

This primitive is a request by LME to set the sample size of the reception diversity.

##### 1.3.1.5 PLME\_ANTENNA.request

This primitive is a request by MAC to select the antenna.

## 1.4 L-PPM Physical Medium Dependent Sublayer

### 1.4.1 PMD\_SAP Detailed Service Specification

#### 1.4.1.1 PHY\_DATA.request

This primitive defines the transfer of data from PLCP sublayer to the PMD entity.

#### 1.4.1.2 PHY\_DATA.indicate

This primitive defines the transfer of data from PMD entity to the PLCP sublayer.

#### 1.4.1.3 PHY\_TXSTART.request

This primitive, generated by the PHY PLCP sublayer, initiates PPDU transmission by the PMD layer. It also provides ANT\_SEL as a parameter to indicate the transmission antenna.

#### 1.4.1.4 PHY\_TXEND.request

This primitive, generated by the PHY PLCP sublayer, ends PPDU transmission by the PMD layer.

#### 1.4.1.5 PHY\_RXSTART.indicate

This primitive, generated by PHY PMD layer, indicate the beginning of the frame reception. It also provides ANT\_SEL as a parameter to indicate the antenna used for receiving this packet.

#### 1.4.1.6 PHY\_RXSTOP.indicate

This primitive, generated by PHY PMD layer, indicate the end of the frame reception. It also provides RX\_ERROR as a parameter to indicate the CRC and symbol errors.

#### 1.4.1.7 PHY\_ED.indicate

This primitive, generated by PHY PMD layer, indicates to the PLCP layer that the receiver has detected RF energy in the current channel.

#### 1.4.1.8 PHY\_CS.indicate

This primitive, generated by PHY PMD layer, indicates to the PLCP layer that the receiver has detected RF energy and preamble is received.

### 1.4.2 PMD Operating General Specifications

The following sections provide general specifications for the 16-PPM physical medium dependent sublayer. These specifications apply to both the receive and transmit functions and general operation of a compliant L-PPM PHY.

#### 1.4.2.1 Operating Frequency Range

The L-PPM PHY will operate in the frequency bands of

5.150 to 5.250 GHz

5.250 to 5.350 GHz

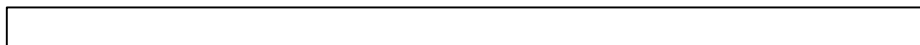
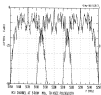
5.725 to 5.825 GHz

as allocated by the FCC for the U-NII devices.

### 1.4.2.2 Channelization

For the three bands, i.e. the lower, middle and the upper bands with 100 MHz available in each band, a total of 9 channels are specified.

Channel_ID	Frequency Band
1	5170 MHz
2	5200 MHz
3	5230 MHz
4	5270 MHz
5	5300 MHz
6	5330 MHz
7	5745 MHz
8	5775 MHz
9	5805 MHz



**Figure 16.** Channelization with Sub-Optimal IF filter.

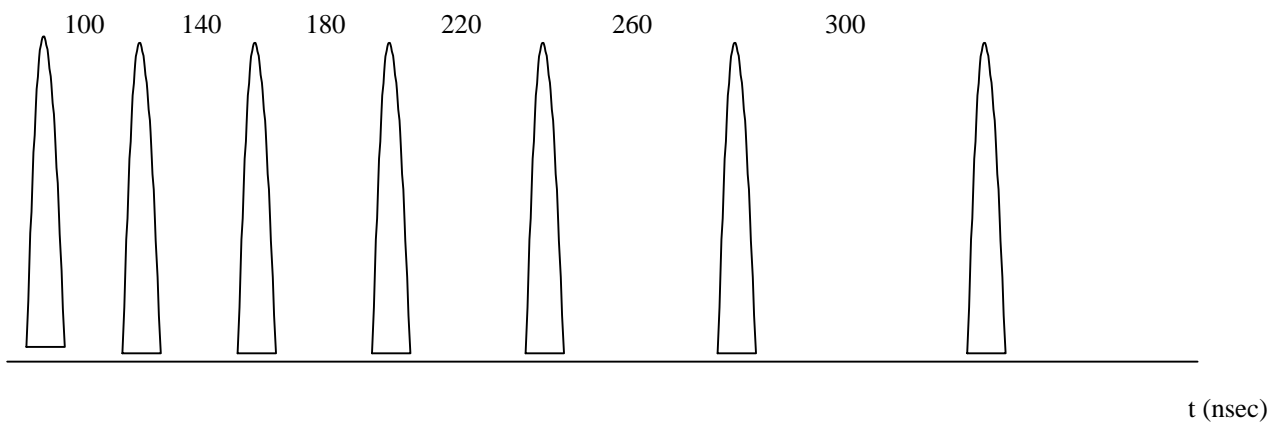
### 1.4.2.3 Modulation

The modulation is 16-PPM for the 20 and 23.88 Mbps, and 4-PPM for the 10 Mbps.

### 1.4.2.4 Encoding

The encoding for the 16-PPM is 4 bits per symbol, and it is based on a differential and overlapping set of pulse positions.

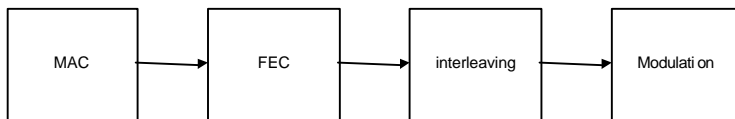
Data	Pulse Position
0000	100
0001	113.3333
0010	126.6667
0011	140
0100	153.3333
0101	166.6667
0110	180
0111	193.3333
1000	206.6667
1001	220
1010	233.3333
1011	246.6667
1100	260
1101	273.3333
1110	286.6667
1111	300



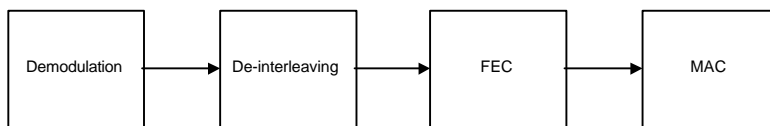
**Figure 17.** Illustration of an example of 3 bytes of data (000000110110100110111111) encoded by 16-PPM..

### 1.4.2.5 Channel Coding

#### Transmitter



#### Receiver



### 1.4.2.6 Forward Error Correction

Reed-Solomon (15,13) will be used only for the coded rate of 23.88 Mbps. The channel error control for all bits in MPDU employs the Reed-Solomon code of which block and information lengths are 15 and 13 symbols ( R-S(15,13) ), respectively. Each symbol has 4 bits. The R-S(15,13) code has an error correction capability against 1 symbol error in each block. 0s should be added to the last R-S block if the length of MPDU size is not a multiple of 52 bits.

### 1.4.2.7 Interleaving

Interleaving with a depth of 4 will be used only for the coded rate of 23.88 Mbps. Interleaving the coded symbols before transmission and deinterleaving after reception causes bursts of channel errors to be spread out in time and thus to be handled by the R-S decoder as if they were random errors. 4-way block interleaver is proposed to avoid channel burst errors. The following shows how the transmitter sends out interleaved symbols:

Input sequence:

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
----	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----

B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
----	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
----	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----

D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
----	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----

Output sequence :

A1	B1	C1	D1	A2	B2	C2	D2	A3	B3	C3	D3	A4	B4	C4
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

D4	A5	B5	C5	D5	A6	B6	C6	D6	A7	B7	C7	D7	A8	B8
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

C8	D8	A9	B9	C9	D9	A10	B10	C10	D10	A11	B11	C11	D11	A12
----	----	----	----	----	----	-----	-----	-----	-----	-----	-----	-----	-----	-----

B12	C12	D12	A13	B13	C13	D13	A14	B14	C14	D14	A15	B15	C15	D15
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

#### 1.4.2.8 Scrambling and Descrambling

Currently under investigation and simulation.

#### 1.4.2.9 Channel Data Rate

Based on a uniform distribution of the data, the average symbol rate is 5 Mega Symbols per second, corresponding to 20 Mbit /s as the primary rate, and 10 Mbps as the fall-back rate, with a third optional & coded rate of 23.88 Mbps.

#### 1.4.2.10 Transmit and Receive In-Band and Out-of-band Spurious Emissions

The L-PPM PHY shall conform to in-band and out-of-band spurious emissions as set by FCC for the U-NII devices as specified in the regulation 15.407, and 15.209.

#### 1.4.2.11 Transmit-to-Receive Turn-Around Time

The transmit-to-receive turn-around time shall be less than 4  $\mu$ sec, measured from the time TXE is de-asserted to the time when the receiver meets full specifications.

#### 1.4.2.12 Receive-to-Transmit Turn-Around Time

The receive-to-transmit turn-around time shall be less than 1  $\mu$ sec, measured from the time TXE is asserted to the time when the transmitter meets full specifications.

#### 1.4.2.13 Receive and Transmit Antenna Port Impedance

The transmit and receive antenna port(s) impedance shall be 50 Ohm if the port is exposed.

#### 1.4.2.14 Receive and Transmit VSWR

L-PPM PHY devices shall withstand no damage and remain stable over the range of VSWR between 0 and  $\infty$ .

#### 1.4.2.15 Receive and Transmit Operating Temperature Range

L-PPM devices for U-NII applications (indoor) shall operate between 0 and 50 degrees.

#### 1.4.2.16 Transmit power levels

The maximum output power for the L-PPM, U-NII devices are 50, 250 and 1000 mW for the lower, middle and upper bands respectively. The maximum EIRP for the L-PPM, U-NII devices are 200, 1000, and 4000 mW for lower, middle and upper bands respectively.

#### 1.4.2.17 Basic Pulse-Shape and Parameters

The basic pulse-width will be 70 nsec. The pulse shape will be raised-cosine with a  $\beta = 0.5$ .

#### 1.4.2.18 Receiver Minimum Input Level Sensitivity

The BER shall be less than  $10^{-5}$  for an input level of  $-75$  dBm for the 10 Mbps,  $-72$  dBm for the 20 Mbps, and  $-70$  dBm for the 23.88 Mbps, measured at the antenna connector.

#### 1.4.2.19 Receiver Maximum Input Level

The BER shall be less than  $10^{-5}$  for an input level of  $-20$  dBm measured at the antenna connector.

#### 1.4.2.20 Receiver adjacent Channel Rejection

The adjacent channel rejection shall be equal to or better than a goal of 10 dB for 10 Mbps, and 7 dB for the 20 and 23.88 Mbps with suboptimal IF filter. The adjacent channel rejection shall be equal to or better than a goal of 15 dB for 10 Mbps, and 12 dB for the 20 and 11 dB 23.88 Mbps with more optimal IF filter.

#### 1.4.2.21 Clear Channel Assessment

The PHY should be able to perform Clear Channel Assessment (CCA) according to the physical energy and carrier sense. These two status are given by the PMD primitive, PHY\_ED.indicate and PHY\_CS.indicate, respectively. The CCA should indicate IDLE if there is no energy detect or carrier sense. If the PHY receives 4 symbol errors within 1  $\mu$ sec when CCA is BUSY, the carrier is lost and the CCA changes to IDLE.



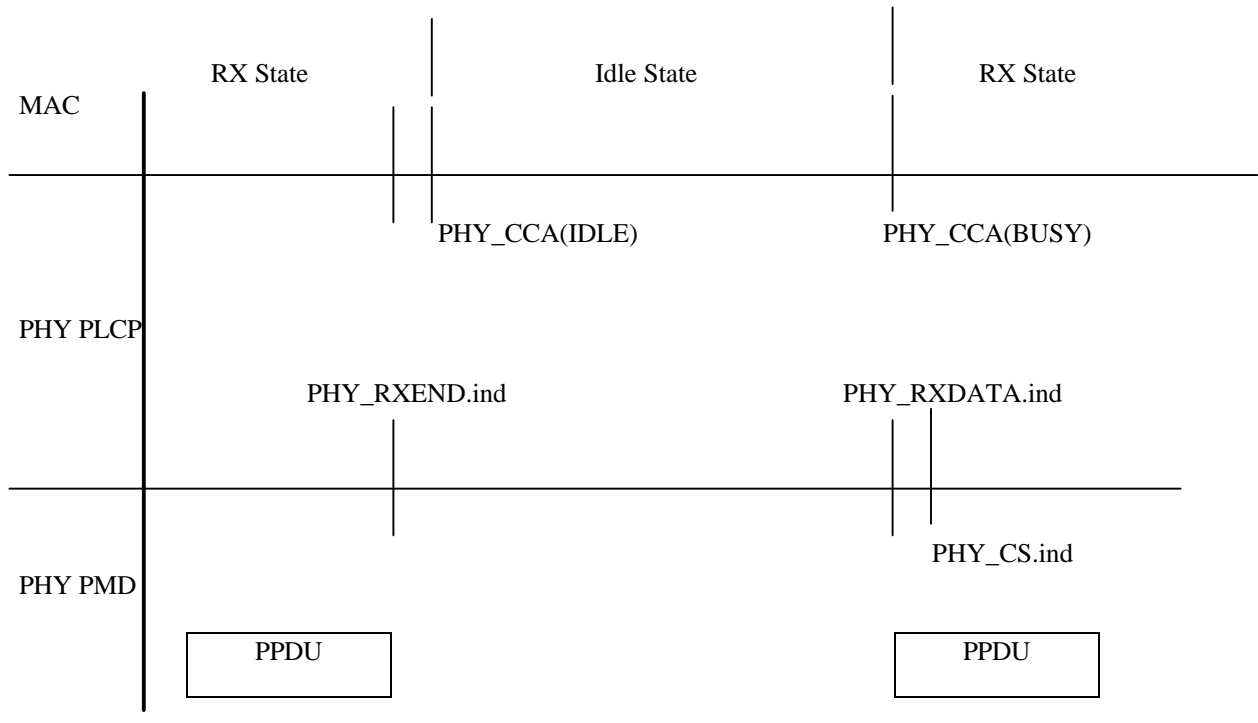


Figure 18. Clear Channel Assessment

### 1.4.3 Overhead related parameters

#### 1.4.3.1 Slot time

The slot time includes the RX to TX turnaround time ( ~1 microseconds), energy detection time (~25ns), and propagation delay (~300ns). The slot time is 3 microseconds.

#### 1.4.3.2 Short Inter Frame Space Time

The SIFS time is slightly larger than the transmit-to-receive turn-around time ( 4 microseconds ), and is defined as 5 microseconds.

#### 1.4.3.3 Preamble

The preamble is used for AGC settling-time, synchronization, diversity sampling, and antenna switching. The PHY has to be able to synchronize on the preamble within 12 symbols time. Once the preamble byte is found, PHY\_CS.indicate is issued to PLCP. The diversity sampling starts after the preamble byte is received. If any symbol error occurs during the diversity sampling time, PHY will switch to the other antenna. The PHY must see another preamble byte in order to get synchronized to the data stream.