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Proposal for GMSK/OQAM-based 5 GHz High Speed PHY

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Abstract

The purpose of the current document is to present an initial proposal for 5 GHz High Speed PHY. The guiding principle behind the proposal is to enable varying levels of complexity on the receive side, with the ability to trade performance for implementation complexity. The proposal stresses commonality with HIPERLAN type 1 (H/1) wherever appropriate, assuming that dual-mode equipment may be produced, and that acceptance in Europe will be facilitated by that.

The proposal is based on Offset QPSK for the Basic Rate or Offset QAM for optional High Rate mode. With appropriate pulse shape and after a saturated amplifier the basic rate waveform is equivalent to GMSK. The proposed basic rate is 20 Mbit/s and the proposed high rate is 40 Mbit/s.

The data is differentially precoded to enable discriminator detection. For multilevel signaling, Gray mapping is utilised.

The proposed preamble is 256 bits long. The preamble structure is derived from “complementary sequences” which enable particularly simple correlator structure for detection and channel estimation purposes.

The Error Control coding is based on BCH(31,26,3) code, as in H/1. The 24 bit long PLCP Header will be protected by Golay code, which will be used both for error correction and error detection (instead of CRC).

Accuracy requirements are briefly discussed. In particular, 10 ppm accuracy is proposed for both clock and carrier frequency.

Modulation Method Proposal for 5 GHz Higher Speed PHY

Modulation Format

The modulation method to be used is an Offset Quadrature Modulation, which in complex-baseband notation may be described as:

$$s(t) = \sum_{k=1}^{N} a_k \exp(j\pi k/2)\, p(t - kT_S)$$

where

a_k is the k-th real-valued symbol
T_S is symbol period (bit period for binary signaling)
$p(t)$ is the transmit pulse shape.

The values a_k may accept are +/-1 for binary signaling, and -1, -1/3, +1/3, +1 for 4-level signaling. For 4 level signaling a Gray mapping is used.

Bit value	Transmitted value
0	-1
1	1

Bit values	Transmitted value
00	-1
01	-1/3
11	1/3
10	1

The $\exp(j\pi k/2)$ term takes care of successive rotation of the transmitted symbols in increments of 90 degrees, so that they modulate alternately the I and Q coordinates.

The suggested pulse shape is a convolution of a half-sine waveform (with $2T_S$ null-to-null duration) with a Gaussian filter of width $0.3/T_S$.

The symbol rate shall be 23.52940 MHz +/-10 ppm.

Note: The definition of a single bit as a symbol differs from a common practice for OQPSK of defining two-bit interval (both I and Q) as a symbol time.

Discussion: In absence of Gaussian filter the resulting waveform (with binary data) is equivalent to an MSK modulation and is a constant envelope signal. The variant with multilevel signaling also appears in the literature with the name of MultiAmplitude-MSK. With

Gaussian filter, there are slight amplitude variations (1.2 dB ptp for BT=0.3). When such signal passes a saturated amplifier it becomes essentially equivalent to a GMSK signal. The small peak-to-average ratio in the binary mode turns into an advantage also in the OQAM (multilevel) mode, as smaller backoff is required in the RF power amplifiers.

The two-level and the four level both have same extremal values, as the limiting factor is PA peak power.

The Gray mapping has the benefit that adjacent levels differ by one bit only. As error correction is used, this is important. The fact that the MSB determines the polarity while the LSB determines the magnitude will be utilized for differential precoding.

The symbol rate is same as for HIPERLAN, and it results from usage of a rate 26/31 ECC (to be described) with 20 Mbit/s data rate. Usage of same rate will ease dual mode equipment manufacture.

Sensitivity

Receive sensitivity requirement in AWGN will be no worse than

Binary	-76 dBm
4-level	-67 dBm

Discussion: The sensitivity requirements are based on noise floor of -174dBm/Hz, data rate +73 dBHz, noise figure +10 dB, E/N_0=+10dB and an implementation margin of +5 dB. The coding gain (about 2 dB?) is not counted for. For 4 level modulation the distance between adjacent levels (for same average receive power) is 7 dB smaller and additional 2 dB are allowed for implementation loss, thus giving the 9 dB difference in the requirement. Of course, everybody is encouraged to improve on noise figure and on implementation loss!

Preamble

The preamble we propose is based on “complementary sequences”. The complementary sequences are constructed as

$A_1 = 1$
$B_1 = 1$
$A_{2n} = A_n\ \ B_n$
$B_{2n} = A_n\ -B_n$
e.g. A_2 = 1 1, B_2 = 1 -1, A_4 = 1 1 1 -1, B_4 = 1 1 -1 1, A_8 = 1 1 1 -1 1 1 -1 1, B_8 = 1 1 1 -1 -1 -1 1 -1 etc.

The proposed preamble is

$-B_{32}$ $-B_{32}$ $-B_{32}$ $-B_{32}$ A_{32} B_{32} A_{32} $-B_{32}$ A_{32}

which is 256 bit long.

Discussion: The complementary sequences have good correlation properties and have a particularly efficient (in terms of amount of arithmetic elements) correlator implementation. The repeated $-B_{32}$ terms are used for signal detection and antenna selection; the A_{32} B_{32} A_{32} $-B_{32}$ (equivalent to A_{128}) part, with $-B_{32}$ preceding it and A_{32} following it, are used for estimating the propagation channel through which the signal arrived by correlating the incoming signal with A_{128}. The relatively large length of the preamble is necessary for many reasons - we need to select antenna, to acquire carrier and to estimate a relatively long channel impulse response.

PLCP header

The PLCP header will be transmitted in a binary mode. The header will consist of 24 data bits. The suggested division is 12-16 bits for length, 4-6 for rate and ECC method, and the rest will be reserved. The header will be protected by an (24,12,8) extended Golay error correcting and detecting code. The data will be divided into two parts, each 12 bits long; two 24 bit long Golay codewords will be formed, and those will be interleaved. The code is able to correct 3 errors and detect 4. I suggest that 0, 1 or 2 errors will be corrected, while 3 or 4 errors will be discarded, and no separate CRC will be added.

Discussion: The 24 bits seem to suffice for a header, including extensions. The error protection for the header should be on a par with the error protection of the data payload. This implies that the header should be transmitted at the lowest rate supported, and have a similar or better ECC. As the proposed error correction method is based on BCH(31,26,3) code, a stronger Golay code is used for the header. The increased correction/detection capability will be used to avoid a separate CRC for the header by discarding words which are beyond correction capability. Allowing up to 2 errors in each of the interleaved Golay codewords enables bursts of up to 4 errors to be corrected, giving thus increased protection in case a DFE equalizer is used (DFE typically produces bursts of errors).

Mapping a Bit Stream Onto Symbols

The symbol stream may consist of both binary and multilevel data. Most notably, the preamble and the PLCP header are always binary, while and the data part may consist of either binary or multilevel symbols. The formula of the transmitted signal facilitates naturally this transition.

The data is differentially precoded. In the case of multilevel signals the differential precoding is performed on MSB only. The differential precoding will start with the first bit of the PLCP header and will continue into the payload region of the packet.

Example:

symbol number	1	2	3	4	5	6	7	8	9	10	11	12

data symbol	0	0	1	0	1	1	11	00	10	01	10	11
transmitted symbol	0	0	1	1	0	1	01	00	10	11	00	11
transmitted value	-1	-1	1	1	-1	1	-1/3	-1	+1	1/3	-1	1/3

Discussion: The reason of using the differential precoding is to enable discriminator based detection for those wishing to attempt it. If there is a general agreement that in typical multipath channels the usage of discriminator based detection is improbable, the author will gladly extract this part from the proposition, as the differential precoding causes error multiplication.

Error Correction Coding

It is suggested that a HIPERLAN-like BCH (31,26,3) error correcting code with an interleaver will be used. An interleaver with interleaving depth of 8 (as opposed to 16 in HIPERLAN) is suggested. The length of the transmission will be a multiple of 26 symbol octets (multiple of 31 symbol octets after encoding).

For multilevel signals, the blocks of 31 symbols, 2 bits each, will be partitioned into two 31 bit codewords. The first will consist of MSB-LSB-MSB-....-LSB-MSB of the symbols, while the other will consist of LSB-MSB-LSB-....-MSB -LSB of the symbols.

(More detailed description of the proposal will be presented in January)

Discussion: The use of HIPERLAN-like parameters (including signaling rate of 23.5xx MHz) eases production of dual-mode equipment, including similar channelization scheme. This may ease licensing in Europe, when time comes. The reduced interleaving depth is proposed here in order to reduce the granularity involved with interleaving. For example, most of the control frames may be accommodated in 26 octet block, including 4 octet CRC. The average granularity overhead in data packets is reduced from 26 to 13 octets. The reduced interleaving depth also reduces the memory requirements; it is good for decoding latency and for data preloading lead time. The reduction in error burst length tolerance may be offset by shorter block size within which no two error events are tolerated.

The “strange partitioning” of groups of symbol into codeword is due to the fact that the MSB and LSB have somewhat different error probability, and the proposed mapping gives the two codewords similar performance. At some performance penalty a much simpler “all MSBs - all LSBs” partitioning may be used. Yet another simple method of taking both MSB and LSB of same symbol into same codeword is not proposed here because the argument “only one of them will be in error with Gray mapping” may not hold when DFE error propagation is concidered.

Channelization

The chanellization is based on using multiples of symbol rate as center frequencies, as in HIPERLAN. 7 channels are proposed.

Ch#	symbol rate multiple	Center frequency MHz	Power limits in US	Corresponds to HIPERLAN chennel
1	218	5,129.4092	Low power	N/A
2	219	5,152.9386	Low power	N/A
3	220	5,176.4680	Low power	0
4	221	5,199.9974	Low power	1
5	222	5,223.5268	High power	2
6	223	5,247.0562	High power	3
7	224	5,270.5856	High power	4

Center Frequency tolerance

The center frequency of the transmitter will be accurate within +/- 50 KHz.

Discussion: The center frequency accuracy affects both signal detection (if it is corelation based) and carrier tracking loop acquisition performance. The requirement of 50 KHz (about 10 ppm at 5 GHz) is a reasonable compromise between cost and performance.

Modulator waveform deviation from nominal

The waveform needs to be accurate, in particular during preamble.

Phase noise specifications are required

Specifications will be more stringent for units supporting multilevel modulation.

Discussion: The modulation accuracy requirements should assume that a coherent receiver must be able to demodulate the data. This implies a quadrature-modulator-based transmitter implementation. This requirement is important as during the reception initiation step the receiver does not know that a message from a relaxed-specification transmitter is arriving and cannot prepare to that by, for example, switching to an appropriate algorithm with wider tracking loops or differential detection.

Particular care is required during the mid-to-end of the preamble, where parameters of the received signal are learned.