1. Overview

1.1. General Signal Structure

The signal within any channel is transmitted as a TDM burst consisting of a windowed OFDM synchronization symbol and windowed OFDM data symbols with serially concatenated convolutional coding and iterative decoding. There are two burst modulations, a lower rate requiring a lower signal to noise ratio, and a higher rate maximizing throughput at the expense of a greater signal to noise ratio requirement. Critical characteristics are the spectral containment, adjacent channel rejection, and the required average signal-to-noise density for the specified packet error rate.

1.2. Summary

Section 2 describes the Time Division Multiple Access (TDMA) slots into which each individual channel is divided, and also describes the burst transmissions that occupy those slots. Section 3 describes the different modes available for a given burst. Section 4 describes time, frequency and phase acquisition using the reference symbol. Section 5 describes the modulation and filtering, demodulation and phase tracking, while Section 6 describes the coding and decoding. Section 7 describes the link layer processing.

2. Slots and Bursts

A TDMA structure is used on any given frequency channel. The slots within a frame are defined with respect to the 1 pulse per second time tick provided from the GPS receiver or the associated flywheel clock. Thus, slots in different channels are synchronized with respect to one another. There are 116 equal duration slots[1] within a frame of one second duration, so the slot duration is 1 sec/116 = ~8.62 msec.

Information is exchanged in bursts of RF energy. To allow for possible transmitter timing drift, each burst is transmitted starting 5 µsec[2] after the beginning of the slot. Only one burst may be transmitted within a slot. The relationship between the slots and the received burst timing is shown in Figure 1 below.

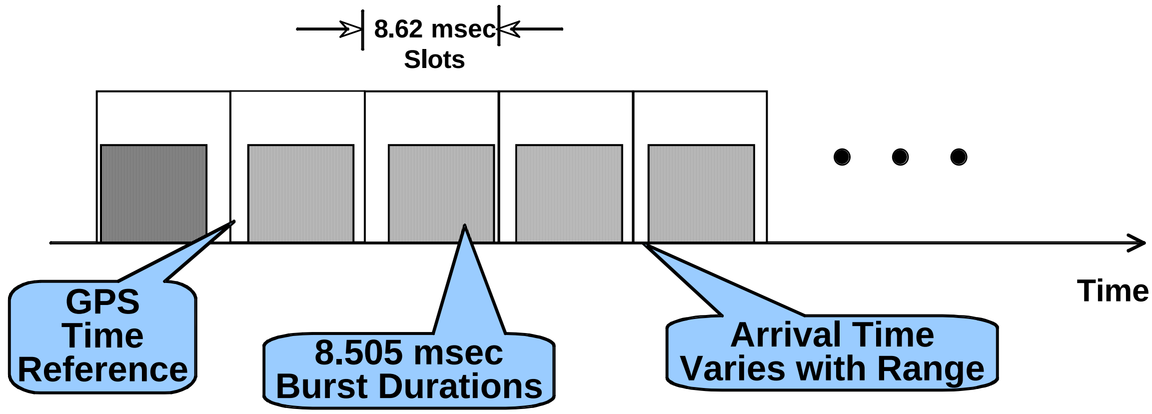

Figure 1 Slots and Received Bursts

The burst of RF energy is 8,505 µsec in duration. The 120 µsec difference between the slot duration and the burst duration is the allowance for transmit-receive turn around, timing errors and delay variation from unknown range. The burst consists of a reference symbol, a guard space of 200 µsec, and 14 contiguous data symbols, as shown at a high level in Figure 2 below. Appendix B provides the detailed timing of a transmit burst.

[1] OT-TES is implemented using software defined radios, that will permit different slot and burst structures for future enhancements.

[2] This delay may be shortened to 2 µsec, depending upon the OT-TES transceiver performance.

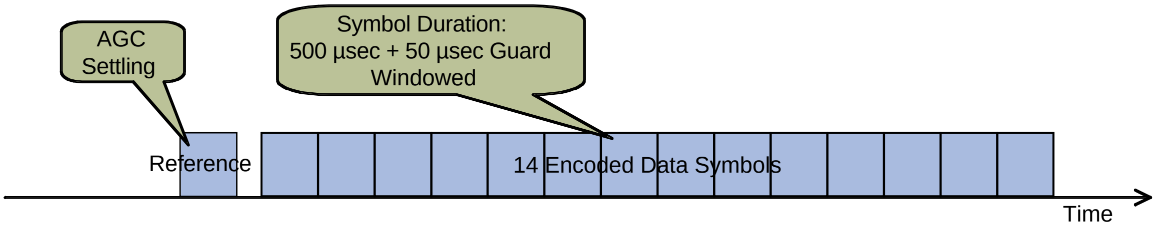

Figure 2 Burst Structure

The various functions necessary to construct the data portion of a transmit burst are shown in Figure 3 below.

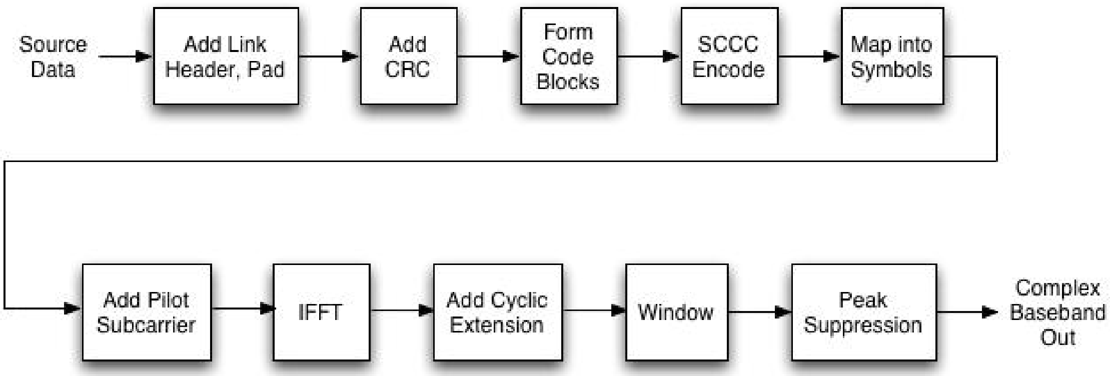

Figure 3 Transmit Signal Processing for Data

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3. Reference Symbol and Acquisition

The Reference Symbol is used to estimate: the gain setting for the AGC function preceding the A/Ds, the reference level for demodulator soft-decision scaling, the time-frequency origin of the incoming signal, and the phase references for the coherent OFDM data symbol subcarriers.

The Reference Symbol is identical to an OFDM data symbol as described in Section 4 below, but with a special subcarrier modulation to give an excellent ambiguity function within the range of possible time-frequency uncertainty.

Specifically, for the narrowband mode the Reference Symbol in general consists of a set of 61 orthogonal, equally powered subcarriers on 2 kHz centers. However, for our Reference Symbol, half of the subcarriers have zero amplitude, as described herein.

Considering all the subcarriers to have a common phase reference (for convenience called "0" degrees phase here), alternate individual subcarriers have binary phase modulation according to the sequence given in Appendix A. This binary modulation results in a waveform whose correlation peak in the frequency domain drops almost to zero magnitude for a reference signal frequency offset of one or more frequency resolution bins of 2 kHz.

The signal processing associated with acquisition of the reference symbol is shown at a high level in Figure 4 below.

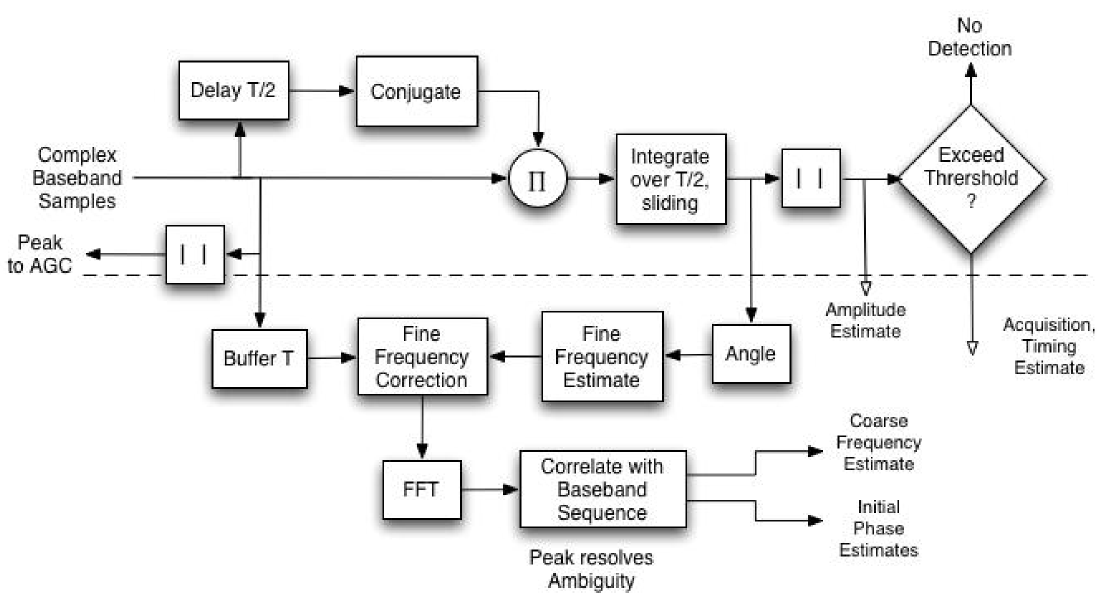

Figure 4 Acquisition Processing

4. Symbols, Modulation and Demodulation

Each OFDM data symbol consists of a set of orthogonal, equally powered subcarriers with individual data modulation. The center to center subcarrier orthogonal spacing is 2 kHz. There are 61 subcarriers, all of which are modulated by information derived from the source data, except for the center subcarrier.

Subcarriers are numbered from 1 to a maximum value, with number 1 corresponding to the lowest frequency and the center subcarrier is number 31.

The reciprocal of the orthogonal spacing is T_{orthog} = 500 μsec. The symbol is cyclically extended by T_{guard} = 50 μsec. The 50% amplitude duration of the symbol is slightly less[3] than $T_{symbol} = T_{orthog} + T_{guard}$ = 550 μsec. The symbol is windowed with a raised cosine function over transition intervals of duration $\beta\ T_{symbol}$. The transition parameter $\beta = 0.1$, so the transition interval duration is 55 μsec. In order for the window transitions to go all the way to zero amplitude with the desired 50% amplitude duration, the symbol is constructed by cyclically extending the basic symbol duration T_{symbol} by an additional $\beta\ T_{symbol}$, and then to window with a raised cosine applied to the leading and trailing $\beta\ T_{symbol}$ segments. Thus the zero to zero duration of one symbol is 605 μsec. These relationships are illustrated in Figure 5 below.

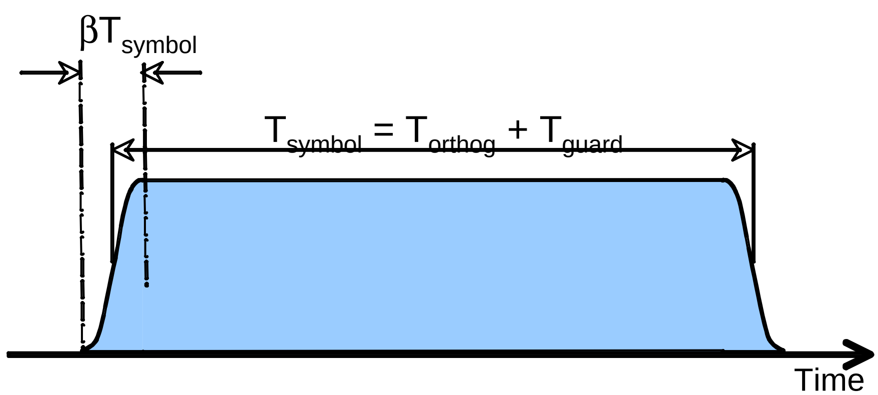

Figure 5 Envelope of Windowed Symbol

Note that contiguous data symbols overlap during the transition intervals, such that the time between centers of two successive data symbols is T_{symbol} = 550 μsec.

[3] The window is at half amplitude at the center of it's transition interval of 55 μsec.

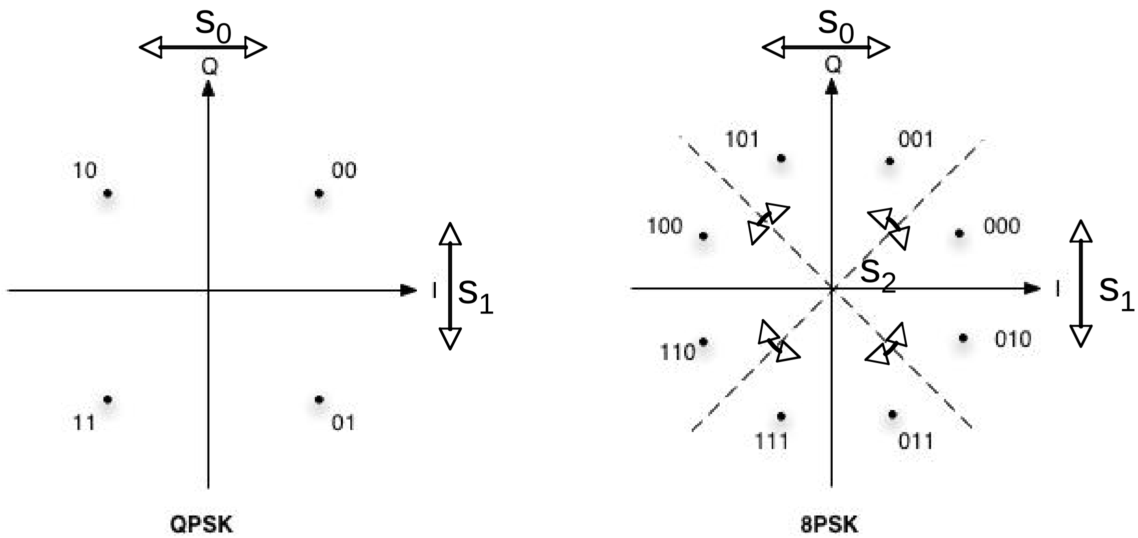

Figure 6 Decision Regions for QPSK and 8PSK

Referring to Figure 6, the axes are shown after derotation for channel phase shift. For QPSK, the soft decision on s_0 is the value on the I axis, and the soft decision on s_1 is the value on the Q axis. The soft decisions are quantized over the integer range +4 to -4, including 0, to be input to the SCCC decoder. The scaling is set relative to the expected signal amplitude obtained from the acquisition processing of the Reference Symbol. [SCALING DETAILS TO BE PROVIDED].

Similarly, for 8PSK the soft decisions on s_0 and s_1 are the values of the I and Q components respectively. The soft decision on s_2 is approximately the distance from the nearest dotted line boundary of Figure 6. A detailed description of this simple metric is given in the associated simulation. The s_2 soft decision is also quantized over the integer range +4 to -4, with scaling set relative to the expected signal amplitude obtained from the acquisition processing of the Reference Symbol.

The demodulation process for any subcarrier uses the current estimate for the reference phase. The initial value of this reference phase was calculated by the acquisition process on the Reference Symbol. NOTE: the phase reference is the currently evaluated value for the linear fit to the phases over [10] contiguous frequency bins.

The demodulator also outputs a phase error estimate, which is approximately the angular distance from the actual (I,Q) pair of the demod statistic to the nearest data point in the I,Q plane. The phase error estimates for each set of [10] contiguous frequency bins are fit to a linear phase reference correction. The phase reference linear fit is updated by adding [half] of the calculated correction fit to the previous fit[4]. NOTE: these are just updates to the coefficients of the composite linear fit, Those coefficients are then evaluated at each frequency bin for the reference for the next demodulation bin.

[4] NOTE: provision to unwrap any 2π wrap arounds are necessary.

The demodulation processing operations for data symbols are shown in Figure 7 below. The SCCC decoder and post-decoding operations are discussed in the following sections.

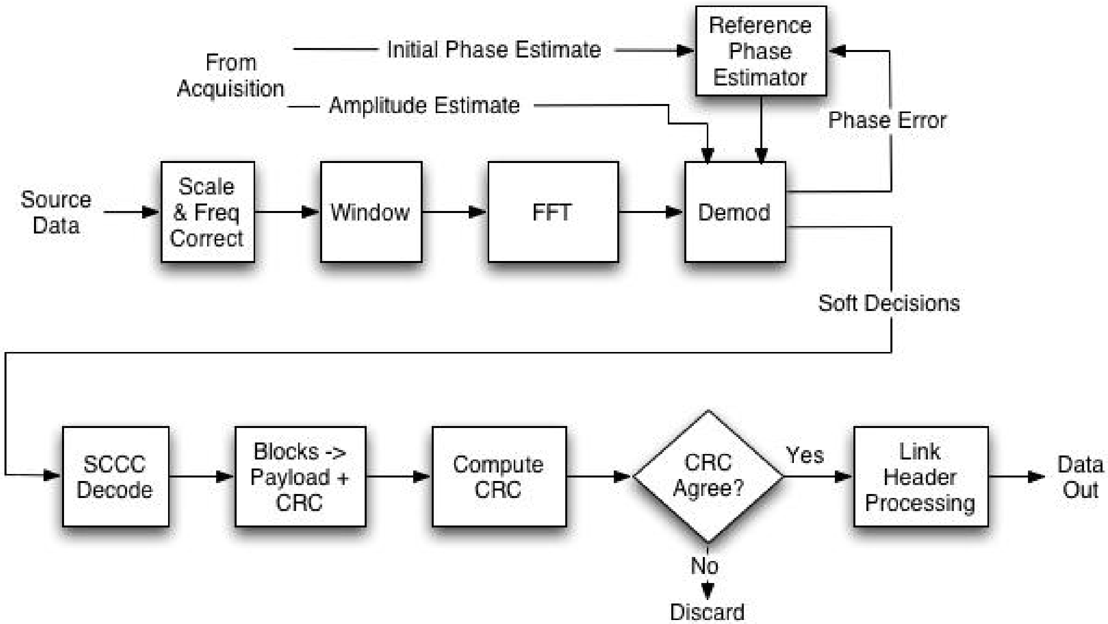

Figure 7 Receive Processing of Data Symbols

A. Appendix A. Reference Phase Sequence

A1. Narrowband Mode

Subcarrier modulation. By definition, the subcarrier at the center frequency (subcarrier number 31) has modulation 0^o. Note that "0" means zero amplitude, "+1" means 0^o and "-1" means 180^o.

The full modulation is constructed from replicas of the 30 element sequence bseq:

bseq=[1 0 -1 0 -1 0 -1 0 1 0 -1 0 -1 0 1 0 1 0 -1 0 1 0 -1 0 1 0 1 0 1 0].

The total modulation sequence of 61 elements, starting with the lowest occupied frequency, is:

[bseq bseq 1].

[bseq bseq bseq bseq bseq bseq bseq 1].

Appendix B. Detailed TimeLine of Transmit Burst

This figure shows the Reference Symbol followed by the first two data symbols of the burst.