Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Proposed Revision to Section 8.3.5.12 (Unique Word Specification)**
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Re:	Proposal to revise Section 8.3.5.12 (and descending subsections) of document 80216ab-01_01r1 with provided text.
Abstract	Explanation of benefits of the revision, and full replacement text for this revision.
Purpose	Incorporate provided text as revision of Section 8.3.5.12 (and descending subsections) of document 80216ab-01_01r1.
Notice	
Release	
Patent Policy and Procedures	

Proposed Revision to 8.3.5.12 (Unique Word Specification)

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1. Purpose

The purpose of this proposal is to revise Section 8.3.5.12 (and descending subsections) of the 80216ab-01_01r1 document. This section deals with specification of the Unique Word within the Single Carrier mode of the document.

2. Introduction

Unique Words are used for channel and timing estimation, and can, in some burst profiles, be used to facilitate frequency domain equalization by serving as cyclic prefixes. Burst mode preambles and the Continuous mode frame header preambles also are composed of Unique Words.

Key characteristics of a Unique Word are that it has good periodic correlation properties, and that its symbols have a constant amplitude. In other words, ideally, the sequence is a CAZAC (Constant Amplitude Zero Auto-Correlation) sequence, which exhibits zero periodic autocorrelation for off-zero lags.

3. Previous Definition of Unique Word

In Section 8.3.5.12.2 of 80216ab-01_01r1, the Unique Word is defined as a Milewski sequence, which does, in fact, qualify as a CAZAC sequence. The length of a Milewski sequence is $U = 2^n - 1$, with n being an integer, and the I channel component of this sequence is derived from a pseudo-noise (pn) sequence, also of length $U = 2^n - 1$. The Q channel component of the Milewski sequence signal is a constant, with value

$$\frac{1}{\sqrt{2^n - 1}}$$

3.1 Issues with the Previous Definition

One issue with the Milewski sequence is that, although it is fairly simple to generate using a PN generator, its length is not exactly $U = 2^n$. This complicates the use of some FFT-based channel estimation schemes, either narrowing the architectural choices available to demodulator designers, or reducing the performance of some of their choices. In order to increase receiver design options, as well as potentially reduce receiver complexity and/or increase the channel estimation performance, we propose that CAZAC sequences with lengths exactly equal to $U = 2^n$ be used.

4. Proposal of a New Definition for the Unique Word

Two other types of CAZAC sequences are Frank-Zadoff [1] and Chu [2] sequences. Frank-Zadoff sequences exist for lengths U = 16, 64, and 256, and seem highly suited to our application, since their constituent symbols are derived from QPSK, 8-PSK, and 16-PSK alphabets, respectively.

As document 80216ab-01_01r1 mandated U = 63, we propose that implementation of the length 64 sequence be mandatory. Since a number of length options, from 7 to 511 symbols were provided in the original 80216ab-01_01r1, we propose that definitions for such options be provided in its revision. For the length U = 16 and 256 options, we propose the use of Frank-Zadoff sequences, and propose that use Chu sequences be used otherwise---for lengths U = 8, 32, 128, and 512. This is possible because Chu sequences exist for any sequence length.

4.1 Discussion

The reason that Chu sequences are not specified for U = 16, 64, and 256 is that Chu sequences are generally polyphase in nature, since they may be characterized as ‘constant envelope phase chirp’ sequences. Their implementation in the transmitter may require additional design considerations.

Nevertheless, the complexity of a transmitter designed to accommodate even the polyphase Chu sequences may not be exceedingly greater than that of one designed for Milewski sequences. Recall that a Milewski sequence must transmit a Q channel component of $1/\sqrt{2^n - 1}$, and, in order to scale the sequence so that it has unit magnitude, both the I and Q components must each be multiplied by $\sqrt{1 - 2^{-n}}$. In this sense, the Milewski sequence, like the Chu-sequence, can be considered an irregular polyphase sequence, with the difference being that with the Milewski sequence only uses 2 phases for any symbol. Therefore, the raised cosine transmit filter operation used to shape and interpolate between symbols in a digital modulator would seemingly require the same degree of multiplication precision (for the Q-channel at least) for a Milewski sequence as a Chu sequence.

Another point to remember, too, is that generation of the mandatory 64-symbol mode requires only 8-PSK transmission capability, since a Frank-Zadoff sequence is used in that case.

The benefits to a receiver are much greater. As previously indicated, the primary benefit is that fact that $U = 2^n$ lengths improves the performance of efficient radix-2 FFT-based channel estimation algorithms in a receiver. With $U = 2^n$ lengths, such algorithms are both low in complexity and high in performance.

What’s more, the use of length $U = 2^n$ Unique Words should facilitate MAC bookkeeping of the amount of overhead introduced in a payload through incorporation of Unique Words (as preambles and/or as pilot symbols). This should also align the MAC calculations of overhead due to training and/or pilot symbols more closely with the OFDM modes in the 802.16ab.

5. Exact Text Revision Proposed for Section 8.3.5.12

What follows is the exact text that we propose should replace Section 8.3.5.12 and its 2 descending subsections. This text defines the newly proposed Frank-Zadoff and Chu sequences, and slightly modifies the description of the design criteria used to select a Unique Word sequence.

5.0.0.1 Unique Word

5.0.0.1.1 Unique Word Sequence Design Criteria

The choice of a structure for the Unique Word is critical, because a Unique Word may be used for channel estimation, and it may also be used as a cyclic prefix element in some frequency domain equalizers implementations. Its cyclic prefix role imposes one constraint: the Unique Word must be at least as long as the maximum delay spread to be experienced by an intended receiver. Its channel estimation role imposes added constraints: the Unique Word should have good periodic correlation properties, and/or equivalently possess a broadband, un-notched frequency response. In addition, since it may be a component within an acquisition preamble and play a role in the initial channel estimation and acquisition of a receiver, the Unique Word should have an symbol magnitude profile that is constant, to minimize AGC requirements. And lastly, since the Unique Word introduces overhead, it should be no longer than it need be; installations that experience less delay spread should not be burdened with the overhead of excessively long Unique Words. This implies that some flexibility in the choice (or construction) of Unique Words is desirable.

5.0.0.1.2 Unique Word Sequence Specification

Frank-Zadoff [1] and Chu sequences [2] are two constructions of CAZAC (Constant Amplitude Zero Auto-Correlation) sequences that possess the desired periodic correlation and constant amplitude properties. As Table 1 indicates, support of a Frank-Zadoff sequence of length 64 is mandatory in a compliant device. For applications with longer or shorter delay spreads, an operator may desire to use other, optional sequences of differing lengths. For this reason Table 1 defines optional Frank-Zadoff and Chu sequences of various lengths.

Table 1—UW lengths, Types, and Support Status

Length, U (symbols)	Sequence Type	Support Status
0	---	Optional
8	Chu	Optional
16	Frank-Zadoff	Optional
32	Chu	Optional
64	Frank-Zadoff	Mandatory
128	Chu	Optional
256	Frank-Zadoff	Optional
512	Chu	Optional

The I and Q components of a length U, $0 \le n < U$, Unique Word sequence are generated from

$$I[n] = \cos(\theta[n])$$
$$Q[n] = \sin(\theta[n]) \quad (1)$$

where $\theta[n] = \theta_{chu}[n]$ when generating a Chu sequence, and $\theta[n] = \theta_{frank}[n]$ when generating a Frank-Zadoff sequence. For a Chu sequence,

$$\theta_{chu}[n] = \frac{\pi n^2}{U} \quad (2)$$

and, for a Frank-Zadoff sequence,

$$\theta_{frank}[n = p + q\sqrt{U}] = \frac{2\pi pq}{\sqrt{U}}$$
$$p = 0, 1, \ldots, \sqrt{U} - 1 \quad (3)$$
$$q = 0, 1, \ldots, \sqrt{U} - 1$$

The length U = 16, 64, and 256 Unique Word sequences are composed of symbols from QPSK, 8-PSK, and 16-PSK alphabets, respectively. However, the length U = 8, 32, 128, and 512 sequences are derived from polyphase symbol alphabets that may require additional care in a hardware implementation. The error vector magnitude (EVM) computed for Unique Word symbols in a transmitter implementation should conform with the general EVM requirements for transmitted symbol modulation accuracy found in 8.3.5.17.1.5.

References:

[1] R. L. Frank and S. A. Zadoff, “Phase shift pulse codes with good periodic correlation properties,” IRE Transactions on Information Theory, Oct. 1962, pp. 381-382.

[2] D. C. Chu, “Polyphase codes with good periodic correlation properties,” IEEE Transactions on Information Theory, July 1972, pp. 531-532.