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Title	Energy Keying as a Modulation Technique for IEEE 802.16h Coexistence Applications
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Re:	Recirculation of Working Group Review of Working Document 80216h-06_015
Abstract	Energy Keying for CSI communications between systems raises PHY compliance and interference detection performance issues. It is shown in this paper that Energy Keyed signaling using OFDM as a source signal results in the broadening of the OFDM signal in a manner that can violate the IEEE 802.16 emission masks. Detection of Energy Keying, especially by receivers having different detection bandwidths, will result in asymmetrical interference detection performance. Energy Keyed techniques for interference detection will likely show lower sensitivities compared to existing demodulation techniques currently specified for IEEE 802.16
Purpose	This contribution is submitted in a effort to itemize the difficulties faced by implementing the Energy Keying concept and the changes it can make to the PHY layer performance of IEEE 802.16
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Patent Policy and Procedures	

Energy Keying as a Modulation Technique for IEEE 802.16h Coexistence Applications

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Introduction

Energy Keying is a technique suggested for communications with IEEE 802.16h systems. The technique would be used for interference detection and coexistence between systems having different IEEE 802.16 PHY profiles. For example, systems operating using 20 MHz OFDM bandwidths would have a means of communicating with systems having 1.75 MHz Bandwidths. The scheme would be universally adaptable and used in the Single Carrier, OFDM, and OFDMA modulation formats suggested by IEEE 802.16-2004.

Discussion

Energy Keying (Ref. 1) relies on the rapid pulsing of a OFDM signal at a “CSI symbol rate” which can be in the order of 10’s to 100’s of microseconds in duration (Ref 2). The pulses would be concatenated over the duration of a CSI slot, which could be in the order of milliseconds in length. The order of the pulses would signify the beginning, end, and content of a coexistence message.

Energy Pulses thus created by this altered OFDM signal (which itself would contain predetermined data content such as a random sequence, etc.) would be detected by means of a modified RSSI system within a receiver. Some indication of how this detection system may be implemented is given in Ref 3. Essentially detection would be undertaken by a demodulator which uses RSSI readings as input.

There are a number of technical issues with Energy Keying that need examination within the context of the IEEE 802.16-2004 standard. There is also a large body technical information and literature available to provide a succinct analysis concerning the implementation and performance of Energy Keying within such a context. In this paper the discussion of the technical issues surrounding the Energy Keying concept will be limited to a general analysis relying on experimental evidence and radio receiver design practice. The results given below can be explained in detail by modulation theory and mathematical analysis which is not provided here in the interest of brevity.

The Time and Frequency Domain Characteristics of Energy Keyed OFDM

Figure 1 is a laboratory setup that was used to generate Energy Keyed symbols. The OFDM signal was created by an IEEE 802.11g 64 QAM OFDM signal generator (Agilent E4438C) that created 2 types of OFDM signals; one having a 1.6 MHz bandwidth and one having a 10 MHz bandwidth (the bandwidths were created by modification of the IEEE 802.11g clock rate; otherwise they were IEEE 802.11 OFDM signals). Thus the bandwidth and signal pilot tone content of the test OFDM was very similar to profiles suggested in IEEE 802.16. The data content of the OFDM signal itself was a psuedo-random data sequence. The OFDM signal had a frame duration of 1 millisecond. The signal was then input into a rapidly activated switch (HMC221) which created an Energy Keyed signal consisting of 10 microsecond ‘off ’ and 10 microsecond ‘on’ energy pulses. These pulses were then fed into a RSSI detector (HP423B) and oscilloscope (for time domain analysis). Additionally, a spectrum analyzer was used to examine the resultant signal in the frequency domain. Figure 2 shows the Energy Keyed signal that could be a candidate for CSI signaling, as per Ref 1. This is the signal input into the oscilloscope and spectrum analyzer. The center frequency for this experiment’s transmissions was 2409 MHz, a typical License-Exempt channel.

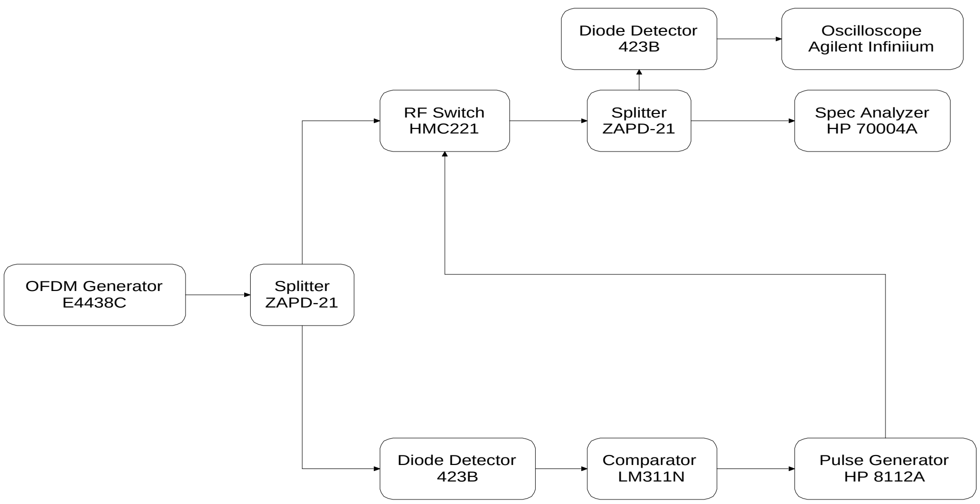

Figure 1: Energy Keying Transmitter/RSSI Detector Experimental Setup

The process of modifying one signal by another can be readily analyzed by signal convolution theory. Taking a modulated signal such as OFDM (or any other signal for that matter) and modifying it using another signaling process, such as burst pulsing, results in changes to the original modulated signal. This will be evident in the transmission spectra and it was apparent in the experiment described above.

Figures 3 and 4 show the effect Energy Keying had on the transmitted OFDM spectrum. Figure 3 shows in the yellow graph the original (un-pulsed) spectrum of the 10 MHz OFDM signal and the blue shows the pulsed spectrum. Similar results are shown in Figure 4, which was done with a 1.6 MHz wide OFDM spectrum.

These data show that an OFDM signal modified by pulsing will result in a transmission spectrum broader than the original (OFDM). The IEEE 802.16-2004 standard (Section 8.5.2) defines the OFDM transmit spectrum masks. It is apparent from the above experiment that OFDM spectrum spreading, as a consequence of Energy Keying, could violate the spectrum mask stipulated by the standard. The violation would be more apparent when smaller bandwidth OFDM modulation techniques are used since the Energy Keyed spectrum (with its 100 KHz pulse rate) is confined to the center frequency and gets covered by wider OFDM spectra. The sloping emission envelope caused by the keying is much more apparent with the 1.6 MHz OFDM signal (Figure 3) than with the 10 MHz OFDM (Figure 4). The wider emission spectrum would only be present for the duration of the CSI burst. Analysis of the adjacent channel effects that the OFDM/CSI burst scheme would have would have to account for the duty cycle of the CSI, amongst other variables.

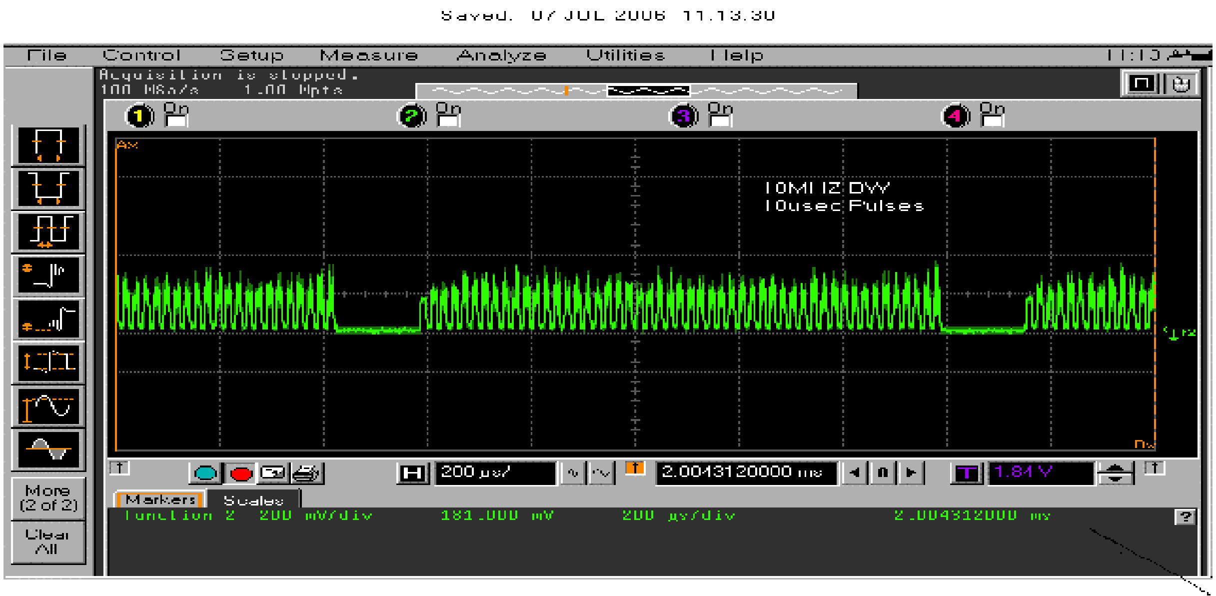

Figure 2: Energy Keyed OFDM: 1 millisecond bursts keyed at a 10 microsecond rate.

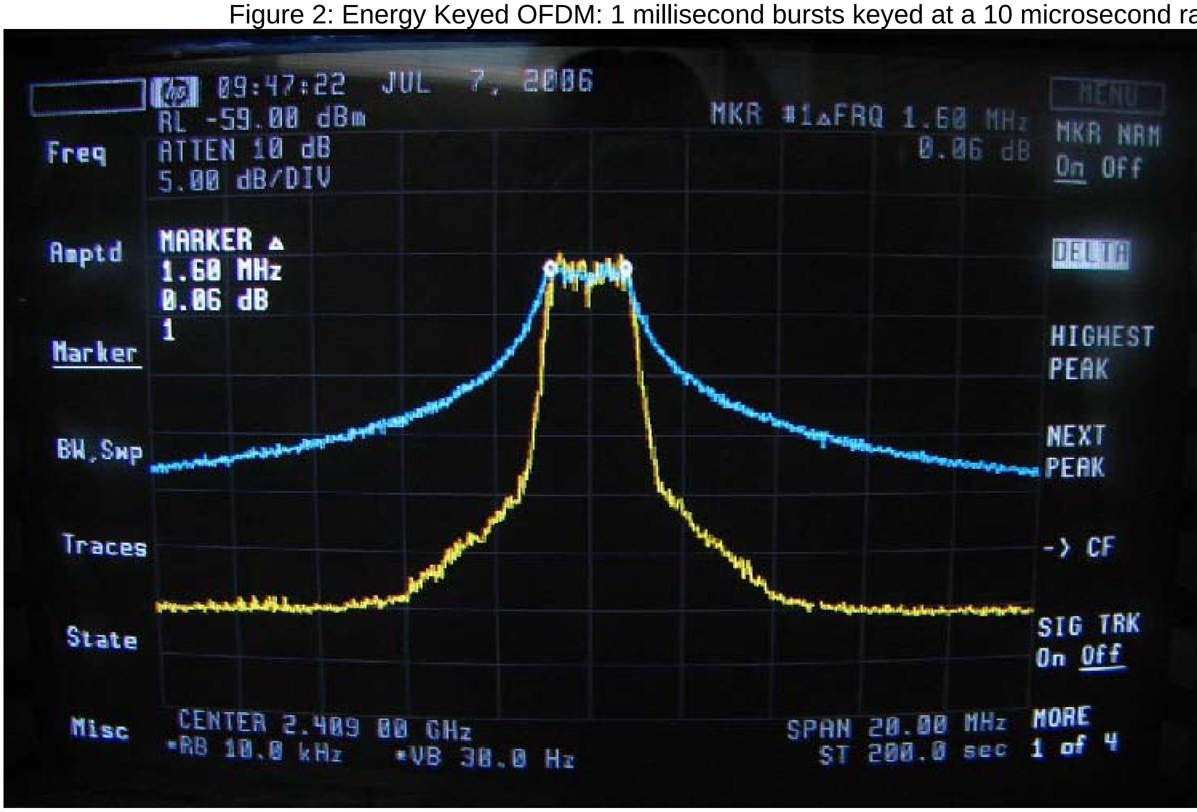

Figure 3: Original OFDM (1.6 MHz wide) in yellow and Energy Keyed OFDM (1.6 MHz) in Blue.

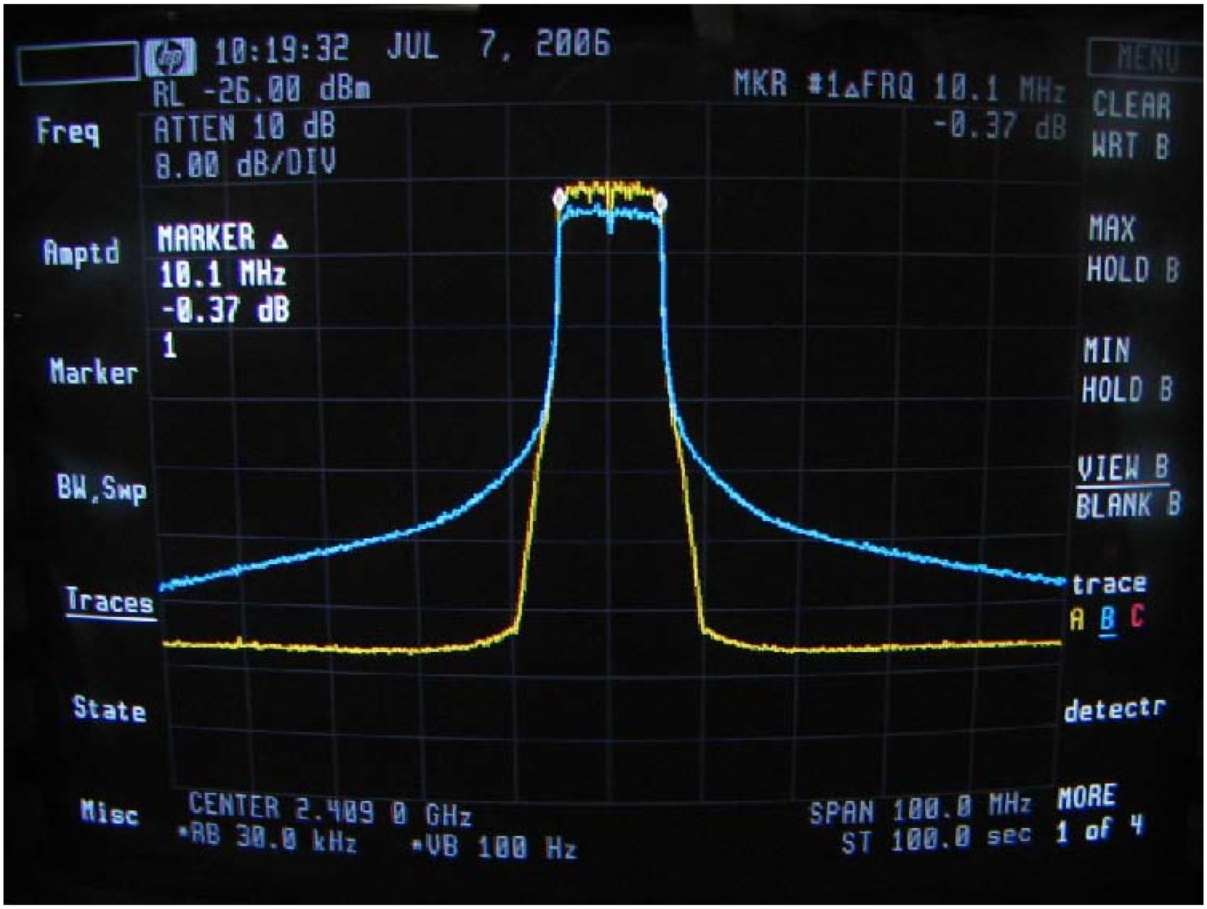

Figure 4: Original OFDM (10 MHz wide) in yellow and Energy Keyed OFDM (10 MHz wide) in Blue.

Detection of CSI Energy Keyed Signals

Detection of an Energy Keyed signal requires knowledge of the threshold between the Off/On portions of the received signal. Determination of this threshold under high noise conditions requires integration of the signal power over a period of time in order to determine a mean level. If the signal is continuous this is much easier to undertake than if the signal is bursty (as proposed with the CSI Energy Pulsing concept). Likely this will necessitate a preamble in the Energy Keyed signaling message.

Implementation of an Energy Keyed detector that is linear over a wide variety of input signal levels and noise power conditions can be problematic especially if it is to differentiate between CSI signaling and other pulse signals, such as radar pulses, which will be co-channel in the some of the LE spectrum (such as 5.4-5.7 GHz) within which IEEE 802.16h is to operate.

Detection of Energy Keyed signals by IEEE 802.16 terminals having different operational bandwidths poses another type of detection problem. Signal detection theory tells us that the bandwidth of a detector should be matched to the signal that is being detected. To not do so will cause degradation to the receiver's performance. For example, detection of a 1.75 MHz Energy Pulsed OFDM signal by a RSSI detector having a 20 MHz receiver bandwidth will result in ~ 10.57 dB excess noise power degradation to the reception process. Unless the 20 MHz receiver can switch its Energy Pulse detection bandwidth to 1.75 MHz, it will be disadvantaged compared to a 1.75 MHz receiver.

Changing the receiver bandwidth itself is not necessarily a difficult undertaking and is usually implemented within the RF to I/Q conversion chain of an IEEE 802.16 receiver.Variable bandwidth receivers are not uncommon. This procedure is more complex and/or impossible in designs resorting to low cost but fixed IF selection (SAW) filter technology. However, even with a variable filtering capability there is the question concerning the procedure a radio receiver must implement to ensure capture of a CSI Energy Keyed message at the right bandwidth at the right time.

There is also the issue of bit error performance. An Energy Keyed detector using minimally coded energy bursts will not incorporate the powerful FEC and other coding techniques made available by the IEEE 802.16 standard. This means that there will likely be a higher error rate on the Energy Keying signaling compared with the encoded OFDM modulation for a given transmitted power. As a consequence using Energy Keying for inter-system signaling will be a less efficient technique compared to the demodulation approaches already contained in the IEEE 802.16 standard. The effect of this can be illustrated by an example. Assuming two interfering systems operating on the same band and having the same receiver bandwidths; these systems would be more sensitive and effective in the detection of their mutual interference by exchanging standard OFDM encoded interference messages than by exchanging the minimally coded Energy Keyed symbols. Energy Keying in these applications runs in contradiction to the principle of interference detection at the lowest operating signal to noise ratios.

It has been noted that Energy Bursts will be detectable in the same manner as Radar pulses in DFS systems (Ref. 3). This may be true but it must be remembered that DFS systems operate at fairly high Radar signal levels (typically -62 dBm) and have repetitive patterns which facilitate detection and mitigate false alarm. A radar detector cannot easily differentiate between a “01” and “10” pulse required with the detection of Energy Keyed signaling. Furthermore, as mentioned above, the necessity of a RSSI detection system to differentiate between Radar pulses and Energy Keyed (CSI) signaling results in increased system complexity and is likely not a simple modification to a IEEE 802.16 demodulator.

Summary

The use of Energy Keyed communications within the context of IEEE 802.16 introduces numerous technical issues that are not addressed in the current IEEE 802.16h study group work and draft document and pose problems with its acceptance and implementation :

1. The normal IEEE 802.16 transmitted spectrum will be modified by use of Energy Keyed symbols composed of OFDM power constrained to pulses of 10-100's microseconds duration. The broadened transmitted spectrum created by this raises the issue of compliance with the requirements of IEEE 802.16-2004 Section 8.5.2, especially for narrower bandwidth OFDM systems. Broadened spectral emission will impact adjacent channel performance.
2. The detection of Energy Pulses will require the development of a special demodulator in order to determine the threshold of On/Off energy pulse presence. This detector must be linear and may require that the Energy Keyed bursts carry a preamble so that detection thresholds can be determined. The detector will become more complex if it needs to differentiate between Radar pulses and CSI keying.
3. The implication that Energy Pulses will be received by a variety of IEEE systems operating using different receiving bandwidths indicates that there will be a variation in the sensitivities of these systems due to the different noise powers they will be receiving. Unless proper scaling of receiver noise power bandwidths commensurate with signal bandwidth is undertaken, terminals with different receiver bandwidths will exhibit different Energy Keying detection behaviors.

4. The poorer BER performance of minimally coded Energy Keying compared to existing OFDM modulation techniques is a disadvantage to its use especially amongst interfering systems operating on the same receiver bandwidth.

References:

Ref 1:2006-06 C80216h-06_048 Sections 15.3.1.1.1-15.3.1.1.3 Draft IEEE Standard for Local and Metropolitan Area Networks PART 16: Air Interface for Fixed Wireless Access Systems

Ref 2: Private communications: John Sydor/ Wu Xuyong June/July 2006

Ref 3: 2006-07-10 IEEE C802.16h-06/054 Discussion on implementing the energy pulse.
Contribution By Wu Xuyong, Huawei.