Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Comparison of QPSK/QAM, OFDM, and Spread Spectrum for 5-6GHz PMP BWAS**
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Re:	In response to a Call for Contributions by September 8, 2000, to assist the Study Group in deciding on the applicability of existing/proposed standards such as the IEEE802.16.1 PHY and the ETSI BRAN Hiperacces PHY, to the proposed WirelessHUMAN Standard.
Abstract	The contribution compares the advantages/disadvantages of PMP Fixed Broadband Wireless Access Systems' use of Single-Carrier QPSK/QAM, or OFDM, or Spread Spectrum signaling techniques, and based on this analysis and actual in service experience with PMP BWAS in the U-NII bands proposes that QPSK/QAM (as specified in the IEEE802.16.1 PHY and the ETSI BRAN Hiperacces PHY) be specified in the WirelessHUMAN Standard.
Purpose	The Study Group should propose that Single-Carrier QPSK/QAM(as specified in the IEEE802.16.1 PHY and the ETSI BRAN Hiperacces PHY) be used in the proposed WirelessHUMAN Standard.
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Comparison of QPSK/QAM, OFDM, and Spread Spectrum for 5GHz PMP BWAS

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Single-carrier QPSK/QAM

Single-carrier QPSK/QAM(as specified for the IEEE802.16.1 PHY and for the ETSI BRAN Hiperacces PHY) is proven technology. Time-division systems (as opposed to spread spectrum) can provide fast, dynamic capacity allocation, which is ideal for statistical multiplexing of bursty sources. For many users, web-browsing demands high downstream data rates, and low upstream data rates (asymmetrical capacity). However, small businesses may demand symmetrical capacity in both directions, or perhaps even a higher upstream capacity for web-hosting. This means that dynamic allocation of the downstream and upstream capacity is very important.

One problem with single-carrier systems is that in severe multipath channels, an adaptive equalizer is needed, requiring intensive processing at high data rates. However, for line-of-sight (LOS) BWA systems with directional antennas, only a short equalizer of not more than 8 feedforward taps would be required. Another problem with single carrier systems operating in unlicensed bands is susceptibility to interference. In order to solve this problem, some form of dynamic frequency selection (DFS), or else slow frequency hopping, will be required.

Single-Carrier QPSK / QAM	
Advantages	Disadvantages
1.High bit rates, proven technology, chosen by 802.16.1 and ETSI BRAN Hiperaccess	1. Susceptible to multipath interference (needs an equalizer)
2. Efficient, dynamic capacity allocation for bursty sources.	2. Susceptible to interference (needs interference avoidance technique)

OFDM

Orthogonal frequency division multiplexing (OFDM) is a type of multicarrier modulation. OFDM uses overlapped orthogonal signals to divide a frequency-selective channel into a number of narrowband flat-fading channels. Instead of transmitting the data symbols sequentially at a high symbol rate on a single carrier, a block of symbols is encoded using the Fast Fourier Transform (FFT), and transmitted in parallel over a number of subchannels. The subchannels are spaced by the inverse of the symbol time, so making them orthogonal. Individual subchannels will have a symbol period longer than the multipath delay spread, and so OFDM is useful for avoiding multipath interference. If a particular subchannel has high noise or interference, then it can be deactivated, so reducing the effects of fading and interference.

OFDM technology is still under development, and there are a number of problems to be solved. Firstly, the guard bands and cyclic prefix reduce data throughput. Frequency offsets between transmitter and receiver must be removed with automatic frequency control (AFC), otherwise the subcarriers will no longer be orthogonal. Synchronization of multicarrier schemes is more difficult than single carrier because there may be hundreds of samples per multicarrier symbol. Finally, because there are a large number of subcarriers, the combined signal has a very large peak-to-average power ratio, and to maintain linearity over this range, the power amplifier (PA) requires backed-off as much as 10dB.

OFDM	
Advantages	Disadvantages
1. Mitigates multipath	1. High complexity and deployment costs
2. Mitigates fading & interference	2. Guard bands reduce efficiency
	3. Frequency offsets require accurate AFC
	4. Synchronization is difficult
	5. High peak-to-average power ratio requires PA back-off

Spread Spectrum

Spread spectrum is divided into 2 groups: frequency hopping spread spectrum (FHSS), and direct sequence spread spectrum (DSSS) (also known as CDMA). Spread spectrum (both FHSS and DSSS) is proposed in IEEE802.11(b), for bit rates up to 11Mbps. In the USA, radios operating in the 2.45GHz ISM band are required to use spread spectrum if their transmit power exceeds 0dBm.

Spread spectrum systems simplify frequency planning, because additional users can be added in an ad-hoc manner, with only a small degradation in signal quality as the number of users increases. Spread spectrum gives high immunity to interference, and this is particularly important in the unlicensed frequency bands. The major problem with spread spectrum is that data rates higher than about 10Mbps are difficult to achieve due to the large bandwidth needed. It is possible for DSSS systems to co-exist with single-carrier TDMA systems, providing that notch filters are used by both systems to remove interference. DSSS systems may use a RAKE receiver to improve performance in the presence of multipath propagation, although this adds extra complexity.

FHSS	
Advantages	Disadvantages
1. Simple frequency planning	1. Low bit rates
2. Good interference rejection	
3. Low-power, low-cost radios	

DSSS	
Advantages	Disadvantages
1. Simple frequency planning	1. Medium bit rates (up to 11Mbps)
2. Good interference rejection	
3. Very low access delay	

Proposal

Considering the above analysis, the single-carrier QPSK/QAM technology is recommended for the proposed WirelessHUMAN Standard due to its high efficiency in dynamically allocating capacity, QPSK/QAM systems are simple to implement with the lowest peak-to-average power ratio requires no PA back-off, and QPSK/QAM use a proven technology and is the technology that has been chosen by both 802.16.1.and ETSI BRAN Hiperaccess. Interference avoidance measures in the 5-6 GHz unlicensed bands can be handled with a simple adaptive equalizer and Dynamic Frequency Selection (DFS) techniques.