
Project **IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
Document No. **IEEE 802.16.3p-00/43**
Title OVERVIEW OF STC+OFDM PHYSICAL LAYER PROPOSAL FOR IEEE 802.16.3
Date 2000-11-37
Source H. El Gamal and A.R. Hammons
Hughes Network Systems
11717 Exploration Lane
Germantown, MD 20878 USA
helgamal, rhammons@hns.com
Re: Call for Initial Proposals for 802.16.3 BWA PHY Layer (2000-9-15) see 802.16.3c-00/43
Abstract A brief summary of a physical layer proposal based on space-time coded OFDM with QPSK subcarrier modulation.
Purpose Discussion and development of 802.16.3 BWA PHY.
Notice This document has been prepared to assist MEE 802.16. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.
Release The contributor grants a free, irrevocable license to the IEEE to incorporate text contained in this contribution, and any modifications thereof, in the creation of an IEEE Standards publication; to copyright in the IEEE's name any IEEE Standards publication even though it may include portions of this contribution; and at the IEEE's sole discretion to permit others to reproduce in whole or in part the resulting IEEE Standards publication. The contributor also acknowledges and accepts that this contribution may be made public by IEEE 802.16.
Patent and Policy Procedures The contributor is familiar with the IEEE 802.16 Patent Policy and Procedures (Version 1.0) <http://ieee802.org/16/ipr/patents/policy.html>, including the statement "IEEE standards may include the known use of patent(s), including patent applications, if there is technical justification in the opinion of the standards-developing committee and provided the IEEE receives assurance from the patent holder that it will license applicants under reasonable terms and conditions for the purpose of implementing the standard."
Early disclosure to the Working Group of patent information that might be relevant to the standard is essential to reduce the possibility for delays in the development process and increase the likelihood that the draft publication will be approved for publication. Please notify the Chair <mailto:r.b.marks@ieee.org> as early as possible, in written or electronic form, of any patents (granted or under application) that may cover technology that is under consideration by or has been approved by IEEE 802.16. The Chair will disclose this notification via the IEEE 802.16 web site <http://ieee802.org/16/ipr/patents/notices>.

802.16.3 PHY Proposal Summary: Space-Time Coded OFDM for MMDS

A. Roger Hammons Jr. and Hesham El Gamal

**Hughes Network Systems
Germantown, Maryland USA**

MMDS Channelization

- 2596 MHz - 2686 MHz is allocated for MMDS application in the U.S.
- 2644 MHz - 2686 MHz are interlaced with ITFS
- 2686 MHz -2689.9 MHz can be used as MMDS Response
- Each of the MMDS and ITFS channels are 6 MHz wide



MMDS Application Model

- **Broadband Fixed Wireless Services**
 - Residential: 2-4 Mbps down, 256 - 384 kbps up
 - Small Business: 2-5 Mbps down, 256 - 1000 kbps up
 - Primarily IP Services, 99.9% availability, 10^{-6} BER
 - Bandwidth Efficiency > 2.5 bps/Hz/cell
- **Two way communications accomplished by either**
 - TDD in the MMDS band, or
 - A different band/service such as 3G for uplink
- **Reasonable Subscriber Unit Cost and Size, self-installation desirable**

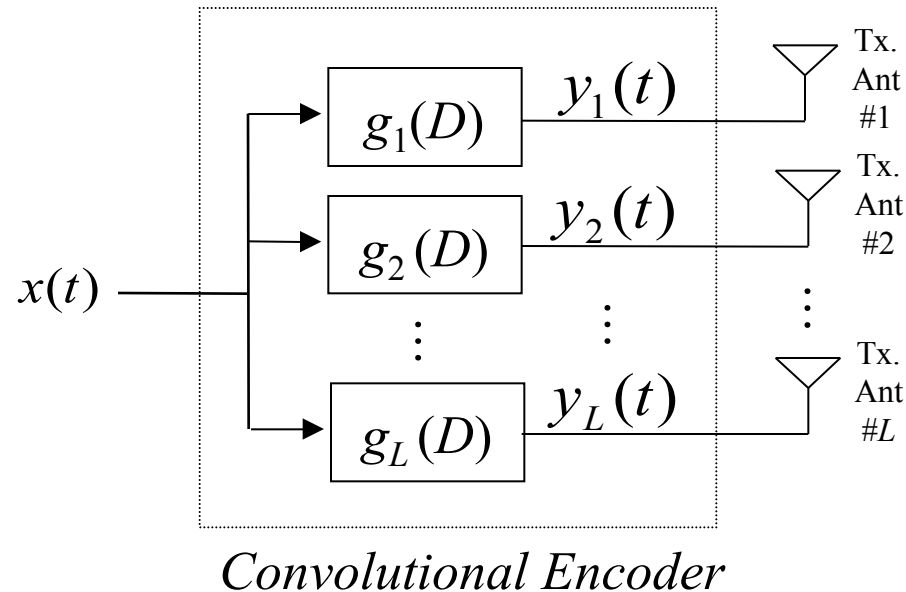
Shortcomings of Conventional Approaches and Remedies

- Super cell with line-of-sight (LOS) coverage provides only limited capacity, limited availability, and is potentially difficult to install
- Highly sectored solutions are impractical due to propagation environment and non-uniform subscriber distribution
- High-order modulation is sensitive to multipath and other impairments
- The remedies are
 - Aggressive use of spatial / frequency / time diversity
 - More robust modulation / coding and signal processing techniques in the presence of multipath interference to achieve non-LOS coverage with reasonable complexity

Characteristics of OFDM

- OFDM is a multi-carrier transmission scheme in which a high-rate data stream is transmitted over a number of lower-rate orthogonal subcarriers.
 - It been proposed and/or accepted for broadcasting digital audio and digital television, IEEE 802.11, HIPERLAN, etc.
 - Efficient FFT techniques are used to eliminate hundreds of separate oscillators that derive the separate subcarriers.
 - It is spectrally efficient over conventional FDM as it allows the spectra of individual channels to overlap.
- For data rates beyond 3G, OFDM avoids high complexity of single-carrier equalizer for multipath with delay spread extending over tens of symbols.
- OFDM transforms a highly frequency-selective multipath channel into a block-fading channel facilitating implementation of pilot-assisted synchronization.

Convolutional Codes As Full Diversity Space-Time Codes



“Natural” space-time code associated with rate $1/L$ convolutional code:
Multiplex L output coded bits in space (among antennas) rather than time.

Practical examples of our earlier work on general space-time “Stacking Construction.”

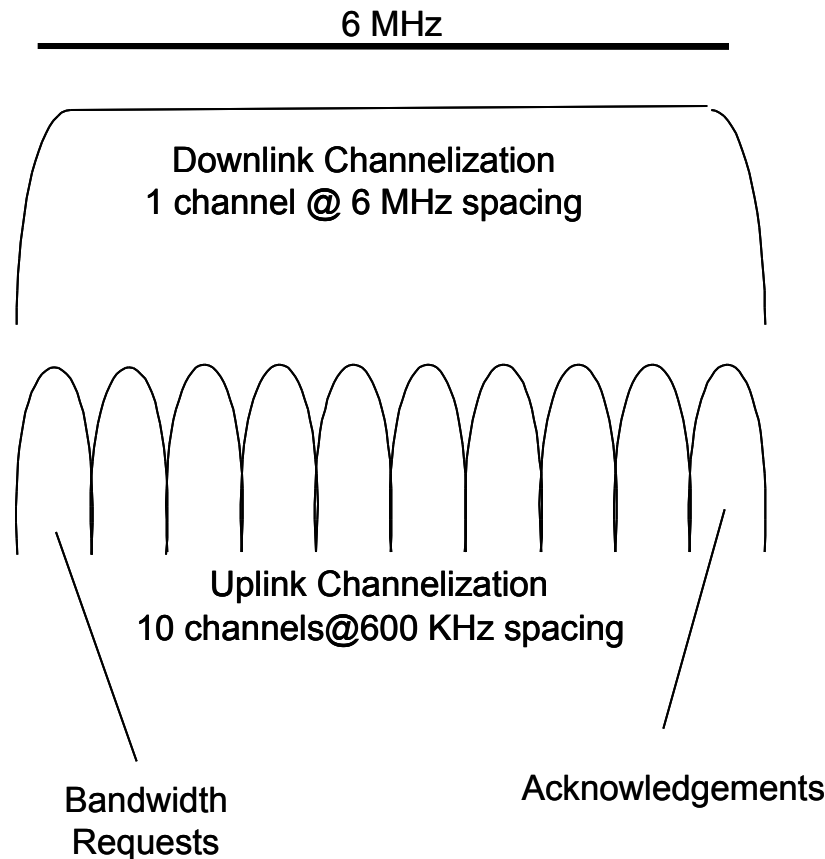
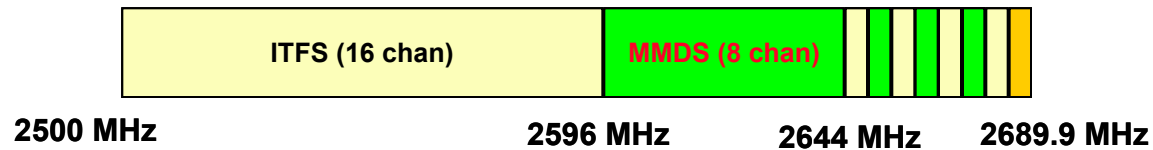
OFDM + “Space-Frequency” Codes Allows Favorable Design Trade-Offs

- OFDM front-end transforms ISI channel into a block fading channel.
- Space-Frequency codes can then be constructed to achieve any desired level of diversity using our MIMO block fading framework.
- Designer can trade diversity advantage for reduced decoder complexity by choice of code parameters.

QPSK, 2bits/sec/Hz, 1 Rx antenna

L	N	d_{\max}
2	1	2
2	2	3
2	3	4
3	1	3
3	2	4
3	3	5

A STC+OFDM System Design for MMDS Applications



- Each of the MMDS and ITFS channels are 6 MHz wide.
- Channel allocation suggests TDM duplex mode with proposed uplink/downlink channelization
- 2 transmit/2 receive antennas at user terminal
- 4 transmit/4 receive antennas at base station
- Conventional OFDM with QPSK subcarrier modulation.
- Rate 1/2 trellis-based space-time code (64-state)

Proposed STC+OFDM System Compares Favorably Against VOFDM

1-Ray	5 Mbps	10 Mbps	20 Mbps
STC+OFDM	3 dB	8 dB	13 dB
VOFDM	9 dB	15 dB	28 dB

2-Ray	5 Mbps	10 Mbps	20 Mbps
STC+OFDM	2 dB	8 dB	13 dB
VOFDM	6 dB	12 dB	24 dB

4-Ray	5 Mbps	10 Mbps	20 Mbps
STC+OFDM	1 dB	8 dB	12 dB
VOFDM	4 dB	10 dB	22 dB

- STC+OFDM allows transmission of 20 Mbps over 6 MHz channel in a Rayleigh fading channel at a C/I consistent with reuse
- STC+OFDM performance is not sensitive to channel model
- Gain over VOFDM is greater when fade is more severe

Proposed STC+OFDM System Yields Capacity Exceeding 2.75 bps/Hz/cell

	1x3 Reuse				2x2 Reuse with dual polarization			
	Sectors	D/L Freq	Cap/Sect	Cap/Cell	Sectors	D/L Freq	Cap/Sect	Cap/Cell
FDD	3	3	3.33	3.33	4	2	3.33	6.67
TDD w/ 75% time for D/L	3	3	2.75	2.75	4	2	2.50	5.00

- Per-cell capacity depends on Uplink / Downlink multiplexing / allocation, and the sectorization / reuse plan
- Conventional 1x3 reuse pattern is supportable with practical subscriber unit antennas.
- Tighter reuse using dual polarization and 4-sector cells requires only two 6 MHz frequencies

Adaptive Transmission Would Allow for Even Higher Throughput

<i>Modulation</i>	<i>Coding Rate</i>	<i>Throughput (bits/sec/Hz)</i>
QPSK	1/2	4
QPSK	1	8
16-QAM	1/2	8
16-QAM	1	16
64-QAM	1/2	12
64-QAM	1	24

- Space-time coded OFDM allows rate adaptation in space and frequency.

Conclusion

- STC + OFDM is the only solution to high data rate MMDS
 - Rayleigh fading channel
 - Slow fading (2 Hz doppler spread)
 - Delay spread between 0 and 5 μ sec
- STC + OFDM allows for simple, robust, scalable transceiver design
 - No equalization is necessary
 - QPSK delivers high data rate
 - 64-state channel decoder