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Title	**Air Interface Proposal Using OFDM with SDM/TDM and OFDMA/TDMA**
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Re:	This paper is in response to the Invitation to Contribute PHY Proposals for 802.16.3 for Session #11 as contained in Published Document IEEE 802.16.3-00/24.
Abstract	An Air Interface is proposed utilizing OFDM modulation with Subcarrier Division Multiplexing and Time Division Multiplexing in the downstream and OFDMA and TDMA in the upstream.
Purpose	This paper is submitted as a PHY layer proposal for 802.16.3.
Notice	
Release	
Patent Policy and Procedures	

Air Interface Proposal Using OFDM with SDM/TDM and OFDMA/TDMA

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Overview

In order to best meet the requirements of the expected MAN deployments in the near term as well as with expected future technologies, it is necessary to consider the implications of many of the facets of the problem when developing the air interface. The most relevant of these are outlined in the 802.16.3 Evaluation Criteria and the Functional Requirements Document. Arguably the most important of these relate to the ability to survive the channel conditions (i.e., close and maintain the link) and facilitate low-cost implementations with good performance. This document deals primarily with a proposed configuration for the modulation scheme that offers good channel performance, a high degree of flexibility for channel and traffic conditions, and a present and future path for very low cost CPE implementations.

The system design presented in this document takes into consideration the full scope of the Functional Requirements Document with the intent of developing a system that will not only exceed the current requirements but provide an exceptional degree of flexibility for operation as well as future evolutionary developments and efficient implementation. As in any engineered system a number of compromises must be made, and this system is developed with the intent of selecting the best possible compromises for the task at hand.

Downstream Modulation

The expected channel conditions include dynamic fading and multipath reflections that present challenges regardless of the selected modulation method. While it is possible to design equalization systems for single carrier modulations that significantly improve performance, the inherent capabilities of OFDM to automatically integrate multipath reflections offers benefits in performance as well as simplification of the equalization system. Adaptive modulation is a necessity in order to maximize system capacity, and presents synchronization and PA backoff difficulties for single carrier modulation. Since OFDM synchronization can be performed largely independent of the modulation scheme, and since modulation order has almost no affect on PA backoff for OFDM, these simplifications provide significant benefit for overall system design. The greatly reduced symbol rate realized with an OFDM system also relaxes timing registration requirements in the return channel for Multiple Access. These are some of the reasons that drive the selection of OFDM for the downstream and upstream modulation.

A number of tradeoffs drive the configuration of the OFDM modulation, the most significant of which are: throughput requirements, phase noise, frequency tracking capability, channel delay spread, and occupied bandwidth. In order to provide the best possible frequency registration for the upstream channel, an FDD configuration with a continuous downstream channel is proposed. This allows the CPE to enter the network by first passively acquiring and locking to the downstream signal. Use of the continuous downstream channel as a frequency reference allows the CPE to enter the upstream channel with minimal frequency error. Continuous tracking of the downstream frequency also minimizes subsequent interference in the OFDMA upstream channel during normal operation.

The channel models submitted by Sprint [1] in document 802.16.3c-00/49r2 outline three different representative environmental models designated A, B, and C, with A representing the hilly terrain model with the longest delay spread, and C representing flat terrain with light tree density and the shortest delay spreads. Table 1 shows the peak and associated RMS delay spreads for each of the three models. The delays associated with terrain model A represent the worst modeled case, but selection of a universal 20us guard time may unduly burden the efficiency of systems deployed in more benign environments like those represented by models B and C. For this reason we select two possible configurations with guard times of 20us for the worst A terrain model cases, and 10us to cover the expected majority of deployment cases. The selection of the guard time can be determined at deployment and could be determined on a per-sector basis for individual cells.

Terrain Model	A	B	C
Peak Delay	20us	4us	0.6us
RMS Delay	5.2us	1.3us	0.2us

Table 1. Peak and RMS delay spreads for the longest delay models of each terrain category from 802.16.3c-00/49r2.

Using the selected guard times and 6MHz channels (consistent with common band plans for MMDS) it is possible to determine the basic parameters of the OFDM modulation for this application. Starting with the 10us guard time case and allocating 1/10 of the symbol duration for the guard time to maintain efficiency yields a 10kHz initial symbol rate. The subcarrier spacing must be 10/9 of the symbol rate for a guard time of 1/10 of the symbol duration, or 11.11kHz. Assuming 6MHz channels a 512 subcarrier system efficiently occupies the available bandwidth while still allowing sufficient guard band for adjacent channels.

For a 4x oversampled system a basic DAC clock rate of 23MHz may be assumed. For this case the FFT for 512 subcarriers will generate 2048 samples, the 10us cyclic extension another 230 samples, and applying 2.5% Raised Cosine weighting to the symbols will incur another 28 sample penalty to the symbol period. Figure 1.a shows the resulting symbol structure with a total period of 2306 samples, for a symbol rate of 9.9740kHz. This yields a subcarrier spacing of 9.9740kHz x (2306/2048) = 11.2305kHz. The 11.2305kHz subcarrier spacing is sufficient for good performance with available rf equipment supporting phase noise levels of –95dBc or better at 10kHz, as well as simplified frequency registration in the return channel.

Extending the cyclic extension guard time to 20us for the A terrain model from [1] and maintaining the 23MHz DAC clock rate, yields the symbol structure shown in Figure 1.b. The total symbol length of 2539 samples, or 110.4us, provides a symbol rate of 9.059kHz, with the same subcarrier spacing as the previous configuration of 11.23047kHz. Maintaining constant subcarrier spacing between modes allows simplified frequency planning for deployments where the two modes must coexist, as well as simplified autodetection in CPEs attempting to register into the system.

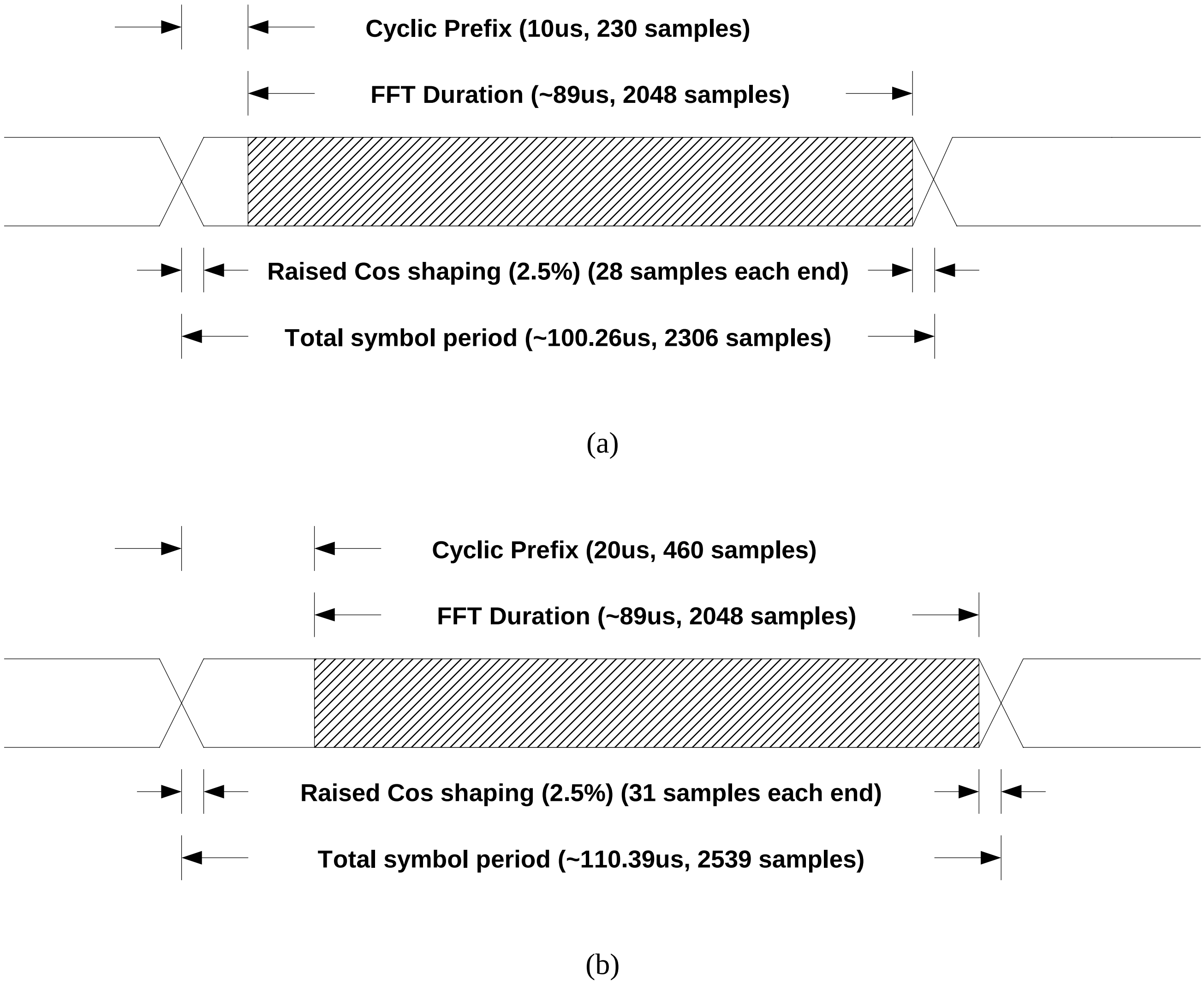

Figure 1. The basic time-domain structure of the OFDM symbols for the 512 subcarrier case assuming a 23MHz DAC update rate. The 10us guard-time case is shown in (a), with the 20us case shown in (b).

In order to support channel estimation at the minimum Nyquist rate, pilot tones must be located at most 100kHz apart, or every 9 subcarriers for the 10us mode. In order to provide good performance in the presence of noise and dynamic fading, a pilot tone spacing of every 8 subcarriers, or 89.844kHz is selected. In the 10us guard time mode the pilots are staggered 4 subcarriers every other symbol, and staggered every 2 subcarriers over a four symbol period in the 20us mode. The end subcarriers are fixed pilots. This provides uniform spacing of the scattered pilot tones with a constant power-of-two interpolation rate (1:8) for channel estimation between the scattered pilots. Figure 2 shows the suggested pilot spacing schemes for both modes.

In order to reduce PAPR as well as facilitate improved synchronization, careful selection of pilot phase scrambling sequences can be employed. For each transmitted downstream symbol known phase scrambling codes are used to both reduce PAPR and provide improved synchronization and tracking. Alternating the pilot phase scrambling sequences between symbols, using at least two different sequences for the scrambled pilots, can improve timing acquisition and tracking performance. Transmitting unmodulated end pilots, which are common to all modes, allows fast and accurate frequency tracking as well as the potential for improved phase tracking for terminals in relatively benign channels. The phases of the scattered pilots are selected according to the scrambling sequences using BPSK modulation, and the scrambling and scattering patterns are used to define the downstream frame structure. This allows the frame structure to be defined with no additional overhead and avoids the need for frame marking symbols. Figure 2 shows an example use of the pilot phase scrambling codes to define the frame boundaries. The end pilots are fixed and not used in the framing structure.

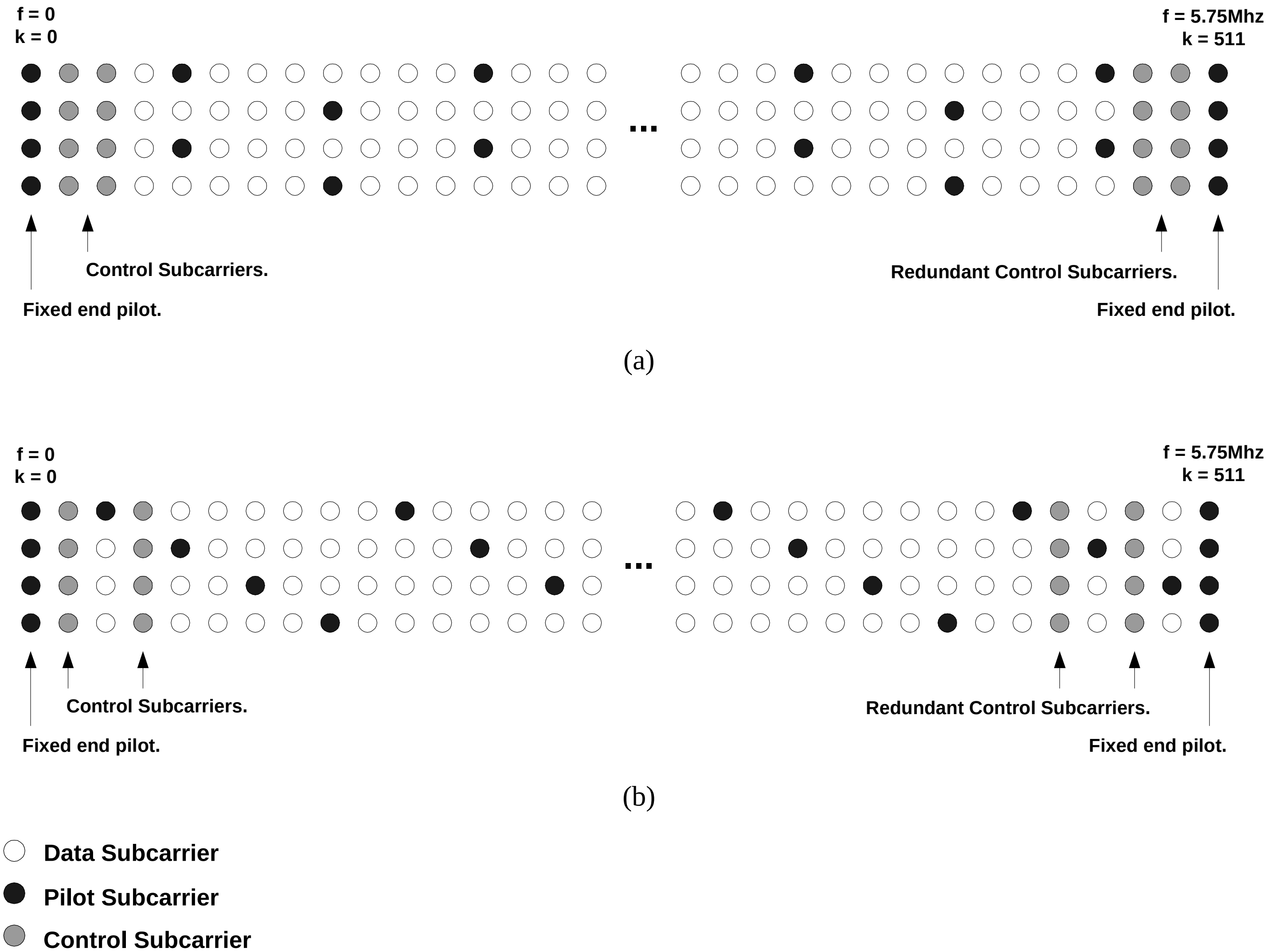

Figure 2. Pilot spacing schemes for the a), 10us and b), 20us guard time modes. Spectral occupancy for both modes is the same, and the scheme is designed such that the unmodulated end pilots are equally spaced for all modes.

Table 2 shows the basic parameters and uncoded data capacity for both modes using 512 subcarriers, as well as for a potential mode using 1024 subcarriers with similar compatible parameters. The pilot tones for the 1024 subcarrier case are arranged similar to the 512 subcarrier case, with pilot tones every 16 subcarriers, staggered every 8 subcarriers every other symbol for the 10us mode, and every 4 subcarriers over four symbols for the 20us mode. Spectral occupancy for the 512 and 1024 subcarrier modes are the same, and the scheme is designed such that the unmodulated end pilots are equally spaced for all modes. A DAC rate of 23MHz is still maintained with the 1024 subcarrier mode. The 1024 subcarrier mode depends on adequate phase noise performance capability of the terminal.

Subcarrier Quantity, N	Guard Interval, T_{guard}	Pilot Overhead	Symbol Rate, R_s	Subcarrier Spacing, Δf	Uncoded Data Rate (Mbps) (QPSK/16Q/64Q)	Spectral Efficiency (bps/Hz) (QPSK/16Q/64Q)
512	10us	12.60%	9.974kHz	11.23kHz	8.93/ 17.8/ 26.78	1.55/ 3.1/ 4.65
512	20us	12.65%	9.059kHz	11.23kHz	8.10/ 16.21/ 24.31	1.41/ 2.81/ 4.23
1024	10us	6.30%	5.25kHz	5.612kHz	10.08/ 20.15/ 30.23	1.75/ 3.5/ 5.26
1024	20us	6.32%	4.986kHz	5.612kHz	9.56/ 19.13/ 28.70	1.66/ 3.33/ 4.99

Table 2. Parameters associated with the proposed downstream OFDM configuration without FEC coding applied. Data rates and spectral efficiency are shown for each mode and modulation type.

Upstream Modulation and Multiple Access

The same rationale for the use of OFDM in the downstream channel applies to the upstream channel. An additional benefit of the selection of OFDM is the ability to use OFDMA for multiple access. If the ability to dynamically alter the number of subcarriers used by an individual terminal in the upstream is included, an additional dimension is added to power management for the return channel, since a terminal's occupied bandwidth can be traded for link margin. The use of OFDMA and TDMA together reduces the granularity of available block sizes and improves the efficiency and statistical multiplexing granularity in the return channel. An additional benefit in reducing the quantity of subcarriers that must be transmitted by a CPE is the potential for reducing the processing required in the modulator. Reducing the bandwidth of the transmitted signal effectively reduces the computational load in the modulator and can provide for substantial reduction in complexity and power requirements.

The upstream OFDM parameters must be considered separately from the downstream since the constraints at the Base Station differ significantly from those at the CPE. Antenna height differences, expected differences in transmit power and antenna patterns, as well as the ability to employ transmit diversity at the BS dictate that the engineering for the two directions be considered independently. Some commonality can be beneficial, and it is prudent for the sake of simplicity (particularly at the CPE) to reuse as much as practical from the downstream configuration.

Maintaining the same subcarrier spacings and quantities for the upstream as used for the downstream allows a common 23MHz system clock to be used for both the CPE modulator and demodulator. This also allows simplified frequency registration for the upstream channel if a common system oscillator is used to facilitate use of the downstream signal as a reference for the upstream tuning. Since a variety of Base Station deployment scenarios are practical, and since evolutionary scaling of Base Station sectorization is likely, it is beneficial to support a programmable length guard time to facilitate the variations in delay spread associated with varying BS antenna beamwidths, terrain variations, TDMA slot times, and transverter ON/OFF ramp characteristics. This flexibility allows maximization of upstream capacity while still supporting robustness in the return channel.

It is also proposed that the OFDMA subcarrier quantity assignment and pilot density be programmable and assignable per terminal, perhaps, but not necessarily, on a dynamic basis. This allows additional flexibility for capacity management in the upstream, which is expected to be a greater challenge than the downstream direction. Figure 3 shows a conceptual diagram of the OFDMA/TDMA scheme, where blocks of contiguous subcarriers are assigned to individual terminals. Each terminal will transmit pilot tones at the ends of its assigned section of subcarriers, and pilot spacing and staggering patterns may be assigned by the Base Station as well. Default pilot patterns compatible with the downstream configuration could also be used. Some upstream subcarriers at each edge of the band will be reserved for registration contention. A registration method somewhat similar to that used in DVB-RCT and proposed in [2] provides an efficient means of terminal registration while incurring little overhead in the channel. In this case a code sequence pair would be transmitted in a contention subcarrier at each edge of the spectrum. Detection of the sequence at the BS would provide timing, frequency and power registration as well as detection of transmit spectrum inversion.

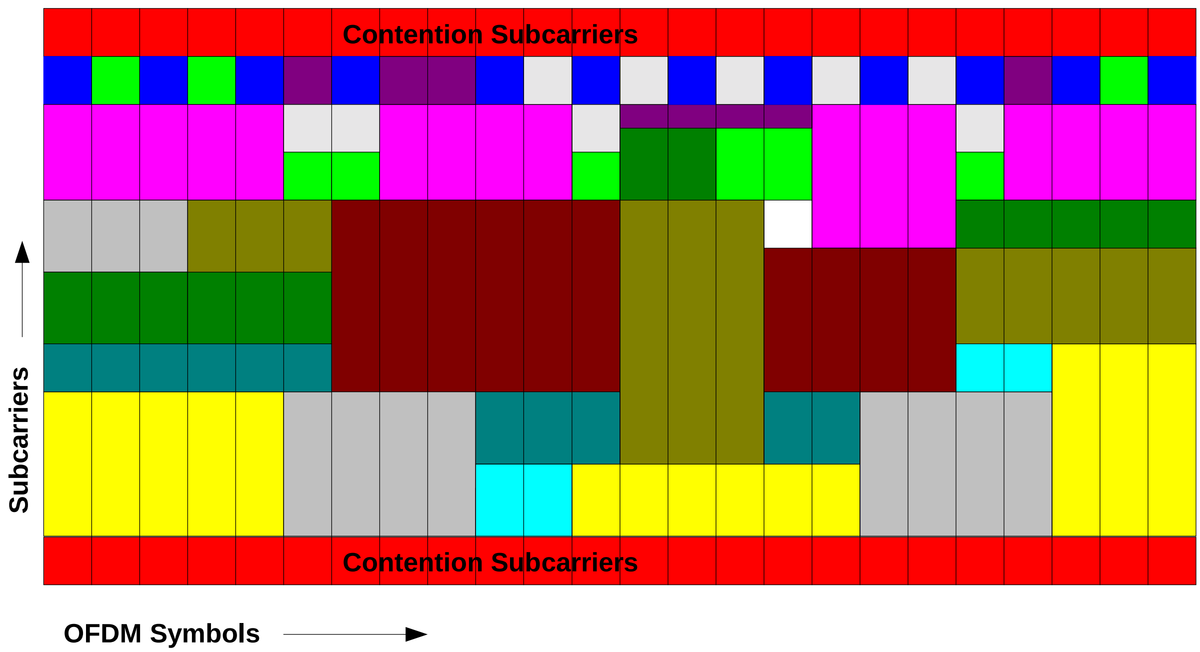

Figure 3. Conceptual diagram of the proposed combination of OFDMA/TDMA. Each colored section represents a block transmitted by a single terminal that can traverse multiple subcarriers and symbols. A small subset of the available subcarriers are reserved at each edge of the spectrum as contention channels using a registration method somewhat similar to that used in DVB-RCT. The Base Station can assign the location and quantity of the subcarriers available to a particular terminal based on demand, link conditions, service level agreements, or a number of other factors.

The proposed OFDMA/TDMA scheme does imply an increase in the complexity of the Base Station MAC, demodulator, and FEC circuit compared to some simpler schemes. Although multiple FEC decoders could be used to decode each of the coincident return channel signals, it is also possible to use a single high-speed FEC decoder that runs at the aggregate data rate. Each terminal must terminate the convolutional encoder trellis at the end of each data block. The Base Station must perform independent channel estimation and FEC decoding for each terminal in the upstream signal. Base Station implementers should have freedom in selecting the most appropriate architecture trade-offs that they feel best meets requirements while adhering to the standard.

Downstream Multiplexing

Reduction of CPE cost is a significant consideration for the target markets. It is anticipated that soft-PHY implementations and power efficient integrated PHY cores will offer substantial advantages for CPE cost as well as capabilities. Minimization of CPE processing requirements helps to bring these advantages closer to realization in practical implementations. System considerations such as multiplexing and multiple access techniques are critical in enabling such cost reduction techniques.

One of the most effective ways to reduce computational requirements in the CPE is to eliminate the need to always process the entire downstream signal. The use of Subcarrier Division Multiplexing, along with joint Time Division Multiplexing, can greatly reduce the processing burden in the CPE. Figure 4 shows an example of how individual user traffic could be multiplexed in both time and frequency using SDM with TDM, similar in concept to the upstream OFDMA/TDMA configuration. Keeping subcarriers assigned to a particular terminal in a contiguous subset simplifies channel estimation in the CPE and can further reduce the processing requirements. Control channel subcarriers may be split into redundant sets to ensure immunity from frequency selective fading.

Using SDM/TDM in the manner illustrated in Figure 4 allows the CPE demodulator to process only those subcarriers of interest, as well as reducing the FEC throughput requirements to only that needed for the individual terminal. The subsequent reduction in processing capability required at the CPE can be used for complexity reduction, power reduction, or implementation with a soft-PHY.

Since each user's data occupies only a subset of the channel with the proposed SDM/TDM scheme, it is important to ensure that frequency selective fades do not cause unacceptable degradation in performance. Given that the expected channel coherence time is sufficiently long one method would involve a handshake and feedback system where a terminal would request bandwidth in a particular region of the channel where it is experiencing the best channel characteristics. This scheme, particularly if used with no additional channel mitigation techniques, could reduce efficiency and add more complexity to the MAC than necessary, particularly for highly dynamic channels with short coherence times. Instead it is proposed that a sufficiently simple channel coding scheme, like that proposed by Alamouti [3], be used to flatten the channel characteristics at the CPE terminal. Use of such a channel coding scheme with transmit diversity at the Base Station should flatten the received spectrum enough to eliminate, or at least greatly reduce, any handshake or feedback requirements for CPE subcarrier assignment.

The proposed SDM scheme does imply a small increase in the complexity of the Base Station scheduler as well as the FEC circuit. Although multiple FEC encoders could be used to generate each of the coincident downstream signals, it is also possible to use a single high-speed FEC encoder that runs at the aggregate data rate. Termination of the trellis at the end of a particular user's data block and then multiplexing the subsequent coded signals supports the proposed scheme with a single FEC encoder. This allows Base Station implementers freedom in selection of the most appropriate architecture trade-offs for complexity, latency, cost, etc.

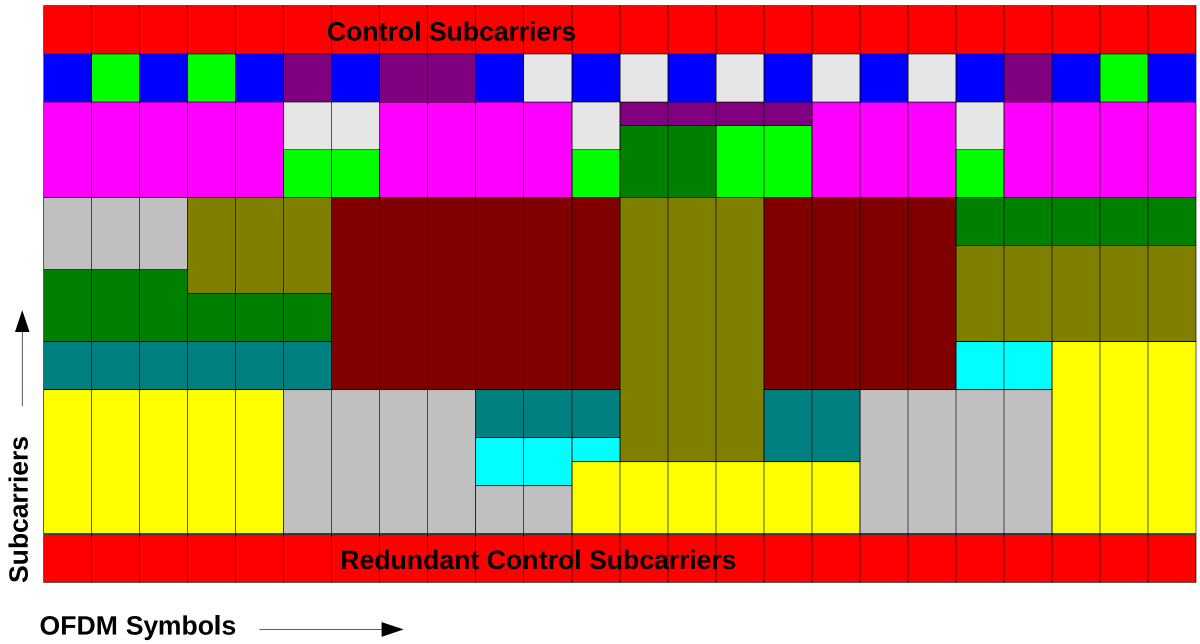

Figure 4. Conceptual diagram of the proposed combination of Subcarrier Division Multiplexing and TDM. Each colored section is a block transmitted to a single terminal that can traverse multiple subcarriers and symbols. A small subset of the available subcarriers are reserved for control channel use. The control channel subcarriers are duplicated for redundancy in the event that a frequency selective fade degrades one set.

Adaptive modulation and coding is easily supported by the proposed scheme, which allows maximization of system capacity. The use of joint SDM/TDM allows reclamation of statistical multiplexing granularity lost by the reduction in symbol rate associated with OFDM.

FEC and Net Aggregate Data Rates

Both the downstream and upstream signals require the use of robust, adaptive FEC schemes in order to survive the expected channels and help maximize the capacity of the system. The requirements of the downstream and upstream channels are expected to differ somewhat due to a variety of factors. While transmit diversity is practical at the BS, it is not necessarily economically feasible at the CPE. Likewise receive diversity may be more practical at the BS, and the differences in expected antenna heights, antenna beamwidths, and processing power suggests that each stream should be considered separately. The bursty nature of the upstream channel and the associated short block lengths, in addition to the already mentioned considerations, suggests that the upstream FEC will likely need to be stronger than that employed in the downstream.

In order to maximize system capacity it is essential to support adaptive modulation and coding. The use of QPSK, 16-QAM, and 64-QAM is proposed with concatenated Viterbi-Reed Solomon FEC. The convolutional encoding rates of R = ½, 2/3, ¾, 5/6 and 7/8, using a K = 7 constraint length in the downstream with the common polynomial (171, 133) (octal), provide good performance with mature solutions. In the upstream the more robust K = 9 constraint length with polynomial (561, 753)(octal) is proposed. For additional protection an outer Reed-Solomon code is included based on GF(256) with programmable parameters N, K, and t where 34 ≤

$N \leq 255$, and $32 \leq K \leq 253$, and t is (N-K)/2. The use of RS polynomials compatible with the DVB specifications (e.g., DVB-S) assures availability of common economical solutions. In the downstream the default RS configuration is (208, 188), and for the upstream (63, 55) would be used as default configuration. An optional programmable interleaver with variable block size may be used between the inner and outer codes. Blocks may traverse multiple OFDM symbols and be interleaved across subcarriers as well as symbols in order to maximize time and frequency diversity within the codewords. The upstream interleaving schemes will generally have to deal with shorter block sizes, and for very small blocks the use of the interleaver may be optional. Trellis coded modulation would be used in the US and DS for 16-QAM and 64-QAM when the convolutional code is employed.

In the downstream each block of user data should be encoded independent of other user data. The convolutional encoder must begin encoding each block from a zero state and terminate the trellis at the end of each block. This ensures that each terminal may focus its resources on processing its own signal and may ignore information intended for other terminals. In the upstream each terminal must begin the convolutional encoder from a zero state for each block, and terminate the trellis at the end of each block. The Base Station must decode blocks from each terminal independently.

The proposed system facilitates support of particular advanced methods such as Turbo Product Codes and other Turbo Coding techniques in both directions. The system will also not preclude the use of other advanced performance enhancing techniques such as future improved FEC solutions, antenna diversity, smart antennas, etc.

Assuming the use of (204,188) RS outer encoding in the downstream, Table 3 shows aggregate data rates for the indicated inner code rates and modulation types for the proposed OFDM configurations. The upstream rates and efficiencies will be dependant not only on the modulation type and FEC code rates, but the number of subcarriers assigned to each terminal as well as the pilot tone density. The downstream rates serve as a benchmark, since the subcarrier spacing and inner code rates are comparable to the upstream. The default RS word size of (63, 55) in the upstream carries more overhead than that used in the downstream, and so will incur a small penalty. Overall it is expected that system and channel constraints will result in upstream data rates somewhat lower than those shown in Table 3.

Subcarrier Quantity, N	Guard Interval, T_{guard}	QPSK (Mbps) (R = ½, ¾, 7/8)	16QAM (Mbps) (R = ¾, 7/8)	64QAM (Mbps) (R = 2/3, 5/6)
512	10us	4.11, 6.17, 7.20	12.3, 14.40	16.45, 20.57
512	20us	3.73, 5.60, 6.53	11.20, 13.07	14.93, 18.67
1024	10us	4.64, 6.96, 8.13	13.93, 16.25	18.57, 23.22
1024	20us	4.41, 6.61, 7.71	13.22, 15.43	17.63, 22.04

Table 3. Downstream net data rates for concatenated FEC coding with the indicated inner code rates and an outer RS code using (204, 188) format. Upstream data rates using similar inner code rates will generally be lower due to expected use of a more robust RS code and potentially higher pilot density.

Benefits and Advantages

The proposed solution offers a high degree of flexibility as well as the opportunity to minimize the cost of the CPE. Use of SDM/TDM in the DS and OFDMA/TDMA in the US maximize the achievable statistical multiplexing granularity while reducing computation requirements in the CPE. The proposed subcarrier spacings avoid difficult and expensive radio solutions, and are designed to allow a common reference clock frequency for the modulator and demodulator in all modes. The phase noise requirements of the BS and CPE terminals are kept within practical limits for the expected transmit frequencies with the proposed subcarrier spacings, which also reduce sensitivity to frequency error. The use of adaptive modulation and coding increases system coverage and capacity.

Drawbacks

The configurations outlined in this proposal cover only 6MHz channelization. It is possible to scale the proposed system to wider or narrower channels and still maintain the benefits of the design, but those possibilities are not explored in this document. The US channel may require a feedback or sounding scheme in order to prevent or mitigate the assignment of a particular terminal to a set of subcarriers that is deeply faded at the BS. This may be avoided or minimized by diversity schemes at the BS receiver. Deep selective fades experienced in the subcarriers of interest at a terminal in the DS may be mitigated by the use of transmit diversity and channel coding at the BS [3]. The need for system feedback for selective fade mitigation in both directions is already greatly reduced with the use of robust FEC, channel coding, and the relatively long channel coherence times indicated in [1]. The proposed system does increase the complexity of the BS modulator and demodulator compared to some simplified systems. The scope of the complexity increase is not large and can be implemented in a number of possible architectures that provide suitable tradeoffs for BS designers.

Conclusion

The proposed system offers a high degree of performance, flexibility, and cost reduction opportunities while maintaining channel survivability and system capacity. The inherent flexibility in the system provides a suitable platform for future extensions and improvements related to new technologies, changes in market deployment, etc. Minimization of CPE computational complexity, the use of a unified system clock, and conservative subcarrier spacing all contribute to significant cost reduction in the user terminal.

Intellectual Property Statement

The proposed downstream transmit diversity scheme described in [3] may include Intellectual Property associated with AT&T. The proposed upstream terminal registration scheme may include Intellectual Property of RunCom Technologies which included an Intellectual Property Statement in their proposal [2]. The author is not aware of any additional Intellectual Property which may be required to implement the proposed system.

References

[1] K.V.S. Hari and Carl Bushue , "Interim Channel Models for G2 MMDS Fixed Wireless Applications", IEEE Document 802.16.3c-00/49r2, submitted to IEEE 802.16, November, 2000.

[2] Yossi Segal, Zion Hadad and Itzik Kitroser, "Initial OFDM/OFDMA PHY proposal for the 802.16.3 BWA", IEEE Document 802.16.3c-00/33, submitted to IEEE 802.16, October, 2000.

[3] Siavash M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications", *IEEE JSAC*, vol. 16, No. 8, October, 1998.

Appendix – Evaluation Table

#	Criterion	Response
1	Meets system requirements.	The proposed system is expected to meet system requirements in all areas.
2	Channel spectrum efficiency.	Channel spectrum efficiency is outlined in the proposal and offers very good performance while maintaining robust channel performance. Table 2 includes calculated gross efficiencies for the proposed system.
3	Simplicity of realization. a) Subscriber Station b) Base Station c) Installation Cost	a) The proposal is specifically designed to minimize CPE complexity. b) Some additional complexity is required in the Base Station compared to simplified proposals, although all of the complexity increase is in the baseband processing. Some Base Station radio requirements are simplified in this proposal. c) Installation costs at the CPE as well as BS are not expected to differ from traditional proposals.
4	Spectrum resource flexibility	The proposed solution offers a very high degree of flexibility in both the US and DS. The SDM/TDM and OFDMA/TDMA schemes are selected specifically for flexible allocation of spectral resources.
5	System spectrum efficiency	The proposed solution offers a high degree of system spectrum efficiency. The system is designed to easily occupy the 6MHz channelization currently planned in the expected frequency bands. The use of adaptive modulation and coding ensures that coverage is obtained without taxing frequency reuse. Additionally, OFDM allows shadow-filling with simple repeaters (as in Single Frequency Networks), that mitigates additional frequency allocation.
6	System service flexibility.	The proposed PHY solution is independent of service classes, which would be handled in the Transmission Convergence Layer and MAC. There are no features of the proposed PHY which are anticipated to limit flexibility in System Services.
7	Protocol interfacing complexity.	Protocol interfacing would be handled in the Transmission Convergence Layer and MAC. There are no features of the proposed PHY which are anticipated to limit flexibility or performance in Protocol Interfacing.
8	Reference system gain.	The use of adaptive modulation and FEC coding in both directions, as well as selectability of transmit bandwidth in the upstream (through subcarrier quantity assignment) provides high system gain in the DS and US. The use of known powerful FEC solutions contributes to the high gain.
9	Robustness to interference.	The use of OFDM modulation in the US and DS with reasonable channel guard bands provides interference robustness in a fundamental sense. Symbol shaping is used to further reduce out-of-band emissions.

10	Robustness to channel impairments.	The system is designed with the proposed channel models [2] in mind. The use of OFDM with carefully planned pilot densities as well as DS transmit diversity with simple Space-Time coding [3] strengthens the performance. Adaptive modulation and FEC coding maximizes efficiency while maintaining the capability to survive the channel. The US pilot densities, subcarrier occupancy, modulation, guard interval and FEC coding all adaptable to the channel conditions.
11	Robustness to radio impairments.	The 512 subcarrier mode is intended to mitigate radio impairments by reducing phase noise and frequency tracking requirements. For systems with adequate phase noise and performance as well as improved frequency stability the 1024 subcarrier mode is proposed.
12	Support of advanced antenna techniques.	Base Station transmit diversity is proposed. There are no features of the proposed PHY which are anticipated to limit the flexibility of use with additional advanced antenna techniques.
13	Compatibility with existing relevant standards and regulations.	Some of the features of this proposal are similar to those used in DVB-T and DVB-RCT.