

An Adaptive Multimode Modulation Modem for Point to Multipoint Broadband Radio

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ABSTRACT

Future broadband fixed wireless access systems for Local Multipoint Distribution Services (LMDS) will use an adaptive multimode modulation in order to provide high data rates with high reliability and high spectral efficiency. The new complex physical layer requires new concepts to meet the requirements of high performance and at the same time to reduce the hardware effort to a reasonable size. This paper presents a modem concept focusing on the power and cost efficient implementation of a high performance adaptive multimode modulation system. The demodulator architecture is based on specifically adapted symbol rate algorithms for demodulation functions rather than on straightforward burst receiver techniques. This is the key for realization of cost efficient subscriber equipment without performance compromises.

1 INTRODUCTION

Broadband fixed wireless access systems, operating in the frequency range of 20 GHz and higher, are commonly used for Local Multipoint Distribution Service (LMDS) networks. They are an attractive solution for network operators to provide high bitrate interactive voice and data services in a fast and efficient way. These systems usually are based on a cellular point-to-multipoint (PMP) network structure using e.g. four sectors per base station and QPSK as modulation format.

To be able to serve future demands with respect to data rate per subscriber and guaranteed Quality of Service (QoS), new developments will employ adaptive multimode modulation [1], as it is under standardization in the ETSI BRAN and IEEE 802.16 standardization groups. The adaptive multimode modulation combines increased network capacity due to higher order modulation schemes with the possibility to adapt the modulation format to the available channel situation. This paper addresses a modem concept that allows a cost and power efficient implementation of the advanced multimode modulation physical layer without per-

formance compromises, especially on the more cost sensitive subscriber equipment side, using standard programmable logic devices or ASICs.

2 ADAPTIVE MULTIMODE MODULATION

In a cellular network structure the intercell interference due to the frequency reuse in adjacent cells is the major capacity limiting effect. The interference in downlink direction is influenced e.g. by the subscriber location within the sector and the beamwidth of the antenna. Changing weather conditions and traffic load of interfering base stations results in time variance of the interference. Typical interference zones within a sector, together with the possible modulation format assignment, are shown in Figure 1. Here four sectors per base station and free space Line-of-Sight (LOS) propagation are assumed and only the nearest interfering base station is considered [2].

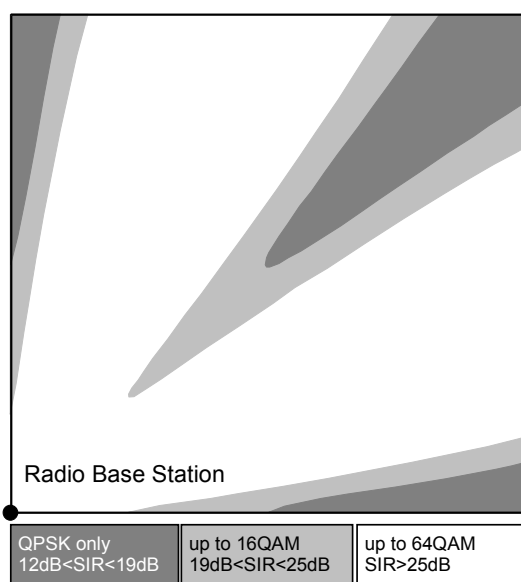


Figure 1: Interference zones within a sector and possible modulation formats.

In uplink, the interference scenario is different. If a power control is assumed, the uplink interfer-

ence level depends only on the position and power level of the interferer and is the same for all subscribers within the sector.

The adaptive multimode modulation assigns modulation formats with different interference sensitivity and hence different spectral efficiency to the subscribers adaptively according to their current interference situation. This means that the transmission quality has to be monitored and the modulation format assignment has to be changed by specific Media Access Control (MAC) functions. In this paper, we assume the modulation formats Quaternary-Phase-Shift-Keying (QPSK), 16- and 64-Quadrature-Amplitude-Modulation (QAM). While using 16- or 64QAM instead of QPSK for subscribers with sufficiently low interference degradation, the overall capacity of the sector will be increased by a factor of two to three, depending on the number of base stations in the network and the wave propagation scenario, as outlined in [1].

3 MULTIMODE MODEM ARCHITECTURE

The systems considered here use single carrier multi-mode quadrature amplitude modulation (QAM). The symbol rates range from 10 to 40 MSymbols/s. Multiple access in downlink is achieved by TDM and TDMA.

The main requirements for the design of a downlink receiver are given by the used multimode modulation framing structure (Figure 2). The different modulation types are ordered according to their modulation grade, starting with QPSK. Depending on channel and noise environment, a terminal will be able to demodulate QPSK, 16QAM or even 64QAM. Each downlink frame may have a different structure as scheduled by the MAC. Further each frame may contain a gap of variable length between end of 64QAM and the next frame start. This requires additional burst mode capabilities in the receiver.

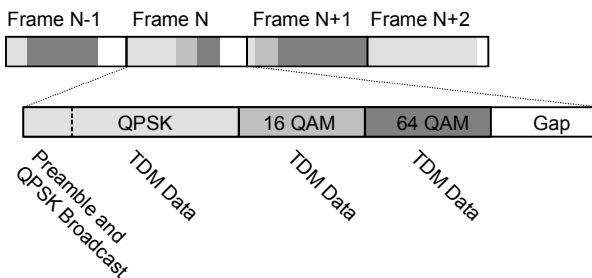


Figure 2: Multi-mode modulation framing

3.1 Multimode Transmitter

The multimode transmitter is straightforward. It basically includes a framer, a multimode constel-

lation mapper, a scaling function and a digital pulse shaping filter (Figure 3). The data to be assigned to the different modulation formats are written into separate buffers. The framer reads the data and builds the frame according to the currently valid frame structure defined by the MAC. Two digital-to-analog converters, a quadrature modulator and an IF to RF converter complete the transmitter. The constellation mapper has to take into account the proper scaling of the three different modulation schemes. They have different peak-to-average power ratio, which increases for higher order schemes: 0 dB for QPSK, 2.5 dB for 16QAM and 3.7 dB for 64QAM. Two possible options for output scaling are using constant peak power or constant average power for the different modulation formats. With constant peak power, the higher order modulation formats are more affected by interference and the area coverage is lower. The constant average power approach, however, has higher linearity demands for the RF components.

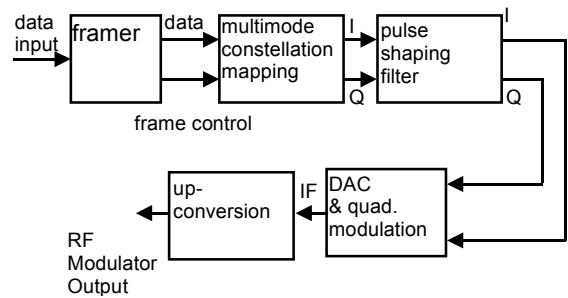


Figure 3: Multimode Transmitter Block Diagram

3.2 Multimode Receiver

In this section an approach for a cost efficient multimode modulation burst downlink receiver is presented. The main focus within this paper is on burst mode synchronization of carrier and symbol timing for modulation formats up to 64QAM at very high symbol rates. Starting from standard burst mode receiver techniques, a different way for burst mode synchronization is shown, which takes benefit from some special properties of the downlink (DL) and leads to an implementation which is efficient in terms of gate count, power consumption and cost.

3.2.1 Common Burst Receiver Techniques

A common burst receiver estimates signal power, carrier phase, symbol timing phase and channel response from a training preamble at each burst start. With these estimates, the burst is then demodulated. Besides signal-to-noise-ratio the estimation error variance depends mainly on the signal processing effort at the correlator, preamble length

in symbols and oversampling ratio. For example, 16QAM demodulation requires a timing phase accuracy of 1.25 % rms of symbol time T for a BER degradation of 0.1 dB at a BER of 10^{-6} . A preamble correlator length of about 60 symbols is necessary to achieve this accuracy with a single shot estimation [3]. The required complex-numbered cross-correlation calculation usually leads to expensive signal processing units.

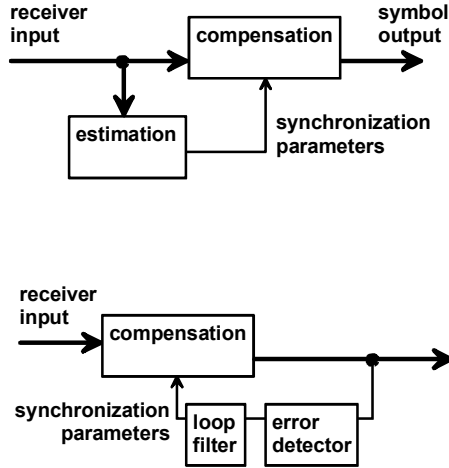


Figure 4: Feed Forward (FF) Estimation and Error Feed Back (FB) Loop

Generally a burst receiver uses feed forward (FF) estimation techniques (Figure 4) for the acquisition of the synchronization parameters. If bursts are short and parameter drifts low, a single estimation from burst start is valid for the duration of the complete burst. But for an adaptive multimode modulation system, where the burst length is varying from burst to burst, an additional parameter tracking during demodulation of longer bursts is required. This can be realized either by calculating further FF estimates during the burst or by using an error tracking feed back (FB) loop (Figure 4).

An advantage of FB algorithms is that they mostly operate on symbol rate. In contrast, FF algorithms mainly work with oversampled waveforms. So an optimum burst mode receiver for adaptive multimode modulation may be a combination of some FF estimation structures and some additional FB error tracking loops.

3.2.2 Looking for a Different Approach

It is not recommended to use a common burst mode receiver for demodulation of variable length bursts with adaptive modulation up to 64QAM at up to 40 MSymbols/s. Since this would require a signal processing rate of 160 MSamples/s at an oversampling factor 4, a low cost customer prem-

ises equipment (CPE) with this approach seems impossible.

So a different approach has been selected, exploiting some advantageous properties of the physical layer framing: Bursts always start at the beginning of a fixed-length frame with a QPSK preamble and some hundred QPSK symbols. Here broadcast information relevant for all terminals is transmitted.

The adaptive modulation portions within a single burst are ordered by the modulation grade: QPSK, 16QAM and last 64QAM. So it is sufficient if the parameter estimations accuracy increases step-by-step during a burst. Finally most parameters like symbol rate, carrier frequency and channel response are nearly constant from burst to burst. Other than in uplink, they always stem from a single transmitter and channel. This allows averaging over several bursts to further decrease parameter variances. All these points enable an approach for a burst multimode modulation receiver derived from a continuous mode receiver rather than a common burst receiver.

3.2.3 Track & Hold Burst Synchronization

The DL system, as described above, works in fact in a "gated-continuous" mode. This generally enables the application of Feedback (FB) error tracking algorithms as commonly used for continuous mode receivers. We only have to modify the tracking loops, which then are working as 'track & hold' Phase-Locked Loop (PLL). The basic structure of the extended PLL is shown in Figure 5:

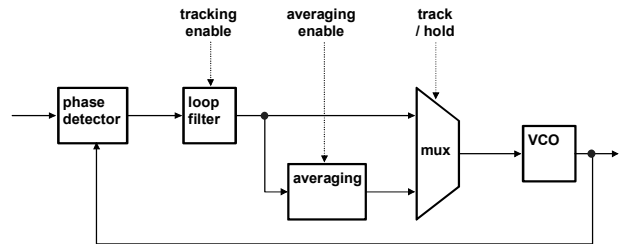


Figure 5: General Structure of the Track & Hold PLL

The 'track-and-hold' PLL filters for both the carrier and timing recovery, consist of a loop filter with track and hold capability and some switching logic. For blind acquisition of the symbol timing and the carrier, the PLLs are switched to the tracking mode during the first few QPSK symbols always available after each burst start. With the PLL parameters (loop damping and natural frequency) set to appropriate values at least a small frequency correction towards the target frequency

is achieved. The PLL frequency has to be kept constant over the gap in the frame, until the next frame preamble occurs. Then the acquisition continues so that the frequency at each burst start is getting closer to the target frequency. After several bursts the acquisition finally succeeds.

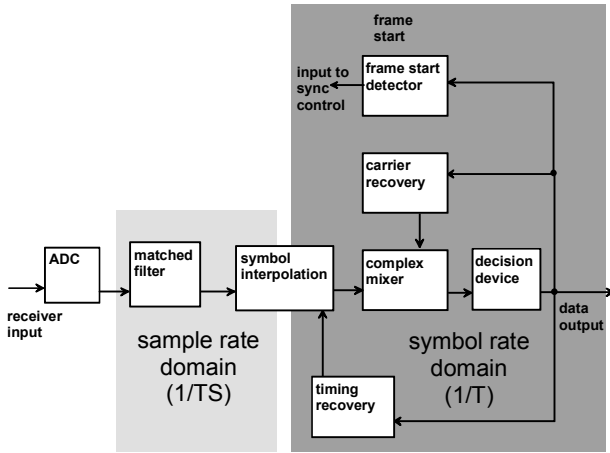


Figure 6: Diagram of the Inner Digital Receiver Synchronization Blocks

Initial synchronization after power up, however, requires rough knowledge of the burst start. So prior to the synchronization a burst start detection is required which must operate with symbols having neither the correct sampling phase nor the correct carrier frequency. This is achieved by a very simple symbol rate multiplier-free preamble correlation with an adaptive peak detection, offering a high tolerance with respect to missing and false detected peaks. After frame synchronization, the joint recovery of the symbol timing and carrier is fired off. The receiver blocks concerned with synchronization are shown in the block diagram in Figure 6.

3.2.4 Selection of Algorithms

Two special classes of synchronization algorithms have been envisaged for the design:

1.) Decision-directed FB algorithms, because they normally require less computational effort than FF estimation algorithms. No absolute error estimation is required, since error FB systems always tend to reduce the error towards zero independently of the exact error detectors characteristic curve.

2.) Symbol rate based algorithms, because they allow an implementation for higher system symbol rates respectively lower cost than algorithms working with oversampled data.

For the recovery of the symbol timing at symbol rate T a complex-numbered Mueller & Müller (M&M) timing error detector (see e.g. [5]) is used. For low noise scenarios as required for 64QAM

demodulation the performance is superior to many other error detectors due to the self-noise-free nature of the timing error computation. But also some problems must be regarded: The M&M error detector (as originally designed for baseband communication systems) suffers from residual carrier frequency error and occasional hang-ups during acquisition for higher modulation grades like 16QAM.

For the recovery of the residual carrier a Costas loop is used. The error detector and de-rotation of the symbols with a complex mixer operate completely in the symbol rate domain. After carefully dimensioning the PLL parameters the Costas loop offers very fast and reliable acquisition and tracking performance. Even in presence of noise and strong Inter-Symbol Interference (ISI) the loop is able to acquire. This robustness against ISI, as also generated from a non-locked timing recovery, makes it ideal suited for a joint acquisition of symbol timing and carrier together with the M&M loop.

3.2.5 Burst Acquisition Results

The 'track-and-hold' PLLs have been analyzed by simulation and implemented in an adaptive multi-mode LMDS demonstrator system, working with 22.4 Msymbols/s and a frame length of 1 ms. The acquisition results of a low noise and a high noise + Intersymbol Interference (ISI) scenario are presented. Noise comprises white Gaussian noise, phasenoise and ISI from channel and hardware imperfections.

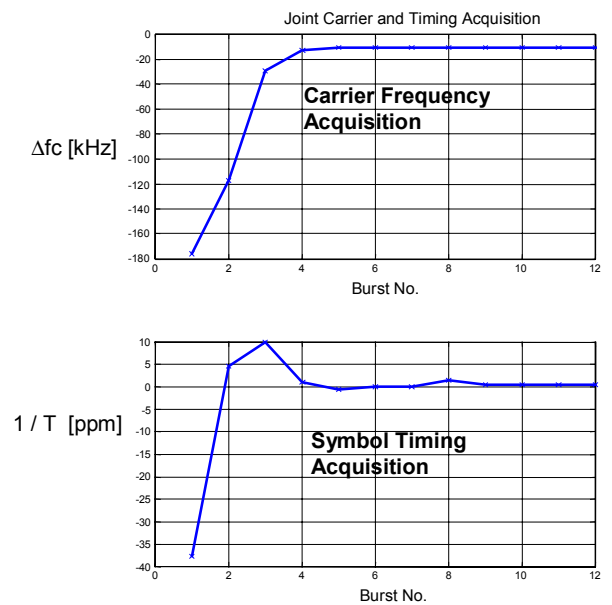


Figure 7: Acquisition Measurements of Carrier and Symbol Timing for a Low Noise Scenario

For high signal-to-noise (SNR) ratio (40dB SNR) the acquisition of carrier frequency and symbol timing was achieved 5 bursts after start of acquisition (Figure 7). Initial timing error was 25 ppm, residual carrier frequency error Δf_c was 200 kHz. With strong noise and ISI the non-linear acquisition obviously takes longer and depends on the loop start conditions. An example acquisition measurement is shown in Figure 8. This scenario represents the acquisition under worst case radio channel conditions with strong ISI (see [4]) and an SNR of 10 dB.

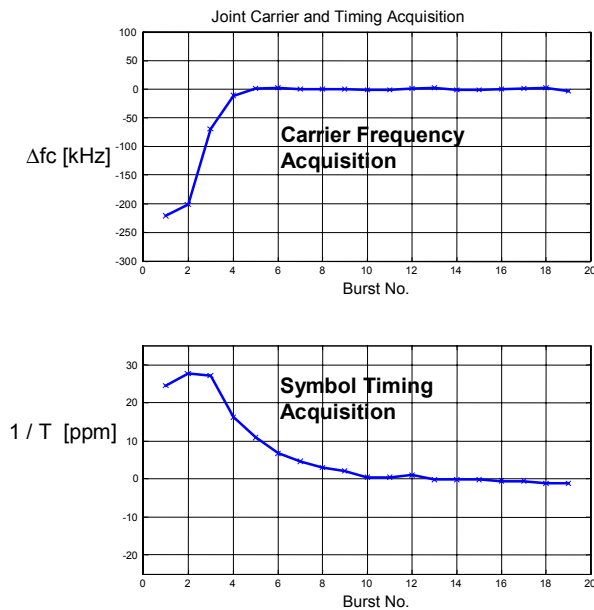


Figure 8: Acquisition Measurements of Carrier and Symbol Timing for a Worst Case ISI Channel with Strong Noise

4 CONCLUSION

This paper presents a new multimode modulation modem concept for future point to multipoint LMDS access systems. This concept is well suited for cost efficient implementation especially of the subscriber station equipment. Specifically adapted symbol rate based algorithms for synchronization and demodulation of the downlink multimode bursts, rather than using oversampling, lead to digital devices with low power consumption and moderate gate count and allows use of standard FPGAs. The good performance results of the carrier and symbol timing recovery has been shown by simulations and implementation.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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