Equalization Requirement Study For Broadband MMDS Wireless Access Systems

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Abstract

Dependent upon terrain and land use, the propagation characteristics of fixed broadband wireless access (BWA) channels can vary from Ricean through to Rayleigh (ie, from line of sight (LOS) to non-line of sight (NLOS) operation). The delay spreads associated with such channels can be detrimental when high data rates are considered. To combat the inter symbol interference (ISI) induced by these dispersive channels, the receive modem must use an equalizer.

This paper examines the equalizer requirements for BWA systems in the multi-channel multipoint distribution services (MMDS) band.

It is shown through Monte-Carlo simulations written in C++, which type of equalizers is most suitable. Proposed channel models for the MMDS band are used to evaluate the equalizer requirements. Different tap-update algorithms and implementation architectures are taken into consideration. The performance of the different equalizers is measured in terms of their convergence time, bit error rate and complexity. In particular it is shown that LSlat has advantages for MMDS systems giving an excellent performance at lower complexity than RLS.

I. Introduction

The interest in BWA systems as an alternative to digital subscriber line (DSL) or cable has recently increased. Either as a competitive service, or simply as the only possible solution because the subscriber is not served by DSL or cable, BWA systems offer a flexible approach to bridge the 'Last Mile'. Further, BWA systems offer a very cost-effective way of building an access network. Easy maintainability, incremental costs and portability are key benefits of the wireless alternative.

In order to be competitive, BWA systems must offer similar data rates to their wireline counterparts. At high data rates, the ISI induced by dispersive channels becomes a severe problem. The key building block in combating ISI is the equalizer. The higher the data rate, the more complex the equalizer. In this study we investigate the trade-off between equalizer complexity and performance for BWA systems.

Standardization of BWA systems is currently carried out by the IEEE 802.16 Working Group on Broadband Wireless Access Standards [1]. It shows that neither single-carrier nor multi-carrier systems are ideal for all operating frequency ranges. Sometimes multi-carrier systems show an advantage and in other situations single-carrier systems or even a mix of both proves better. Further, choices regarding time-domain or frequency-domain equalization, the type of equalizer and the type of tap-update algorithm widens the design space. LOS and/or NLOS conditions, the frequency band, as well as the required data rate determines which system is the most suitable one.

This paper examines time-domain equalization for MMDS BWA systems. A linear equalizer (LE) with least mean square (LMS) updating, a decision feedback equalizer (LMSDFE) with LMS updating, a decision feedback equalizer with recursive least square (RLS) updating and a recursive least square lattice decision feedback equalizer (LSlat) with recursive least square updating are considered. In the literature the LSlat equalizer (i.e. RLS implementation with linearly increasing complexity), has not been considered for MMDS BWA systems. We show here that the RLS lattice decision feedback equalizer (DFE) is actually a good choice for MMDS systems.

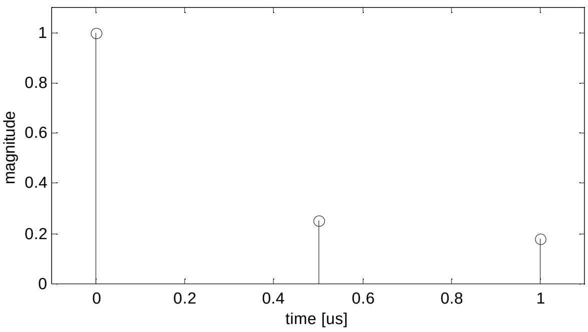
First we present the channel model used in this simulation study. Then in section III, we describe the simulation model for our MMDS system. In the subsequent section IV we discuss the simulation results of our study. Finally we draw conclusions and point out directions for future work in section V.

II. Channel Model

The statistical channel model (SUI-2) of Fig. 1 is used [2]. Erceg published a total of 6 different radio channel models for type G2 (i.e. LOS and NLOS) MMDS BWA systems in 3 terrain categories. SUI-2 represents a worse case link for terrain type C (flat/light tree density). SUI-1 and SUI-2 are Ricean channels, whereas the other channels from Hari (SUI-3 till SUI-6) are Rayleigh channels. The Rayleigh channels are more hostile and exhibit a greater rms delay spread (D_{RMS}) and therefore even longer time-domain equalizers will be required for those channels.

The probability of symbol error (Ps) is evaluated by averaging over 250 channel realizations and the convergence plots are averaged over 500 realizations.

We assume burst mode digital communication (i.e. the channel stays constant during one burst) and hence neglect the Doppler Effect.



Channel Model SUI-2			
Delay [µs]	0.0	0.5	1
Power	1	0.0631	0.0316
Power [dB]	0	-12	-15
Magnitude	1	0.2512	0.1778
K-Factor	10	0	0
D_{RMS} [us]	0.2	0.2	0.2

Fig. 1: G2 MMDS channel model ‘SUI-2’

III. Simulation Model

The simulation model is shown in Fig. 2. QPSK modulation is assumed with a symbol rate of 5 mega symbols per second (MS/s), giving a gross data rate of 10Mb/s. The two root raised cosine filters have a roll-off factor of 0.35, use 20 samples per symbol and are truncated to 200 samples.

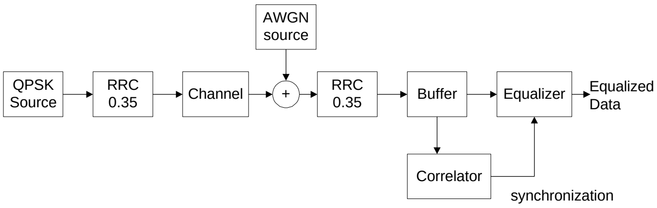


Fig. 2: Simulation Model

The LMS and RLS algorithms used in this simulation are based on [3] and the LSLat algorithm is based on [4]. A similar study of these algorithms is also presented in [5], but not explicitly for fixed broadband access systems. The stepsize of the LMS algorithm is 0.01 and the weighting factor for the RLS and LSLat is 0.99. The maintap for both systems is set to be equalizer tap 6. The convergence plots are evaluated with an SNR of 20dB at the equalizer input. We train all equalizers for 700 symbols in order to make sure that they are fully converged. The payload was set to 10000 symbols. 200 symbols are reserved for synchronization. Hence the total packet length is 10900 symbols.

IV. Results

In this section the simulation results are presented. It was found through a number of convergence simulations with different FF and FB-filter lengths that a minimum equalizer length of 15 taps is required for channel SUI-2. In the case of a DFE, the equalizer consists of 8 FF taps and 7 FB taps denoted as (8, 7). The LE has a total number of 15 taps.

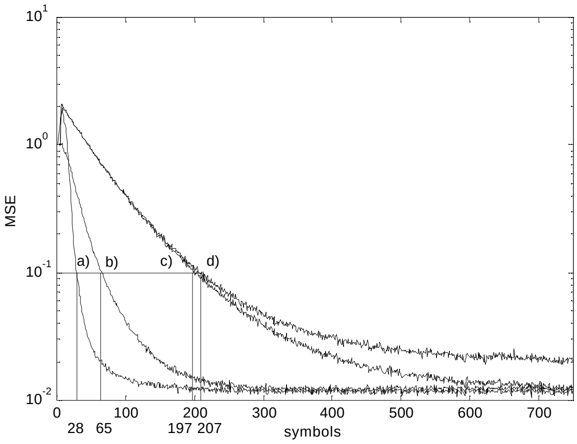


Fig. 3: convergence rate for channel SUI-2:
a) RLS, b) LSlat c) LMSDFE and d) LE

It is advantageous to have an equalizer as short as possible, since the longer the FF-filter, the higher the noise enhancement.

The convergence plots of Fig. 3 show that the RLS is the fastest tap-update algorithm, followed by the LSlat, followed by the LMSDFE and then by the LE. For example in order to achieve a MSE of 10^{-1} the RLS needs 28 samples, the LSlat needs 65 samples, the LMSDFE needs 197 samples and the LE needs 207 samples. The LMS algorithm is very slowly converging for use in the SUI2 channel. Further the results indicate that the LE shows poor performance and is therefore not suitable for MMDS systems. Additionally the LE converges to a higher MSE and hence will show worse Ps compared to the other equalizers.

Fig. 4 gives Ps as a function of SNR with channel SUI-2. It is seen that all the DFE arrangements (RLS, LSlat and LMSDFE) have a similar Ps. Hence the main advantage of using the LSlat compared to the LMS algorithm is the increased convergence speed, since the Ps performance of all the equalizers is more or less the same. The LE exhibit a poor Ps and hence is not powerful enough for G2 MMDS BWA systems. The dashed lines show the performance if the symbols fed back are correct. Comparing the performance when the correct symbols are fed back with that when the detected symbols are fed back it is seen that the effect of error propagation in the DFE is insignificant.

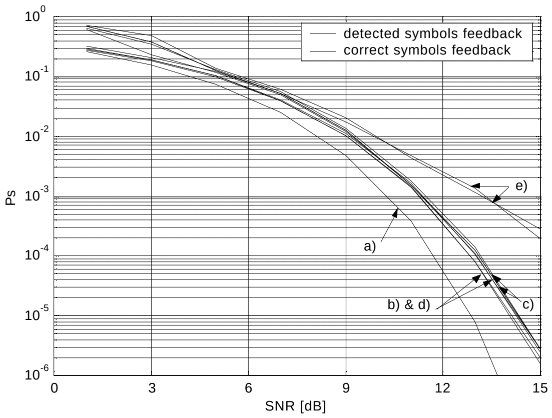


Fig. 4: Probability of symbol error for channel SUI-2: a) matched filter bound for AWGN channel, b) RLS, c) LSlat, d) LMSDFE and e) LE

Although the Ps of the LMSDFE is similar to the other DFEs, this will not be the case for a system with a short training sequence length (see Fig. 3). In this case the LMSDFE will not be fully converged, when switched to the decision directed mode. We emphasize here convergence speed with regard to Ps, because for BWA systems bandwidth is a scarce resource and fast converging algorithms are therefore essential especially in the uplink.

We now draw our attention to computational complexity of the LMS, RLS and LSlat tap-update algorithms. In BWA systems complexity is a crucial issue and therefore low complexity algorithms with good performance are vital. The complexity curves are shown in Fig. 5. Hence from Fig. 5 and Table 1 with a total number of 15 taps, the simulated equalizers have a complexity of 630 operations per output for the RLS, 378 operations per output for the LSlat and 31 operations per output for the LMS algorithms.

The complexity of the LSlat is nearly half of the RLS. Thus for G2 MMDS terrain type C systems it is clear that an RLS algorithm with a linearly increasing complexity (e.g. LSlat) offers the best performance/complexity trade-off. In this case LSlat offers similar performance to RLS, with greatly reduced complexity.

The complexity of the LMS is very low for a total number of taps of 15. However, despite the advantage of the low complexity the LMS algorithm does not offer an acceptable convergence rate as seen in Fig. 3.

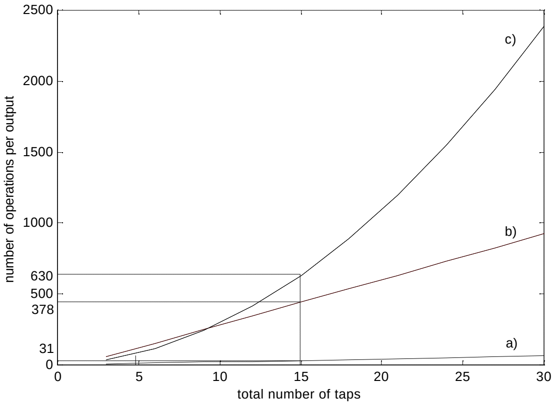


Fig. 5: complexity: a) LMS, b) LSlat and c) standard RLS (for equations see Table 1)

Algorithm	Operations (Total)	Divisions
LMS	2·Ntaps+1	0
RLS	$2.5 \cdot Ntaps^2 + 4.5 \cdot Ntaps$	2
LSLat	18·FF+39·FB-39	2·FF

Table 1: arithmetic operations per sample [4]

With a Ricean K-factor of 10 and two multipath components following the direct path, the SUI-2 channel results in relatively strong ISI for terrain type C. However, SUI-2 is still much less hostile than the Rayleigh channels (i.e. channel models: SUI-3 to SUI-6) for other Terrain types. For these channels, time domain equalization becomes more and more complex as the equalizer size increases. In the most severe channel cases, it may be necessary to use frequency domain equalization or possibly OFDM to reduce the complexity [6].

Complexity, as for similar HiperLAN systems, is a major limiting factor in the design of BWA systems. However, there is a great deal of literature concerning HiperLAN equalization complexity reduction.

Specifically: Complexity reduction may be achieved at the hardware level [7, 8], through tap-selective equalization [9], through a special equalizer architecture [10] where no training is needed for the FB-filter or via other fast start-up techniques [11].

V. Conclusions

The lattice equalizer has not been considered previously for use in BWA systems. It is seen that for the MMDS system the lattice equalizer offers an excellent complexity-performance trade-off. Although the LMSDFE offers similar Ps performance, its convergence speed is much slower. Comparing the LSlat with the RLS, the LSlat wins regarding complexity at a reasonable performance trade-off.

High order modulation schemes such as 16 and 64 QAM as well as higher data rates will be considered in the future. The anticipated results will indicate the highest possible data rate and the highest possible modulation order for systems using time-domain equalization.

Acknowledgements

The authors would like to thank Adaptive Broadband Corp. for sponsoring this research. Special thanks to Paul Hiscock for coding a powerful simulator in C++, which facilitated the Monte-Carlo simulations.

They are also indebted to Dr. Georgia Athanasiadou from Adaptive Broadband Corp. and last but not least Prof. Andy Hopper from the University of Cambridge for their guidance and encouragement.

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