Efficient FMT equalization in outdoor broadband wireless systems

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Abstract— **In conventional Orthogonal Frequency Division Multiplexing (OFDM) systems [1], the longer the RMS delay spread of the multipath channel, the higher the inefficiency because we need to introduce a longer Cyclic Prefix (CP). In Filtered Multitione (FMT) systems [2], the CP is not needed which improves the performance although adequate per subchannel equalizaiton is necesary. Assuming subchannel flatness, efficient equalization schemes have recently been proposed for FMT systems [6] using a combination of a fixed DFE equalizer that compensates for the effect of the filter bank plus a one tap equalizer (based on a channel estimate) to compensate for the phase and amplitude distortion introduced by the channel. However, subchannel flatness does not hold in channels with long RMS delay spread typical in outdoor environments and the performance of FMT with a one tap equalizer rapidly deteriorates. Instead, to equalize FMT systems in the outdoor environment, we propose a fixed DFE equalizer computed offline in combination with a short adaptive linear equalizer with 1,2 or 3 taps. The equalizer is adapted using the RLS algorithm and convergence is achieved using only a small number of training symbols and low computational complexity. In this way, we show how FMT can deal with channels with a long delay spread.**

I. Introduction and Proposed System

In conventional OFDM systems [1] we obtain zero intersymbol interference (ISI) and zero intercarrier interference (ICI) by means of frequency domain overlapped sinc functions in which adjacent carriers are at the nulls of the sinc(f) function. A Cyclic Prefix (CP) longer than the maximum excess delay is added to avoid ISI which occurs in multipath channels and destroys orthogonality. However, the longer the delay spread of the channel, the higher the transmission inefficiency due to the cyclic prefix.

In contrast, FMT modulation proposed in 1999 for VDSL systems [2] is based in non overlapping spectral partitioning methods. With M subcarriers, the non overlapping base band signal $x(n)$ is obtained by a uniform filter bank. Here, each of the transmitter pass band filters consists of a frequency shifted version of a low pass prototype $h(n)$ whose frequency response is zero outside the interval $|f| \leq 1/2T$ where T is the FMT symbol period.

$$h^{(i)}(n) = \frac{1}{\sqrt{M}} h(n) \cdot e^{j2\pi \frac{i}{M} n}, \qquad i=0,1,\ldots,M\text{-}1,\ n=0,\ldots,M\gamma\text{-}1 \tag{1}$$

where γ is called the overlap.

This arrangement reduces ICI to such a low level that it can be neglected when compared to the levels of other noise sources.

At the receiver, we will have a matched implementation with a delay of $M\gamma$ samples in each of the filters: $g^{(i)}(n) = (h^{(i)}(M\gamma\text{-}n))^*$ obtaining:

$$g^{(i)}(n) = \frac{1}{\sqrt{M}} h(n-1) \cdot e^{j\frac{2\pi}{M} ni}, \qquad i=0,\ldots,M\text{-}1,\ n=1,\ldots,M\gamma \tag{2}$$

In [3] we show how the efficient implementation shown in Fig. 1 can be derived using the M polyphase components of the prototype filter $\{h_{(i)}(k)=h(kM+i),\ i=0,1,\ldots,M\text{-}1\}$ each of length γ and the Fast Fourier Tranform (FFT).

Since in FMT the low pass prototype $h(n)$ is not designed to satisfy the perfect reconstruction condition but to have high spectral containment [2], ISI will be present in each subchannel and equalization will need to be used at the receiver. However, assuming that the subchannels are well separated in frequency, as is the case in FMT, the overall response for each of the subchannels will be independent of the adjacent channels and we can apply independent per subchannel equalization.

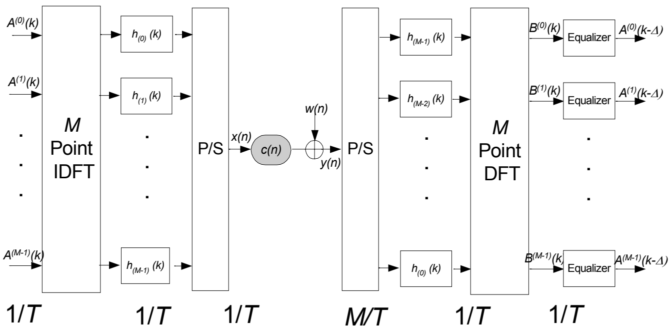

Fig. 1 FMT efficient implementation with per subchannel equalization

In [6], assuming that the frequency response in each of the subchannels is flat, a fixed DFE (computed offline) is used to compensate the known ISI introduced by the prototype filter and a complex gain is used to compensate the amplitude and phase distortion introduced by the channel. This efficient approach shown in Fig. 2 is interesting because the required complex gain coefficient can be computed straightforwardly in the frequency domain with the aid of a known training symbol. However, in a channel with a small coherence bandwidth compared with subchannel separation (i.e. a long RMS delay spread) typical found in outdoor environments, the assumption of subchannel flatness does not hold and if we use the proposed equalization approach, the FMT performance decays as the RMS of the delay spread increases.

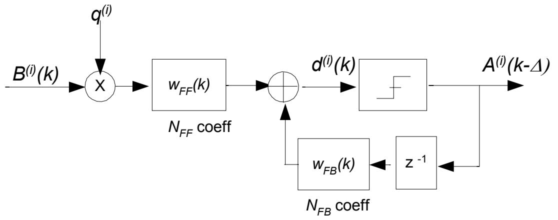

Fig. 2 Previously proposed efficient per subchannel equalizer

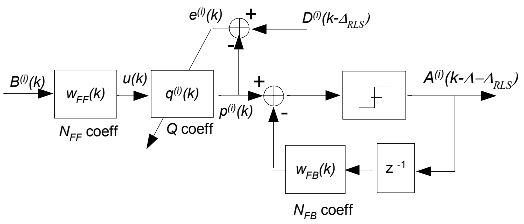

Fig. 3 Proposed per subchannel equalizer as a cascade of a fixed DFE and an short adaptive transversal equalizer

We remind ourselves here that the major advantage of FMT modulation over conventional OFDM modulation is that FMT does not need the use of the CP. This improvement will be greater in long delay spread situations where longer CPs are needed in OFDM. However, the previous equalization scheme presented can only deal with short delay spreads.

We propose a scheme in which we have a cascade of two filters:

a) A fixed DFE filter $\{w_{FF}, w_{FB}\}$ computed offline that compensates for the effects of the prototype filter (as in [6]).

b) An adaptive transversal filter, $q^{(i)}(k)$, that compensates for the effect of the channel. For moderately high delay spreads, we still know that the frequency response of a subchannel will not vary much across the band therefore, the order of the adaptive equalizer with Q taps can be low (for example, Q = 1, 2 or 3 taps).

This implementation is shown in Fig. 3 where the adaptive algorithm updates the filter coefficients $q^{(i)}(k)$.

The error used in the adaptive algorithm is the difference between the training sequence $D^{(i)}(k\text{-}\Delta_{RLS})$ and the output $p^{(i)}(k)$ produced by the adaptive filter with coefficients $q^{(i)}(k)$.

The training sequence $D^{(i)}(k)$ shown in Fig. 3 is computed as follows:

$$D^{(i)}(k) = w_{FF}(k) \otimes \left\{ \left(g^{(i)}(n) \otimes h^{(i)}(n) \right)_{\downarrow M} \right\} \otimes A^{(i)}(k) \qquad (3)$$

where $A^{(i)}(k)$ are the known training symbols and $\otimes$ indicates convolution.

II. Results and Conclusion

We compare mulitcarrier systems operating at a frequency of 5.2GHz with a sample rate M/T=20MHz as proposed in HIPERLAN/2 [4]. We model the multipath channel as an exponentially decaying Rayleigh fading channel with RMS delay spreads in the range of 27ns to 210ns. We consider M=64 subcarriers. The number of useful subcarriers will be 52 in OFDM and 62 in FMT since we need fewer Virtual Carriers in FMT systems. The overlap of the prototype is γ= 10.

The results are given in the form of the achievable bit rate that is computed as:

$$rate = \left\{ \sum_{i=used\ \ tone} \log_2\left(1 + 10^{\frac{SNR_i - \Gamma}{10}}\right) \right\} \frac{M}{(M+\upsilon)T} \qquad (4)$$

where SNR_i (dB) is the signal to noise ratio at the decision device in the ith subchannel and Γ=6dB is the SNR gap.

By υ we denote the CP equal to $3\cdot\sigma_{RMS}\cdot M/T$+5 in OFDM and υ =0 in FMT.

In Fig. 4 we compare 6 different schemes:

-OFDM with a cyclic prefix length υ suited to the RMS delay spread and a one tap equalizer.

-FMT system perfectly equalized with a DFE.

-FMT system with a fixed DFE equalizer and 1 tap equalizer given by the inverse of the channel estimate as in [6].

-3 different FMT systems with a fixed DFE and a transversal filter with 1,2 or 3 taps trained using the RLS algorithm [5].

As shown in Fig. 4, our proposal with 2 or 3 taps in the adaptive equalizer can efficiently deal with longer delay spreads and the improvement with respect to conventional OFDM increases as the delay spread increases. Moreover, FMT would give a better performance compared to OFDM in a more realistic scenario where the OFDM CP would be chosen to deal with the highest of the possible delay spreads encountered in a specific environment.

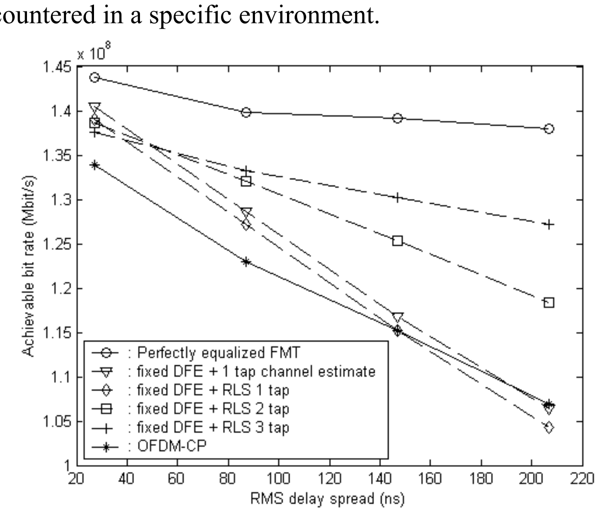

Fig. 4 Achievable bit rates (Mbit/s) for different FMT architectures in a multipath channel with RMS in the range [27ns-210ns]

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