Interference Aware Iterative Receiver Performance for the Uplink of LTE-A

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Abstract— In this paper we study the performance of an interference aware iterative block decision feedback equalizer (IBDFE) for the uplink of LTE-Advanced with single carrier (SC) transmissions. The receiver makes use of the correlation between the interference in the receiving antennas and minimizes the mean squared error (MMSE) of the detected symbols. Link level simulation results show that the proposed receiver clearly outperforms the conventional IBDFE and the linear interference rejection combining (IRC) detector. System level simulation results show that the use of the new iterative receiver achieves additional throughput gains. However, the gains obtained depend on the schedulers employed and on the number of receiving antennas.

1. INTRODUCTION

Mobile data traffic is growing exponentially in 4G networks with new multimedia applications on smart mobile devices putting more stringent demands on the quality of service. In addition to supporting efficiently the signaling and traffic from interactive video and gaming applications, 4G networks also need to handle the signaling and traffic from a multitude of machine-type communication devices. In order to tackle the inter symbol interference (ISI) caused by the channel time dispersion, 4G networks use orthogonal frequency division multiplexing (OFDM) [1] or SC [2] transmission techniques. While OFDM allows a simple implementation of both the transmitter and receiver it suffers from a large peak to average power ratio (PAPR) which makes it more suitable for the downlink. For the uplink, the use of single carrier block transmissions with frequency domain equalization (SC-DFE) is often preferred due to its lower PAPR while still being robust in ISI inducing channels [3] (see also the 3GPP Long Term Evolution (LTE) [4]). However, in this case, the performance of low complexity linear receivers is far from the matched filter bound (MFB) [5]. In order to reduce this gap, one has to resort to nonlinear schemes [6], with the IBDFE [7–10] being one of the most promising solutions.

Besides the channel dispersion problem, the emergence of denser heterogeneous cells creates large levels of interference among users which must be dealt using techniques like coordinated scheduling, cooperative processing or interference cancellation. Even though the interference can be removed using similar approaches to those used by spatial multiplexed receivers [11, 12] the resulting complexity can be excessive. Lower complexity techniques exist like the linear IRC [13] which does not require the estimation of the interferers' streams. This receiver is a direct extension of the conventional minimum mean squared error (MMSE) detector and has been studied for use in 3GPP LTE systems [14–17]. However, linear IRC detectors applied in SC schemes will perform far from optimum in severe time dispersive channels. Therefore, in [18] we designed a modified IBDFE for SC transmissions whose feedforward and feedback filters are implemented in the frequency domain and optimized by taking into account the presence of correlated interference between multiple receiving antennas. In this paper we evaluate the performance of the interference aware IBDFE proposed in [18] for the uplink of LTE-Advanced and compare it against other receivers, namely the conventional IBDFE and the linear IRC detector. The comparison is accomplished through link level and system level simulations in time dispersive channels with cochannel interference.

The rest of this paper is organized as follows. Section 2 describes the structure of an interference aware IBDFE with several antennas. Section 3 presents the system level simulation scenario. Numerical results are shown in Section 4 followed by the conclusions in Section 5.

2. INTERFERENCE AWARE IBDFE

The structure of the interference aware IBDFE proposed in [18] with several receive antennas is shown in Fig. 1. A SC transmission with blocks of N modulated symbols, s_n, $(n = 1, \dots, N)$, appended with a suitable cyclic prefix (CP) is assumed. After the application of an N-point DFT (Discrete Fourier Transform) the sequence of received samples can be written as

$$\mathbf{Y}_k = \mathbf{H}_k S_k + \mathbf{H}_k^I \mathbf{S}_k^I + \mathbf{N}_k. \quad (1)$$

where $\mathbf{Y}_k$ is a $N_{rx} \times 1$ vector containing the samples for the kth subcarrier received in the N_{rx} antennas, $\mathbf{H}_k$ is the $N_{rx} \times 1$ vector containing the frequency domain channel coefficients for the different receive antennas, S_k is the kth DFT sample of the main user's modulated symbols, $\mathbf{H}_k^I$ is the $N_{rx} \times N_I$ matrix whose entries correspond to the frequency domain channel coefficients for the N_I interferers in the different receive antennas (one column for each interferer), $\mathbf{S}_k^I$ is the $N_I \times 1$ vector whose elements are the kth DFT samples of the different interferers symbols and $\mathbf{N}_k$ is the $N_{rx} \times 1$ vector containing noise samples in the frequency domain. It is assumed that both S_k, and N_k are zero mean complex random variables with variances $P_S = E[|S_k|^2]$ and $P_N = E[|N_k|^2] = N \cdot N_0$ (N_0 is the noise power spectral density). The elements of the interferers' vector $\mathbf{S}_k^I$ are also assumed to be zero mean complex random variables with $E[\mathbf{S}_k^I (\mathbf{S}_k^I)^H] = P_S \mathbf{I}_{N_I}$.

The estimates produced by the IBDFE in the frequency domain can be expressed as

$$\tilde{S}_k^{(i)} = \mathbf{F}_k^{(i)} \mathbf{Y}_k - B_k^{(i)} \hat{S}_k^{(i-1)}, \tag{2}$$

where i is the iteration number, $\mathbf{F}_k$ represents a $1 \times N_{rx}$ vector containing the feedforward coefficients for subcarrier k, B_k is the respective feedback coefficient and $\hat{S}_k^{(i-1)}$ is the kth DFT sample of the estimated block $\hat{s}_n^{(i-1)}$ $(n = 1, \dots, N)$ from the previous iteration after the decision device.

The feedforward and feedback coefficients that minimize the MSE between the estimated symbols and the transmitted symbols at the detection point of the receiver in the presence of interferers can be computed using the following expressions (from [18])

$$\mathbf{F}_k^{(i)} = \frac{\gamma^{(i)}}{1 + \phi_k \left(1 - \left(\rho^{(i-1)}\right)^2\right)} \mathbf{\Gamma}_k, \tag{3}$$

for the feedforward coefficients and

$$B_k^{(i)} = \left(\gamma^{(i)} \frac{\phi_k}{1 + \phi_k \left(1 - \left(\rho^{(i-1)}\right)^2\right)} - 1\right) \frac{E\left[S_k \hat{S}_k^{(i-1)*} | \mathbf{H}_k\right]}{P_{\hat{S}}}, \tag{4}$$

for the feedback coefficients, with

$$\gamma^{(i)} = \frac{N}{\sum_{k=0}^{N-1} \frac{\phi_k}{1+\phi_k \left(1 - \left(\rho^{(i-1)}\right)^2\right)}}, \tag{5}$$

$$\rho^{(i-1)} = \frac{\left| E\left[S_k \hat{S}_k^{(i-1)*} \middle| \hat{H}_k\right]\right|}{\sqrt{P_S P_{\hat{S}}}}, \tag{6}$$

$$\mathbf{\Gamma}_k = \mathbf{H}_k^H \left(E\left[\mathbf{H}_k^I \left(\mathbf{H}_k^I\right)^H\right] + \frac{P_N}{P_S} \mathbf{I}_N \right)^{-1}, \tag{7}$$

and

$$\phi_k = \mathbf{\Gamma}_k \mathbf{H}_k. \tag{8}$$

3. SYSTEM LEVEL SIMULATIONS

The core of the system level simulations (SLS) is composed by a discrete event generator with some grade of abstraction. The events generated consist of individual tasks such as CQI reporting, packet processing, radio resources management, etc.. Propagation, traffic and mobility models are also part of the SLS and have great impact in the results that will be outputted, especially in terms of coverage and radio link SNR estimation. Additionally, fast-fading and shadowing conditions are emulated, since channel conditions for every enhanced nodeB/user equipement (eNB/UE) combination are time-varying and location dependent.

The geographical environment used in the simulation can be configured manually (i.e., setting the geographical position of each eNB). A scenario comprising nineteen sites was configured for the simulations. However, to save simulation time the mobile users are only located on the seven cells at the center of the scenario as is illustrated in Fig. 2.

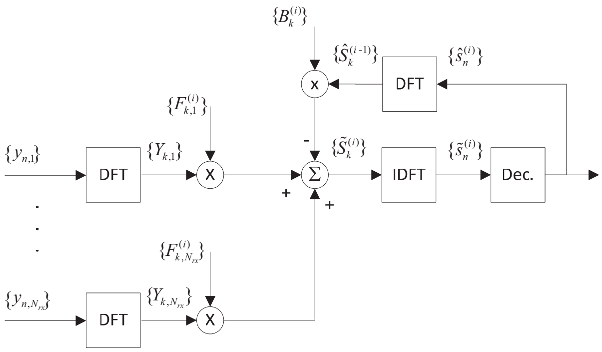

Figure 1: IBDFE receiver structure.

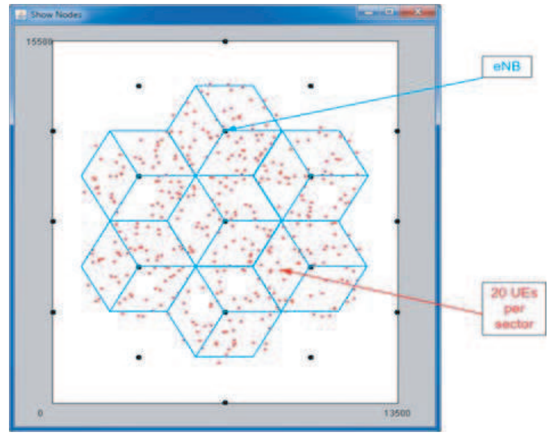

Figure 2: Users distribution inside the scenario.

Another general description of a SLS is presented in [19]. The ITU-R IMT-Advanced MIMO channel model for SLS is a geometry-based stochastic model. It can also be called double directional channel model. It does not explicitly specify the locations of the scatters, but rather the directions of the rays, like the well-known spatial channel model (SCM) [20]. Geometry-based modeling of the radio channel enables separation of propagation parameters and antennas.

Several different scenarios have been evaluated by 3GPP, some considering different traffic services in Point-to-point (PtP) mode. The single-user SU-SIMO scenario will be evaluated in the next section.

4. PERFORMANCE RESULTS

In order to evaluate the link level performance of the different receivers, several Monte Carlo simulations were performed for coded SC transmissions with $N = 1024$, (corresponding to 10 MHz bandwidth of LTE) using QPSK, 16QAM and 64QAM modulations. The channel model adopted was the Extended Typical Urban model (ETU) [21] with Rayleigh fading employed in the different taps. $\mathbf{H}_k$, $E[\mathbf{H}_k^I(\mathbf{H}_k^I)^H]$ and N_0 were assumed to be perfectly estimated at the receiver. Fig. 3 and Fig. 4 present the block error rate (BLER) versus the signal to interference plus noise ratio (SINR) for the conventional and the interference aware IBDFEs receivers, respectively. Each block has 3000 bits, four receive antennas and 1 interferer contributing with interference over thermal (IoT) level of 12 dB is considered. It is obvious that the BLER performance of the conventional IBDFE is worse than the interference aware IBDFE. For the reference BLER = 0.1 the gain in SINR of the latter is around 11 dB. However, we need to consider the system level simulation scenario to get the corresponding throughput gain.

Every UE is individually allocated with resources, and once these are finite, some sort of scheduling mechanism is necessary. Different scheduling mechanisms are tested, using 10 UEs per sector [22]. One traffic model was considered, the File Transfer Protocol (FTP) traffic model emulating the traffic generated by FTP applications. The FTP traffic model obeys the characteristics of the model described by 3GPP in [23], and the average load offered to each UE is around 925 kbps. Three channel aware schedulers are evaluated. The scheduler maximum carrier-interference (MCI), also referred to in the literature as 'Maximum SINR', gives more priority to users with good channel conditions (users located closer to the base-station). The measurement of SINR is performed via constant periodic channel quality indication (CQI) feedback done by every single user. The scheduler chooses the user k with maximum SINR at instant t. The MCI is not fair. There are two 'fair' schedulers: the proportional fair (PF) and the fair throughput (FT). Both are channel aware. We can look at PF as a less aggressive version of Max C/I scheduling algorithm. PF uses feedback sent by users to determine the instantaneous possible data rate a user k can achieve at a given instant t, and also the average throughput a user k had until instant t. This way, users that have instantaneous throughputs higher than their average throughput are scheduled first. The FT scheduling aims at fairness in terms of user throughput (all users, no matter what are their receiving conditions or position inside the cell will have the same average throughput). This is done by scheduling first users who have lowest average throughputs. Cell edge users typically experience worst SINR than users at the center of the cell and they can only use lower modulation schemes

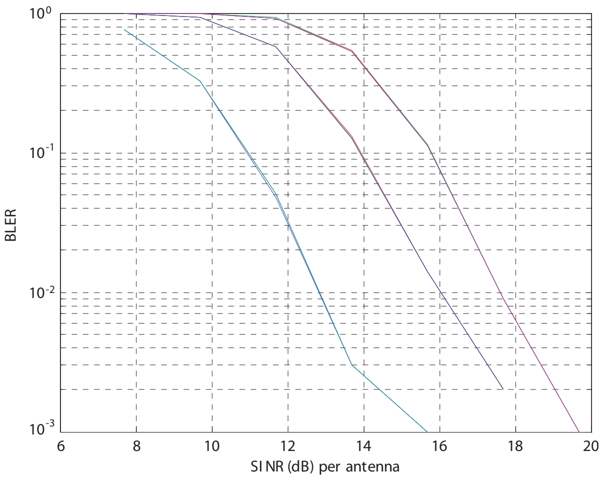

Figure 3: BLER performance of the conventional IB-DFE for 64QAM ($N_{rx} = 4$, $N_I = 1$ with IoT = 12 dB, 3000 bits).

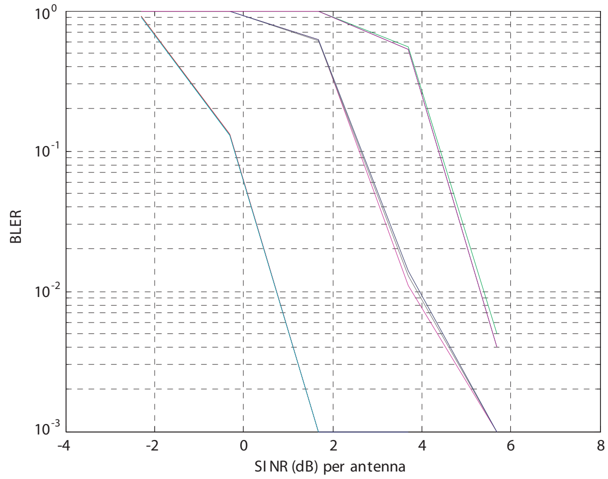

Figure 4: BLER performance of the interference aware IBDFE for 64QAM ($N_{rx} = 4$, $N_I = 1$ with IoT = 12 dB, 3000 bits).

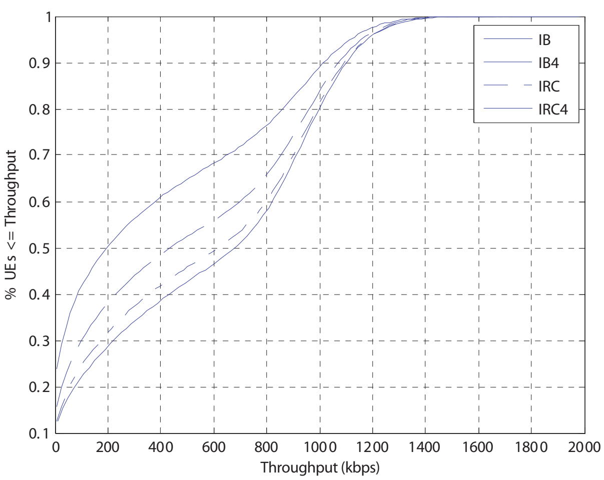

Figure 5: CDF of Throughput for MCI scheduler. (Nu = 10).

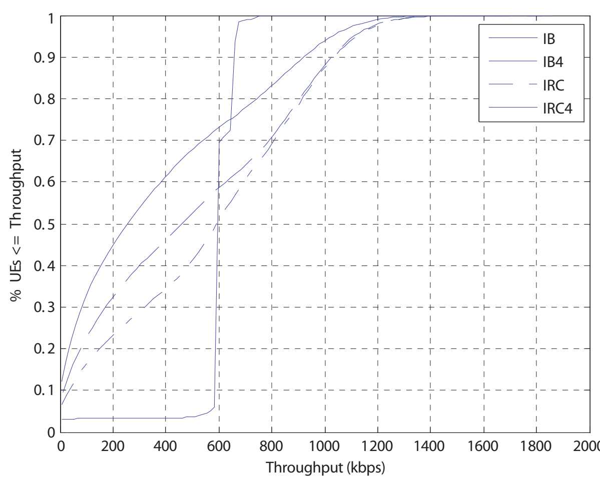

Figure 6: CDF of Throughput for PF scheduler. (Nu = 10).

and coding rates, generally transmitting with lower throughputs than users at the center of the cell. When FT is used these users with lower SINR will be scheduled more often than users with high SINR.

The following results have considered a total of 18 different CQIs, with eleven CQIs QPSK modulated, four CQIs 16QAM modulated and 3 CQIs 64QAM modulated.

In Fig. 5, Fig. 6 and Fig. 7 the cumulative distribution function of throughput (CDF(x)), for SU-SIMO $1 \times 2/1 \times 4$, with the conventional IB-DFE (IB/IB4) and interference aware IB-DFE (IRC/IRC4) is presented for MCI, PF and FT, respectively. The CDF(x) is the probability of the random variable % of UEs with throughput value less than or equal to x. Based on the link level results it is expected higher throughput for the interference aware IB-DFE receiver compared to the conventional ID-DFE. This can be fully observed but the way the scheduler performs is determinant. It is observed that MCI (Fig. 5) provides throughput values above 1000 kbps for only 10% of users. However, for 5% of users (the cell edge users) the MCI performance is very low (null for conventional IB-DFE receiver). To increase the throughput performance of cell edge users the PF scheduler (Fig. 6) should be selected. But if we really want that all users transmit with the same throughput independently of their position within the cell then we must choose the FT scheduler (Fig. 7). It is obvious the throughput gain of the interference aware receiver compared to the conventional. Taking as reference the throughput achieved by 50% of the users we notice that the interference aware receiver IB-DFE 1×4 (IRC4) with MCI provides the maximum of 700 kbps,

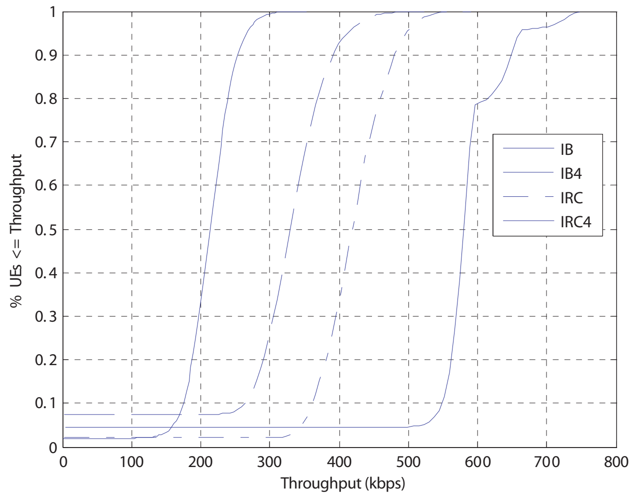

Figure 7: CDF of Throughput for FT scheduler. (Nu = 10).

higher than 600 kbps of PF and 580 kbps of FT. The maximum throughput achievable is 6000 kbps for users close to the base station. When there are 10 active users ($N_U = 10$) per sector it means that with fair schedulers, the maximum of 600 kbps is provided for each user. Only the interference aware receiver IRC4 is capable to provide almost the maximum throughput for the majority of the users which makes the throughput performance independent of the scheduling algorithm as long as they are fair schedulers. This is the reason why the performance of PF and FT is quite similar with IRC4.

5. CONCLUSIONS

In this paper we have studied the use of an interference aware IBDFE for the uplink of LTE-Advanced. It was shown through link level simulations that the interference aware IBDFE achieves substantial performance gains over the conventional IBDFE and linear IRC detector in time dispersive channels with strong cochannel interference. It was shown through system level simulation results that the use of the iterative aware receiver achieves additional throughput gains over the conventional IBDFE. However, the gains obtained depend on the schedulers employed and on the number of receiving antennas.

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