Interference Suppression Technique using Edge-removal Filter, Nulling Filter and Turbo Equalizer for Single Carrier Based Broadband Wireless Transmission

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Abstract—This paper proposes an interference suppression technique using edge-removal filter in the transmitter, as well as, nulling filter and turbo equalizer in the receiver for carrier interferometry (CI) based one-cell reuse single-carrier time division multiple access (TDMA) systems. In the proposed system, the desired signals in the reference cell are interfered by interference including adjacent-channel interference (ACI), co-channel interference (CCI) and intersymbol interference (ISI). At the transmitter, a CI technique is employed to generate CI signal which is equivalent to single-carrier signal with its roll-off factor of zero. After that, ACI components are eliminated by edge-removal filter. At the receiver, the received signal is transformed into frequency-domain signal by a fast Fourier transform (FFT). Co-channel interference (CCI) from adjacent cell is suppressed by applying a frequency-domain nulling filter. Then a soft canceller with minimum mean square error (SC/MMSE) based turbo equalizer is utilized to compensate for channel induced intersymbol interference (ISI) as well as extra ISI produced by the nulling filter. Computer simulation confirms that the proposed scheme can effectively suppress ACI, CCI and ISI.

Keywords—interference suppression; carrier interferometry; edge-removal filter; nulling filter; turbo equalizer

I. INTRODUCTION

For broadband wireless access systems, orthogonal frequency division multiplexing (OFDM) is capturing many spotlight due to its multipath immunity as well as its flexibility for radio resource management in both time and frequency domains. However, due to its drawback in high peak to average power ratio (PAPR), single carrier transmission is capturing spotlight again, especially for the uplink transmission in broadband wireless access systems.

In the single carrier transmission systems, unlike the adaptive modulation introduced OFDM-based systems, improvement of robustness to co-channel interference (CCI) and adjacent channel interference (ACI) is a challenge for one-cell reuse single-carrier transmission systems. To solve this problem, we have proposed an interference suppression algorithm based on frequency-domain signal processing. In the frequency-domain signal processing, the received signal is, first, transformed to the frequency-domain signal format using fast Fourier transform (FFT), interference components are suppressed using the frequency-domain filter and then signal is transformed back to the time-domain signal using inverse FFT (IFFT). The benefit of frequency-domain interference suppression is that it has essentially the same low complexity as OFDM system. In our former work [1], the frequency-domain filter, namely nulling filter, has been proposed to suppress interference at the receiver side. Moreover, a soft canceller with minimum mean square error (SC/MMSE) based turbo equalizer [2, 3] is utilized to compensate for channel induced intersymbol interference (ISI) and extra ISI produced by the nulling filter. In this paper, we will propose an algorithm to further suppress adjacent-channel interference (ACI) by introducing edge-removal filter which conducts in the transmitter side. Edge-removal filter will suppress potential ACI components by omitting both edges of the transmit spectrum before transmission. Moreover, transmit power allocated to the removed spectrum is reallocated to the rest of the spectrum components so that no transmit power loss arises. Therefore, ACI components would not be included in the transmitted signals. At the receiver, CCI suppression using the nulling filter and ISI compensation using SC/MMSE turbo equalizer could also be employed.

II. PROPOSED SYSTEM

A. One-cell Reuse Single-carrier TDMA Systems

This paper assumes one-cell reuse TDMA systems in the uplink, where the desired signal in the reference cell would be interfered by ACI, CCI, and ISI as shown in Fig. 1. The signals from other users in the same cell would cause ACI because adjacent subcarriers could be assigned in the same cell, resulting in the mutual overlaps in the spectra if carrier frequency jitter arises. Even if the ratio of overlapped spectrum is not so large, difference in power levels between the desired signals and interference signals might severely degrade the performances. In addition to the ACI, reuse of the frequency band in the adjacent cell would cause CCI and multipath fading would lead to the ISI effect.
Figure 1. One-cell reuse cellular system for uplink

B. Interference Suppression Algorithm

The transmitter and receiver configuration of the proposed system is depicted in Fig. 2. For each user, signal is transmitted from one antenna to $M$-element receive antennas. At the transmitter, the data bit sequence is first encoded, interleaved and fed to a modulator to generate a BPSK symbol sequence. After modulation, CI signal generation process is operated.

In our previous work, we proposed the scheme for interference suppression that employs the nulling filter to suppress both ACI and CCI in which all processes have been done in the receiver side. In this paper, we propose another method to eliminate the ACI effect by suppressing it at the transmitter side. Configuration of this algorithm is illustrated in Fig. 2 (a). After CI-based single carrier baseband signal is generated, frequency components located at both edge of spectrum is suppressed to remove potential ACI components. Cyclic prefix (CP) is appended at the beginning of each block of CI symbols before quadrature modulation. Moreover, transmit power allocated to the removed spectrum components is reallocated to the rest of the spectrum so that no transmit power loss arises.

The structure of receiver is shown in Fig. 2 (b). After quadrature demodulation, CP is removed from the received block to obtain only the sequence of $N_b$ data symbols. Then, zero-suffix padding is conducted to prevent interference which will be caused by the nulling filter. In this process, 0’s samples of length $N_s$ are appended at the end of the sequence of the received data block. The resulting received blocks then consists of $N_r = N_b + N_s$ symbols. The resulting $N_r$ symbol sequence is converted from serial to parallel and then converted to a frequency-domain signal by the $N_r$-point FFT operation. At this stage, signal to interference plus noise power ratio (SINR) of each frequency component is measured so that nulling filter can utilize these SINR values to null out interference in a certain amount of frequency components having low SINR. In this process, frequency components severely interfered by CCI are nulled out. The nulling filter output signal is transformed back to the time domain signal by the IFFT and is converted from parallel to serial. $N_s$ zero-suffix samples are then removed to obtain the signal block of length $N_b$. If the number of received antennas ($M$) is two or more, the above mentioned process will be done in each branch.

Let the CI-based single carrier baseband signal sequence is denoted by $\{s(t); t=0,\ldots,N_b-1\}$, where $t$ is symbol time index. At the transmitter, this signal sequence is fed to the edge-removal filter to suppress the ACI. First, time-domain signal is converted to frequency-domain signal by FFT operation, given by

$$S(k) = \sum_{t=0}^{N_b-1} s(t) \exp(-j2\pi \frac{t}{N_b}), \quad (1)$$

$k = 0,\ldots,N_b-1$ denotes frequency component index.

Then, the edge-removal filter will remove both edges of the frequency-domain signal. Hence, frequency characteristic of the edge-removal filter, denoted by $W^{ed}(k)$, will be set to zero during the ACI band. The output sequence of the edge-removal filter is

$$\hat{S}(k) = W^{ed}(k)S(k). \quad (2)$$

By applying IFFT operation, the output sequence in time-domain is obtained as

$$\hat{s}(t) = \frac{1}{N_b} \sum_{k=0}^{N_b-1} \hat{S}(k) \exp(j2\pi \frac{k}{N_b} t). \quad (3)$$

Figure 2. Transmitter and receiver configuration.
The signal in (3) is transmitted through fading channel. At the receiver, discrete-time received signal of the mth receive antenna is

\[ r_m(t) = \sum_{i=0}^{L-1} h_m^d(i) s(t-i) + \sum_{i=0}^{L-1} h_m^i(i) s(t-i) + v_m(t). \]  

(4)

where \([i(t); t=0,1,\ldots,N_m-1]\) denotes CCI signal sequence from the outside cell, \(h_m^d(t)\) and \(h_m^i(t)\) are discrete-time channel impulse responses at the mth receive antenna for the transmitted signal \(s(t)\), and that of the interference signal \(i(t)\), respectively. \(v_m(t)\) is additive white Gaussian noise (AWGN). L denotes channel memory length which is assumed to be identical for both desired signal and interference signal.

The time-domain received signal in (4) is converted again into frequency-domain signal. Then, the CCI components will be suppressed in frequency domain utilizing frequency-domain nulling filter. Frequency-domain representation of the received signal in (4) can be expressed as

\[ R_m(k) = H_m^d(k)\hat{S}(k) + H_m^i(k)I(k) + V_m(k). \]  

(5)

The nulling filter will suppress CCI components by multiplying zero to some specific frequency components of the received signal, which is equivalent to null out the components according to the measured signal to interference plus noise power ratio (SINR), whereas the other frequency components are kept the same. Let us assume that the number of frequency components to be nulled out be \(N_{nu}\), frequency components having the lowest \(N_{nu}\) SINR are nulled out, and frequency index of the nulled-out components be \(k_i (i=1,2,\ldots,N_{nu})\). The output of the nulling filter can then be expressed as

\[ \tilde{R}_m(k) = W_{mu}^m(k)R_m(k), \]  

(6)

where \(W_{mu}^m(k)\) is tap weight of the nulling filter [1].

From (2) and (5), \(\tilde{R}_m(k)\) in (6) can be rewritten as

\[ \tilde{R}_m(k) = H_m^d(k)W_{mu}^m(k)\hat{S}(k) + H_m^i(k)W_{mu}^m(k)I(k) + W_{mu}^m(k)V_m(k). \]  

(7)

where \(H_m^x(k) = H_m^x(k)W_{ed}^x(k)W_{ed}^x(k)\) for \(x = d, i\).

It is seen from (8) that the resulting filter response could be calculated from the product of channel response, edge-removal filter response and nulling filter response. Although ACI and CCI signals could be removed in this stage, but \(\tilde{R}_m(k)\) would include the degradation due to the ISI caused by edge-removal and nulling filtering. To compensate for the ISI effect, SC/MMSE turbo equalizer will be utilized after suppressing CCI signal by nulling filter.

### III. Simulation Results

The performance of the proposed scheme has been evaluated by computer simulation. Simulation parameters are as summarized in Table I. For simplicity of our analysis, we will assume that the desired signal in the reference cell (desired signal) is interfered by an interference signal (undesired signal) with a certain average desired to undesired signal power ratio (DUR).

Figure 3 shows the BER versus \(E_b/N_0\) performances in the case that desired signal power to CCI signal power ratio (SCCIR) equals to 0 dB and desired signal power to ACI signal power ratio (SACIR) equals to 0 dB. It is seen that the proposed algorithm can effectively suppress the ACI and CCI. When the ACI suppression performances are compared between the transmitter processing type and the receiver processing type, the transmitter processing type gives slightly better performances. Moreover, the algorithm that suppresses ACI at transmitter side together with transmit power control gives the best performance. In the transmit power control algorithm, after ACI components are suppressed by omitting both edges of the transmit spectrum, transmit power allocated to the removed spectrum is reallocated to the rest of the spectrum components. This algorithm has two potential advantages over ACI suppression algorithm at receiver side. One advantage is that ACI components are eliminated before transmission, therefore ACI components would not be included in the transmitted signal. The other advantage is that transmit power loss would not occur.

BER performances for SCCIR of -5 dB are depicted in Fig. 4. In this case, the desired signals are severely interfered by ACI signals. As seen in the figure, the system without any interference suppression faces bad performances, while the proposed schemes show very good performances. This emphasizes the effectiveness of the proposed scheme for interference suppression.

<table>
<thead>
<tr>
<th>TABLE I.</th>
<th>SIMULATION PARAMETERS</th>
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</thead>
<tbody>
<tr>
<td>Block length ((N_f))</td>
<td>256 symbols</td>
</tr>
<tr>
<td>Zero-suffix ((N_s))</td>
<td>256 symbols</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK</td>
</tr>
<tr>
<td>Encoder</td>
<td>convolutional code ((R = 1/2, K = 3))</td>
</tr>
<tr>
<td>Number of antennas ((N_{tx}, N_{rx}))</td>
<td>1:4</td>
</tr>
<tr>
<td>Channel model</td>
<td>4-path Rayleigh Fading</td>
</tr>
<tr>
<td>Number of subcarriers ((N_c))</td>
<td>256</td>
</tr>
<tr>
<td>FFT point ((N_f))</td>
<td>512</td>
</tr>
<tr>
<td>Edge-removed components ((N_{ed}))</td>
<td>8</td>
</tr>
<tr>
<td>Nullled components ((N_{nu}))</td>
<td>256</td>
</tr>
<tr>
<td>Decoder</td>
<td>Log-MAP</td>
</tr>
<tr>
<td>Num. of decoding iteration</td>
<td>4</td>
</tr>
<tr>
<td>Channel estimation</td>
<td>Perfect</td>
</tr>
</tbody>
</table>
The influence of the number of ACI components on the BER performance has also been investigated as depicted in Fig. 5. The number of ACI components is vary from 0 (no ACI case) to 64 frequency components. It is seen that increase in ACI components results in degradation of BER performance and when ACI components become 64 frequency components the system faces very bad performance.

IV. CONCLUSION

This paper has proposed an interference suppression algorithm employing frequency-domain edge-removal filter and nulling filter combined with SC/MMSE turbo equalizer. ACI effects are suppressed at transmitter by the edge-removal filter before transmission while CCI effects are suppressed by the nulling filter at the receiver. Although the frequency-domain filter produces extra ISI to the received signals, the SC/MMSE turbo equalizer applied after the filter can compensate for this ISI as well as ISI induced by the fading channel. Computer simulation confirms that the proposed system can effectively suppress the effect of interference signals especially when interference signal power is high.

REFERENCES