LOW COMPLEXITY DECISION DIRECTED CHANNEL TRACKING FOR MIMO WLAN SYSTEM

*Ying Chen, Dhammika Jayalath, Thushara, Abhayapala**

Research School of Information Science and Engineering
The Australian National University
Email: Ying.Chen@rsise.anu.edu.au, {Dhammika.Jayalath, Thushara.Abhayapala}@anu.edu.au

ABSTRACT

It is expected that the next generation wireless local area networks will be predominantly based on MIMO-OFDM physical layer. The performance of coherent MIMO-OFDM based systems critically depends on the availability of accurate channel estimations. Preambles, at the beginning of each packet, are used to estimate the channels in IEEE 802.11n Systems. However, in mobile communication, when the channel is time varying, the channel variations within a given packet increases the packet error rate (PER) in the system. So the channel variations have to be tracked by the receiver. This paper proposes a low complexity channel tracking scheme for 802.11n systems to improve the PER. The delay introduced by the channel tracking scheme is within the acceptable limits.

1. INTRODUCTION

Ever increasing demand for faster wireless connection at any time and anywhere drives the development of high capacity wireless networks. Orthogonal Frequency Division Multiplexing (OFDM), which provides robustness against multipath fading, and Multiple Input Multiple Output (MIMO) technique, which guarantees higher channel capacity are potential candidates for the physical layer of high speed wireless networks. With the commercial success of 802.11g, new WLAN standard with higher data rate is in the agenda. Most of the proposals for these new standards use a combination of MIMO and OFDM [1].

It is a challenge to provide a reliable WLAN connectivity for a mobile user. WLAN channel is assumed to be stationary within the length of the packet and estimated only at the beginning of each packet using a preamble. Therefore WLAN systems cannot operate successfully in time varying channels.

Some attempts to address this problem can be seen in the open literature. Pilot assisted and decision directed schemes are commonly used for channel tracking in OFDM based communication systems. In pilot assisted channel estimation schemes, known pilot tones are inserted in each OFDM symbol. Adaptive filters can be used to estimate the changes in their pilot tones and interpolate them to estimate the channel response to the whole band[2][3]. Refernce[4], shows that 4 pilot tones in 64 subcarriers in WLAN systems are not sufficient for pilot assisted channel tracking. It proposes to swap the pilot tones positions in OFDM symbols to track to whole band. But these changes are not compatible with the WLAN standard. Decision Directed Equalization (DDE) can also be used for channel tracking. The Decision Directed channel-tracking schemes had been studied for Single Input and Single Output (SISO) system in [5][6]. Decoded data are used for channel tracking in [5]. The decoded data feedback causes a large delay because of the viterbi decoder. The low complexity decision feedback tracking, proposed in [6], does not consider MIMO system.

In this paper, we propose a low complexity and low delay decision feedback channel tracking method for 802.11n based MIMO OFDM system. We extend the reduced complexity approach presented in [6] to MIMO case. Simulation results show that the proposed method gains at least 2dB PER enhancement at 50km/h, and makes the system working on acceptable levels even for 120km/h. The paper is arranged as follows: Section 2 describes the low complexity decision directed channel tracking scheme for SISO system; while MIMO interference cancellation is presented in Section 3 and the simulation result based on 2×2 802.11n MIMO-OFDM system is present in Section 4.

2. THE LOW COMPLEXITY DECISION DIRECTED CHANNEL TRACKING FOR SISO

The basic structure of the decision derived channel tracking is shown in Fig 1. In the OFDM system, if the source data

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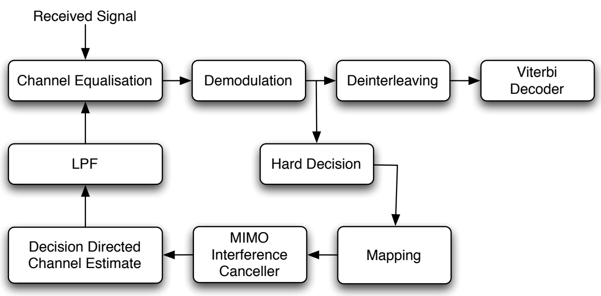

Fig. 1. Structure of low complexity Decision Directed Equalization

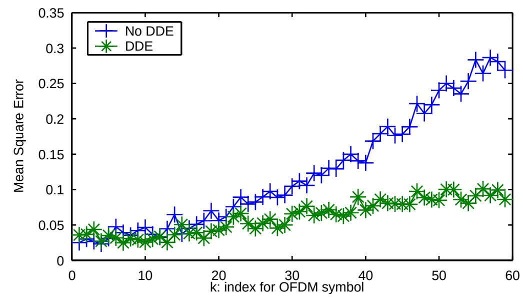

Fig. 2. Mean square error of system without Decision Direct Equalization(DDE) and with DDE.

is given by the vector $\mathbf{X}$, then after IFFT, the transmitted time domain signal $\mathbf{x} = \text{IFFT}(\mathbf{X})$. $\text{IFFT}(\cdot)$ denotes the inverse fast Fourier transform operation. In this paper, time dependence of $\mathbf{x}$ is omitted for convenience. A cyclic prefix will be inserted to $\mathbf{x}$ before transmitting through the channel. The received vector $\mathbf{y} = \mathbf{h} \otimes \mathbf{x} + \mathbf{n}$, where $\mathbf{h}$ is the channel impulse response vector, $\mathbf{n}$ is a vector of Additive White Gaussian Noise (AWGN), and $\otimes$ denotes the convolution operation. In the receiver, after removing the cyclic prefix, received data is converted back to the frequency domain. The frequency domain received data $\mathbf{Y} = \text{FFT}(\mathbf{y})$ is:

$$\mathbf{Y} = \mathbf{H}\mathbf{Y} + \mathbf{N} \tag{1}$$

where $\mathbf{N} = \text{FFT}(\mathbf{n})$, and $\mathbf{H} = \text{FFT}(\mathbf{h})$. Let $\mathbf{Y_0}$ be the received data corresponding to the long preamble $\mathbf{X_{LP}}$, then the initial channel estimation is:

$$\mathbf{\hat{H}_0} = \frac{\mathbf{Y_0}}{\mathbf{X_{LP}}} = \mathbf{H_0} + \frac{\mathbf{N_0}}{\mathbf{X_{LP}}} = \mathbf{H_0} + \mathbf{N'_0} \tag{2}$$

where $\mathbf{N'_0} = \frac{\mathbf{N_0}}{\mathbf{X_{LP}}}$, and division denotes the element by element division. Without Decision Directed Equalization (DDE), for the k^{th} OFDM, $\mathbf{\hat{H}_0}$ is taken as an estimation for $\mathbf{H_k}$, then we get the estimation of k^{th} transmitted data $\mathbf{X_k}$ is:

$$\mathbf{\hat{X}_k} = \frac{\mathbf{H_k X_k} + \mathbf{N_k}}{\mathbf{\hat{H}_0}} = \frac{\mathbf{H_k}}{\mathbf{H_0} + \mathbf{N'_0}}\mathbf{X_k} + \mathbf{N''_k} \tag{3}$$

where $\mathbf{N''_k} = \frac{\mathbf{N_k}}{\mathbf{H_0}+\mathbf{N'_0}}$. The corresponding estimation error between $\mathbf{X_k}$ and $\mathbf{\hat{X}_k}$ is:

$$\varepsilon_1(\mathbf{k}) \triangleq \mathbf{X_k} - \mathbf{\hat{X}_k} = (\mathbf{1} - \frac{\mathbf{H_k}}{\mathbf{H_0} + \mathbf{N'_0}})\mathbf{X_k} - \mathbf{N''_k} \tag{4}$$

If we use DDE in the system, without iteration, the estimation of $\mathbf{H_k}$ is based on the feedback of $(k-1)^{th}$ OFDM data, $\mathbf{\hat{X}_{k-1}}$. If we assume $\mathbf{\hat{X}_{k-1}} \approx \mathbf{X_{k-1}}$, the estimation of $\mathbf{H_k}$ is:

$$\mathbf{\hat{H}_k} = \mathbf{H_{k-1}} + \frac{\mathbf{N_{k-1}}}{\mathbf{X_{k-1}}} = \mathbf{H_{k-1}} + \mathbf{N'_{k-1}}. \tag{5}$$

Then using $\mathbf{\hat{H}_k}$ in (1), the estimation of $\mathbf{X_k}$ is:

$$\mathbf{\hat{X}_k} = \frac{\mathbf{H_k X_k} + \mathbf{N_k}}{\mathbf{\hat{H}_k}} = \frac{\mathbf{H_k}}{\mathbf{H_{k-1}} + \mathbf{N'_{k-1}}}\mathbf{X_k} + \mathbf{\overline{N}''_k} \tag{6}$$

where $\mathbf{\overline{N}''_k} = \frac{\mathbf{N_k}}{\mathbf{H_{k-1}}+\mathbf{N'_{k-1}}}$. Note that $\mathbf{\overline{N}''_k}$ has the same PDF as $\mathbf{N''_k}$. The corresponding estimation error between $\mathbf{X_k}$ and $\mathbf{\hat{X}_k}$ is:

$$\varepsilon_2(k) = \mathbf{X_k} - \mathbf{\hat{X}_k} = (\mathbf{1} - \frac{\mathbf{H_k}}{\mathbf{H_{k-1}} + \mathbf{N'_{k-1}}})\mathbf{X_k} - \mathbf{\overline{N}''_k}. \tag{7}$$

From (4) we derive the Mean Square Error(MSE) for system without DDE is:

$$E\{|\varepsilon_1^2(k)|\} = E\{|((\mathbf{1} - \frac{\mathbf{H_k}}{\mathbf{H_0} + \mathbf{N'_0}})\mathbf{X_k} - \mathbf{N''_k})^{\mathbf{2}}|\} \tag{8}$$

where $E\{\cdot\}$ denotes mathematical expectation. Because $\mathbf{N''_k}$ is Gaussian with variance μ^2, and $\mathbf{N''_k}$, $\mathbf{X_k}$ and $\mathbf{1} - \frac{\mathbf{H_k}}{\mathbf{H_0}+\mathbf{N'_0}}$ are independent of each other. MSE can be written as:

$$E\{|\varepsilon_\mathbf{1}{}^2(k)|\} = E\{(\mathbf{1} - \frac{\mathbf{H_k}}{\mathbf{H_0} + \mathbf{N'_0}})^2\} + E\{|\mathbf{X_k}|^\mathbf{2}\} + \mu^2. \tag{9}$$

Similar, the MSE for system with DDE can be written as:

$$E\{|\varepsilon_2^2(k)|\} = E\{(\mathbf{1} - \frac{\mathbf{H_k}}{\mathbf{H_{k-1}} + \mathbf{N'_{k-1}}})^2\} + E\{|\mathbf{X_k}|^\mathbf{2}\} + \mu^2. \tag{10}$$

Note that the difference between $E\{|\varepsilon_1^2(k)|\}$ and $E\{|\varepsilon_2^2(k)|\}$ is the first term of (9) and (10). Because H_k is a slow varying variable, $\mathbf{H_{k-1}}$ is much closer to $\mathbf{H_k}$ than $\mathbf{H_0}$ is. Thus, we have $E\{(\mathbf{1} - \frac{\mathbf{H_k}}{\mathbf{H_0}+\mathbf{N'_0}})^2\} > E\{(\mathbf{1} - \frac{\mathbf{H_k}}{\mathbf{H_{k-1}}+\mathbf{N'_{k-1}}})^2\}$ and $E\{|\varepsilon_1^2(k)|\} > E\{|\varepsilon_2^2(k)|\}$. From simulation, we can calculate the mean squares of $\varepsilon_1(k)$ and $\varepsilon_2(k)$. The result is shown in Fig 2: With DDE tracking the channel, the mean square error is much lower than the one without DDE.

3. DDE EXTENSION TO MIMO

For a MIMO system with M_t transmitter antennas and M_r receiver antennas, the received matrix $\mathbf{Y_{j,k}}$ on the j^{th} receive antenna, for the k^{th} OFDM symbol can be written as:

$$\mathbf{Y_{j,k}} = \sum_{i=1}^{M_t} (\mathbf{H_{ji,k}X_{i,k}}) + \mathbf{N_k} \tag{11}$$

where $\mathbf{H_{ji,k}}$ is the channel response vector from i^{th} transmitter antenna to j^{th} receiver antenna for k^{th} OFDM data on i^{th}, $\mathbf{X_{i,k}}$ is the data vector at i^{th} transmitter, and $\mathbf{M_k}$ is the noise matrix for the k^{th} OFDM symbol. When using DDE, the estimation of $\mathbf{H_{jv,k}}$, in which v is the v^{th} transmitter:

$$\mathbf{\hat{H}_{jv,k}} = \frac{\mathbf{Y_{j,k}} - \sum_{\binom{i=1}{i \neq v}}^{M_t} (\mathbf{\hat{H}_{ji,k-1}} \times \mathbf{\hat{X}_{i,k}}) - \mathbf{N_k}}{\mathbf{\hat{X}_{v,k}}} \tag{12}$$

Since for each $\mathbf{Y_{j,k}}$, only one $\mathbf{\hat{H}_{jv,k}}$ can be updated without iteration. A directly way to solve this, it is to skip the update for other $\hat{H}_{ji,k}$ in one OFDM symbol to reduce the complexity. If we divide the OFDM symbol into groups with each group including M_t continuous OFDM symbol, then for the v^{th} OFDM symbol in each group, we will only update the $\mathbf{\hat{H}_{jv,k}}$ using (10). And all the $\mathbf{\hat{H}_{ji,k}}$ will be updated after M_t continuous OFDM symbols. This approach is the simplest one for updating the channel response, but the performance will be effected by the noise and the tracking ability will degrade with the increasing of M_t. Another more complexity way is to have M_t time iterations for one OFDM symbol so to update every $\mathbf{\hat{H}_{jv,k}}$, which costs $M_t - 1$ times delay of the non-iteration method and large hardware complexity. Since even for a speed as 120km/h, the Doppler frequency will be 267Hz and for IEEE 11n proposal [1], two antennas transmitter is mandatory, with the option to scale to 4 antennas. And the OFDM symbol rate is 20MHz/80=250kHz, so even for 4 antenna system, the $\hat{H}_{jv,k}$ updating frequency is 62.5kHz, much larger than the doppler frequency. This simple approach will be adequate for the 802.11n proposal.

4. SIMULATION RESULT

In the simulation, we used the mandatory system with 2×2 MIMO following the 802.11n proposal. The simulation is performed by a full system, including all parts such as scramble, interleaving and channel coding, with 20MHz bandwidth. And to test the implementation possibility of the tracking scheme, simulation with frequency offset and sampling error, as practical system, also been conducted.

To simulated the channel tracking method in a practical way, we use non-perfect initial channel estimation $\mathbf{\hat{H}_{ji,0}}$, which is estimated by the system on long preamble. The channel model used in the simulation is ETSI Multipath channel C[7] with Doppler shift added to each multipath taps using Jake's model. All the 'v' shown in the figures are the maximum speed. Simulations are carried out on 16QAM modulation with 1/2 convolutional code, for which the corresponding data rate for each transmit antenna is 24Mbps, and two antenna is total 48Mbps. The packet length shown below is the total packet length of 2 transmit antenna. And the performance is evaluated by packet error rate (PER).

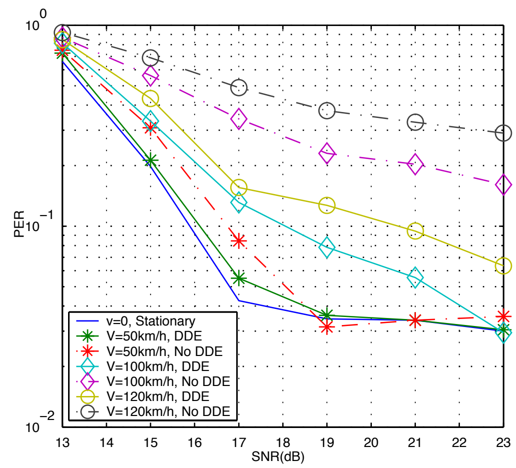

Fig. 3. PER result of 16QAM for 2×2 system in Channel model C, datalength=1000 bytes totally for two transmit antenna per frame.

In Fig 3, the solid line without any mark is the performance of a stationary system; the solid lines with different mark are the results of tracking system; and dash lines with different marks are results for system without tracking. According to the standards, the $PER = 10^{-1}$ generally viewed as a valid working point. For the 50km/h speed, the system with channel tracking are almost gain the same performance with the stationary system. For 100km/h speed, at the $PER = 10^{-1}$, the tracking scheme only lose about 2dB SNR to the stationary simulation. Even for 120km/h, with the tracking scheme, the system still can reach the working points, but without tracking scheme, for speed as 100km/h and 120km/h, the performance goes flat above $PER = 10^{-1}$. So the system with tracking scheme can work even for a 120km/h speed, but the system without tracking can't work well for speed larger than 100km/h.

In Fig 4, the packet length is extend to 1400 byte. Still with the speed at 50km/h, the system tracking system achieves almost same performance with stationary situation. Comparing Fig 3 and Fig 4, we observe that the longer the data the worst the performance in time varying channel. The system with tracking scheme still can achieve a performance to PER nearly 10^{-1} under 100km/h, but can not work prop-

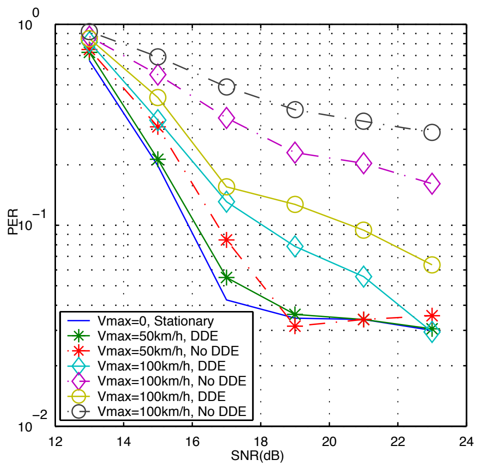

Fig. 4. PER result of 16QAM for 2×2 system in Channel model C, datalength=1400byte totally for two transmit antenna per frame.

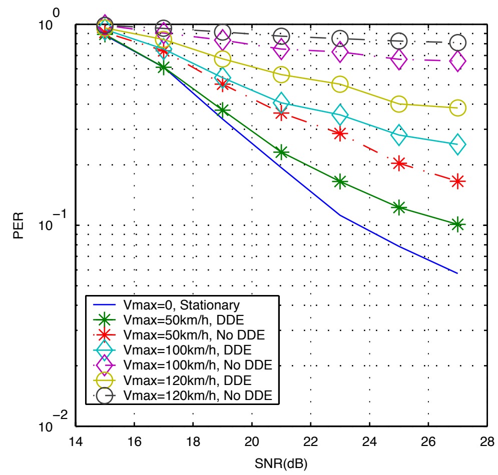

Fig. 5. PER result of 16QAM for 2×2 system in Channel model C, datalength=1400 bytes totally for two transmit antenna per frame, frequency offset=100kHz, sampling error=50ppm.

erly under 120km/h. The performance of system with out tracking is almost flat above $10^{-0.7}$.

In Fig 5, the simulation is done under 100kHz frequency offset and 50ppm sampling error, which are similar to the environment that the system works with in practical situations. The result shows that the tracking scheme works well coexisting with frequency offset and sampling error.

5. CONCLUSION

In this paper, we proposed a low complexity and low delay tracking method for IEEE 802.11n based MIMO OFDM system. The increase of the operations are, taking 2×2 system 16QAM modulation as example, several plus or minus operations, four 2 bits divider for I,Q at receiver antenna 1 and 2 respectively and a constellation block. Even if no blocks shared with the transmitter, the increase of circuits is quit small. Because the update estimation result will be used for next OFDM symbol, and no actually iteration there, when the tracking is performed parallel with deinterleaver and FFT, there is nearly no delay caused by the tracking. From the simulation results, the performance enhancement enable the system to work well in 50km/h speed, still achieving acceptable performance for 100km/h speed, and even for 120km/h in some situations. Further, with frequency offset and sampling error, the tracking method can achieve at least 2dB enhancement in performance.

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