A SPECIAL OPEN-LOOP TRANSMIT ANTENNA SELECTION MODE IN THE SC-FDMA SYSTEMS FOR 3G LTE

Jin Liu, Liang Wang, Mingli You and Pingping Wen
Research and Innovation Center
Alcatel Shanghai Bell Co., Ltd.
Shanghai, P.R.China
Email: {jin.a.liu, liang.a.wang, mingli.you, pingping.wen}@alcatel-sbell.com.cn

ABSTRACT

This work investigates the open-loop transmit antenna selection (OL-TAS) modes in the uplink of the long term evolution (LTE) of 3G standard. The uplink subframe is composed of two slots based on single-carrier frequency-division multiple access (SC-FDMA) system. The conventional OL-TAS mode switches the antennas alternatively for every slot. A non-neglectable performance loss is resulted from the hardware switch of transmit antennas. To reduce the number of antenna switches, a special OL-TAS mode is proposed in this work for LTE uplink, where the antenna switch is only performed in the middle of the subframe. Thus the loss of antenna switches reduces half compared to the conventional mode. In addition, it provides more advantageous interpolation for channel estimation algorithms, since every two slots are transmitted consecutively at one antenna. Benefit from the interpolation, the special OL-TAS mode achieves remarkable performance gain, especially at high velocities.

I INTRODUCTION

It is well known that the Third-Generation (3G) mobile systems based on WCDMA radio access technology are being deployed on a broad scale all around the world. To ensure the continued competitiveness of 3G technology for the future, the Third Generation Partnership Project (3GPP) has begun specifying the long-term evolution (LTE) of 3G cellular systems. The fundamental aim of this evolution will be met by achieving the performance leaps of LTE in data rates, coverage, latency and system capacity. An evolved link layer and an orthogonal frequency-division multiplexing (OFDM)-based radio access technology that supports advanced multi-antenna solutions are believed to be helpful to fulfill the stated targets.

OFDM is a very promising technique for signaling at high data rates over the wireless multipath channel that can overcome inter-symbol interference (ISI) problem. For the uplink transmission of LTE, the single-carrier frequency-division multiple access (SC-FDMA) is profitable to maximize coverage due to its power efficient property.

To reduce the complexity of user terminals, two transmit antennas and only one radio frequency (RF) chain are defined in the current Release 8 of LTE. As a result, the single-user transmit diversity techniques except the transmit antenna selection (TAS) are excluded from the Release 8 of LTE uplink. TAS is adopted as a baseline for its low user equipment (UE) complexity. The open-loop transmit antenna selection (OL-TAS) becomes an important uplink multiple-input multiple-output (MIMO) technology to be investigated.

In the conventional OL-TAS mode, the antennas are switched alternatively for every slot. It is known from [1] that there is a non-neglectable performance loss for TAS resulted from the antenna switches. To reduce the number of antenna switches, a special OL-TAS mode is proposed in this work for LTE uplink, where the antenna switch is just performed in the middle of the subframe, i.e., the antenna switch in the edge of the subframe is left out. As a result, the loss of antenna switches in the novel OL-TAS mode reduces half compared to the conventional mode. Through the simulation results in Section IV, we find that the novel mode does not degrade the performance gain of OL-TAS. In addition, it can provide more beneficial interpolation for channel estimation (CE), which alleviates the CE deterioration for high UE velocity.

II LTE SC-FDMA SYSTEM MODEL

The LTE uplink system is a packet-based MIMO-SC-FDMA system with $M_t$ transmit and $M_r$ receive antennas, as described in [2], Section 9. The single-carrier transmission (SC-FDMA) with cyclic prefix (CP) can achieve uplink inter-user orthogonality and enable efficient frequency-domain equalization at the receiver side. In Release 8 of LTE, it is defined that $M_r = 2$ and only one RF chain is configured for uplink transmission. In this work, it is assumed that $M_r = 2$ for the purpose of simplified illustration. The transmitter and receiver of LTE uplink SC-FDMA system...
for OL-TAS scheme are shown in Figure 1 and Figure 2, respectively.

\[ f(k) = h(k)s(k) + n(k) \]  

where the two dimensional vector \( h(k) \) represents the frequency-domain channel coefficient at the \( k \)-th tone and the vector \( n(k) \) represents the additive white Gaussian noise (AWGN) with zero-mean and variance \( \sigma^2 \) per complex dimension. If the linear minimum mean square error (MMSE) detection is assumed, the multiplier bank coefficient of the detector is given by

\[ D(k) = [h^H(k)h(k) + \sigma^2]^{-1}h^H(k) \]  

and the detection output corresponds to a straightforward vector-vector multiplication according to

\[ \hat{s}(k) = D(k)y(k) \]  

followed by inverse DFT (IDFT). Thus the time-domain signal before demodulation at the \( n \)-th time instant is given by

\[ \hat{s}(n) = \mathcal{F}^{-1} \{ \hat{s}(k) \} = \frac{1}{K} \sum_{k=1}^{K} \hat{s}(k)e^{j\frac{2\pi}{K}(n-1)(k-1)} \]  

where \( \mathcal{F}^{-1} \{ \cdot \} \) denotes the IDFT.

### III Transmission Modes for OL-TAS

As stated in Section II, the subframe is composed of two slots in the LTE uplink SC-FDMA system. Every subframe conveys the information bits encoded by one turbo codeword. According to the period of antenna selection, the OL-TAS can be classified into inter-subframe TAS and intra-subframe TAS. For inter-subframe TAS, the antenna selection is performed on the edge of every subframe, i.e., all information signals encoded by one turbo codeword are transmitted from the same transmit antenna. In general, it is assumed that the channels from two transmit antennas possess the same statistical characteristics. Therefore, during a long term, it seems that the transmitted signals only pass through the channels from one antenna for inter-subframe OL-TAS. In view of that, the inter-subframe OL-TAS has nearly no performance gain over single-input multiple-output (SIMO) system with the same number of receive antennas. On the other hand, for the intra-subframe TAS, the antenna selection is performed on the edge of slot, i.e., the information signals encoded by one turbo codeword are transmitted from two transmit antennas. In one codeword, the information signals go through two sets of very different channels. As a result, a large of diversity gain is achieved by using turbo coding. Our attention is thereby focused on the intra-subframe OL-TAS.

#### A Conventional OL-TAS Mode-I

A conventional mode of intra-subframe OL-TAS is illustrated in Figure 3, where the antennas are switched alternatively for every slot. In the first subframe, the first slot is transmitted at the first antenna and the second slot is transmitted at the second antenna. In the second subframe, similarly the first slot is transmitted at the first antenna and the second slot is transmitted at the second antenna. The number of antenna switches within one subframe is two. It is known from [1] that there is a non-neglectable performance loss (approximately \( 0.5 \sim 0.7 \text{dB} \)) for TAS resulted from the antenna switches. Therefore, it is helpful to find an efficient OL-TAS mode which has little number of antenna switches.
In addition, the various OL-TAS modes have much different effect on the interpolation of CE. As shown in Figure 3, the long block in the middle of every slot is reserved to insert pilots for CE. The pilots located on the two discontinuous slots which are transmitted at the same antenna can be used for interpolation to increase the CE precision, as illustrated by the arrow headed arc in Figure 3. However, the CE is deteriorated by this interpolation at the high UE velocity, since the two slots at the same antennas are non consecutive and the time correlation between the channels through which the two slots are transmitted is very low.

B Special OL-TAS Mode-II

A special OL-TAS mode as depicted in Figure 4 is proposed in this work to reduce the number of antenna switches. In this special OL-TAS mode, the selected transmit antenna for the second slot of the first subframe remains for the first slot of the second subframe, i.e., the antenna switch is only performed in the middle of the subframe. Therefore, the number of antenna switches within one subframe is reduced to one. Correspondingly, the performance loss resulted from hardware antenna switch is halved. The special OL-TAS mode neither incurs any complexity increasing nor impairs performance gain of OL-TAS in theoretical since the structure of intra-subframe TAS is not changed. The simulation results are illustrated in Section IV.

IV SIMULATION RESULTS

The simulation results of the two OL-TAS modes based on LTE SC-FDMA system are discussed and compared in this section. All the curves are obtained by Monte Carlo simulation by using Matlab. The basic simulation parameters and assumptions are described in Table 1. The adopted channel model is the tapped delay line model with fixed correlation.
parameters [2] for Urban Macro scenario, which is a simplification of the extended Spatial Channel Model (SCME) accepted by 3GPP [5] for link level evaluation. At the UE transmitter, the pilots generated from Zadoff Chu sequences [6] are placed into the long block in the middle of every slot. Subsequently, the subcarrier mapping determines which part of the spectrum that is used for transmission by inserting a suitable number of zeros at the upper and/or low end, which is detailed in [2]. A localized mapping corresponds to the transmissions where the DFT outputs are mapped to consecutive subcarriers. For the 16QAM modulation \((m = 4)\) scheme with the coding rate of \(r = 1/3\), the code block size of 1280 bits could be transmitted within one subframe. At the receiver, the linear MMSE detection in frequency-domain is employed to tradeoff the inter-symbol interference (ISI) and noise power. The adopted CE algorithm is the typical least square (LS) [4] with linear interpolation in time-domain.

Figure 5 shows the BER performance of the two OL-TAS modes with ideal CE for different UE velocities of 30km/hr, 120km/hr and 350km/hr, respectively, where "Mode-I" denotes the conventional OL-TAS mode and "Mode-II" denotes the novel OL-TAS mode. As expected in Section III, under the assumption of ideal CE, the two OL-TAS modes have almost the same BER performance without considering the hardware switch loss of transmit antennas. Since the inter-subcarrier interference is not taken into account, the system can get more performance gain as the UE velocity increases. It is reasonable in view of the fact that the faster the channels vary, the more diversity gain the system achieves.

Figure 6 compares the two OL-TAS modes with real CE for velocity 120km/hr, 250km/hr and 350km/hr, respectively. It is assumed that the typical least square (LS) CE algorithm [4] are used for both OL-TAS modes. However, these two OL-TAS modes have different linear interpolation methods of pilots as illustrated in Section III. For low to moderate velocity up to 120km/hr, the two OL-TAS modes achieve similar performance without considering the antenna switch loss. But for high velocity such as 250km/hr and 350km/hr, the performance of the novel OL-TAS Mode-II is remarkably better than that of the conventional OL-TAS Mode-I. When the channels vary slowly, the linear interpolation at discontinuous slots for CE has not much effect on the system performance. However, when the channels vary very fast, the linear interpolation at discontinuous slots introduces much CE errors, which degrades the system performance significantly. These CE errors of OL-TAS Mode-I even lead to the infeasibility of the typical LS CE algorithm at the high velocity of 350km/hr. However, the typical LS is still available for the novel OL-TAS Mode-II in the same case of high velocity of 350km/hr. We note that in the case of real CE, the OL-TAS may have worse performance at high velocity than that at low velocity, which is different from the case of ideal CE. It is due to the fact that the CE deterioration overwhelms the diversity gain of intra-subframe OL-TAS at high velocity. However, due to the advantageous interpolation in the novel OL-TAS Mode-II, the CE deterioration does not overwhelms the diversity gain at the velocity of 250km/hr. Therefore, the novel OL-TAS Mode-II in the case of 250km/hr achieves similar even a little better performance compared with the case of 120km/hr.
V CONCLUSION

The TAS scheme is accepted as a baseline for uplink MIMO by LTE Release 8. It is very important to investigate the OL-TAS modes in SC-FDMA system due to its low complexity and remarkable performance gain. In this work, we propose a special OL-TAS mode for LTE uplink SC-FDMA system, which halves the performance loss due to the antenna switch and also offers the beneficial interpolation for improved CE precision over the conventional OL-TAS Mode-I. The simulation results also illustrate the advantage of the proposed OL-TAS Mode-II.

REFERENCES


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