A TRANSMIT DIVERSITY SCHEME WITH HIERARCHICAL TRANSMISSION FOR BROADCAST IN CELLULAR SYSTEMS

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ABSTRACT
Cyclic delay diversity (CDD) is an attractive approach to achieve spatial and multipath diversity. Its simplicity and conformance with current standards makes it desirable for orthogonal frequency division multiplexing (OFDM) systems. In this paper, we propose the transmission diversity scheme with hierarchical modulation for the broadcast service in the mobile communication system, where CDD is applied between the different cells and space-time block coding (STBC) or CDD is used inside the cell. A hierarchical modulation scheme is adopted in order to provide the layered transmission in the broadcast area with high frequency efficiency. Computer simulation results show that the proposed transmit diversity technique increase the diversity order greatly. Furthermore, this technique with hierarchical modulation scheme outperforms that with the common modulation scheme when different prioritized streams are transmitted.

I INTRODUCTION
The third generation partnership project (3GPP) has begun to standardize the long-term evolution (LTE) from 3G to beyond 3G system [1]. The fundamental aims of this evolution, to further improve service provisioning and reduce the user/operator costs, will be met through improved coverage and system capacity and by improving data rates and reducing latency. Due to its efficient usage of the available frequency bandwidth and robustness to frequency selective fading environments, OFDM as a modulation technique has been already selected for the downlink transmission in 3G LTE. Meanwhile, the multiple-input multiple-out (MIMO) technology will be combined with OFDM to achieve very high spectral efficiency and diversity gain.

Multimedia Broadcast/Multicast Service (MBMS) services will be provided also in 3G LTE system, and the soft combining should be supported for multi-cell broadcast assuming a sufficient degree of inter-cell synchronization [1]. Till now, transmitting the same symbol through the same resource (time and frequency) from multi-cells has been considered basically for multi-cell MBMS services. This achieves energy gain but cannot increase much diversity order by itself. So some forms of additional transmit diversity is expected to bring the significant benefit from multiple cells transmission [2][3].

Different base stations within the same network may have different number of antennas. When the soft combining is employed, this has to be taken into account for designing the multi-antenna schemes. These schemes should also be suitable for the scenarios where the mobile station only has the small number of antennas, e.g. 1 or 2. Furthermore, since more than one antennas (e.g. 2 or 4) may be available at the base station, it is still open question how/whether multiple antenna techniques can be used to further improve the performance and capacity of the MBMS within each cell. In the absence of any feedback from the mobile stations in MBMS, the potential candidates for MIMO could be an open-loop transmit diversity scheme.

However, MBMS service becomes bandwidth limited in an single frequency network (SFN) operation and therefore the high-order modulation techniques become attractive to improve the system throughput with open-loop transmit diversity scheme. Taking into account the transmit/receive diversity gains and the different channel conditions, there will be very large difference of the received signal-to-noise (SNR) between different mobile stations when broadcast in the cellular systems. Therefore, it is quite difficult to keep all the mobile stations with same service at anytime on anywhere under the common modulation. On the other hand, a single logical stream for broadcast service can be separated into base and enhancement layers. It can be interpreted as adding less time sensitive content on top of the core content. So the hierarchical modulation is very promising for broadcast because it offers a mechanism to provide multiple services related to the same logical content across the network, where the lower data rate service provided by a high priority (HP) base layer and higher data rate service provided by a lower priority (LP) enhancement layer [4].

Cyclic delay diversity (CDD) is a simple transmit diversity technique for coded OFDM systems with multiple transmit antennas and has high flexibility in antenna configuration [5]. In this paper, we propose to use the cyclic delay diversity for achieving the macro-diversity gain between different cells. For transmission scheme within each cell, the transmit diversity such as CDD and STBC scheme is applied because of its improvement in coverage and the flexibility of antenna configuration. In order to increase the system throughput and to support multiple services in the same stream, the hierarchical modulation is chosen for broadcast.

The reminder of this paper is organized as follows. After a brief description of the system model in Section II, the transmit diversity within each cell is described in Section III and the hierarchical modulation for broadcast presented in Section IV respectively. The simulation results are given in Section V. Finally our conclusion is drawn.

II SYSTEM MODEL
For broadcast/multicast services, multiple base stations in the same network usually transmit the same content. In this case,
a mobile station receives the broadcast/multicast transmissions from the base stations other than the primary base station in its serving cell. To enhance the quality of the broadcast/multicast service, the mobile station especially when in the cell edge can perform the soft combining across the base stations that transmit the content of interest. Cyclic delay diversity is a simple transmit diversity technique for coded OFDM systems with multiple transmit antennas. The increased frequency-selectivity caused by delay diversity can be picked up by the standard forward error control (FEC) decoder. We choose cyclic delay diversity (CDD) scheme between the different cells because it is flexible in terms of the antenna configuration. Also the common pilot for broadcast/multicast services can be applied when CDD is applied. All the cells are divided into \( N_{grp} \) cell groups to apply order-\( N_{grp} \) transmit diversity, e.g. \( N_{grp} = 3 \).

A block diagram of OFDM system with \( N_T \) transmit antennas in the multi-cell environment is shown in Fig.1. At each transmit antenna in each cell, the data stream is divided into \( N \) parallel substreams, termed as subcarriers. The signal of the \( k \)th subcarrier in the \( i \)th OFDM symbol block is denoted by \( X_i(k), 0 \leq k \leq N - 1, 0 \leq p \leq N_T - 1. \) An inverse discrete Fourier transform (IDFT) with \( N_c \geq N \) points is performed in each block. Then an cell-dependent cyclic delay \( \Delta(\mu) \) of cell group \( \mu, 0 \leq \mu \leq N_{grp} - 1 \) is inserted, resulting in the following CDD signal in transmit antenna \( p \) of the \( \mu \)th cell group:

\[
x_{i,p,k}^{(\mu)}(n) = x_i^{(p)}((n - \Delta(\mu))N_c) = \frac{1}{\sqrt{N_c}} \sum_{k=0}^{N-1} e^{-j2\pi k \Delta(\mu) N_c} X_i^{(p)} e^{-j2\pi mn} \tag{1}
\]

Usually the cyclic delay \( \Delta(\mu) \) between adjacent cell groups are set as equidistant delays.

\[
\Delta(\mu) = \Delta_{grp} \cdot \mu, 0 \leq \mu \leq N_{grp} - 1 \tag{2}
\]

where \( \Delta_{grp} \) is the cell-dependent delay parameter which can be chosen within the range \([0, N_c/N_{grp}]\).

The discrete Fourier transform (DFT) of a cyclically delayed signal \( x_{i,k}^{(p)}(n) \) in (1) translates to a phase shifted version of \( X_i^{(p)} \) in the frequency domain. Cyclic delays by \( \Delta(\mu) \) samples in the time domain correspond to the following phase shift between adjacent subcarriers:

\[
\varphi_{\mu} = \Delta(\mu) \frac{2\pi}{N_c} \tag{3}
\]

The equivalent CDD transmitted signal of antenna \( p \) in cell group \( \mu \) in the frequency domain can be expressed as

\[
X_{i,p,k}^{(\mu)} = X_i^{(p)} e^{-j\varphi_{\mu}} \tag{4}
\]

In order to achieve the transmit diversity gain inside one cell, the necessary space-time process will be taken on the signal before IDFT, which will be described further in the next section. Subsequently a cyclic prefix (CP) of length \( N_{CP} \) samples is added to avoid inter-symbol interference (ISI) before the signal is transmitted over multipath fading channel.

A frequency-selective Rayleigh fading channel with \( L \) non-zero taps, transmitted from antenna \( p \) to receive antenna \( q \), is considered. The channel impulse response remains unchanged during the \( th \) OFDM symbol interval and in the \( \mu \)th cell it can be expressed as

\[
h_{i,p,q}(n) = \sum_{l=0}^{L-1} \alpha_{l,p,q}^i \delta(n - \tau_{l,p,q}/T) \tag{5}
\]

where the \( th \) tap gain \( \alpha_{l,p,q}^i \) with propagation delay \( \tau_{l,p,q} \) is complex Gaussian random variable with zero mean and variance of \( \sigma_{l,p,q}^2 \) in the \( th \) OFDM block of the \( \mu \)th cell. And \( 1/T \) is the sampling rate of the system. All channel taps and all the antennas are assumed to be mutually uncorrelated.

At the receiver of each antenna branch in each cell, the CP is removed first and the received signals are transformed to the frequency domain by DFT. For broadcast/multicast services, multiple base stations in the same network usually transmit the same content. Thus, the received signal on the \( k \)th subcarrier at the \( q \)th, \( 0 \leq q \leq N_R - 1 \), antenna branch in one cell can be expressed as

\[
y_{i,k}^{(q)} = \sum_{p=0}^{N_T-1} X_i^{(p)} \sum_{\mu=0}^{N_{grp}-1} H_{i,p,k}^{(q,\mu)} e^{-j\varphi_{\mu}} + W_{i,k}^{(q)} \tag{6}
\]

where \( W_{i,k}^{(q)}(k) \) is the complex additive white Gaussian noise (AWGN) at the \( q \)th receive antenna with zero mean and variance of \( \sigma_{W_q}^2 \); \( H_{i,p,k}^{(q,\mu)}(k) = \sum_{l=0}^{L-1} \alpha_{l,p,q}^i e^{-j2\pi k N_c l/N} \) is the channel frequency response (CFR), transmitted from antenna \( p \) to receive antenna \( q \), on the \( k \)th subcarrier in the \( \mu \)th cell. The term \( \tilde{H}_{i,p,k}^{(q,\mu)}(k) \) can be viewed as the effective CFR of an equivalent MIMO channel in the multi-cell environment.

III Transmit diversity scheme

Besides the CDD scheme is applied between the different cells, the transmit diversity or spatial multiplexing schemes can be used within each cell to achieve more diversity gain or increase the system throughput. Considering the limited number of the
antennas at the mobile station, the transmit diversity scheme instead of spatial multiplexing scheme is selected as transmission scheme inside one cell for the flexibility of antenna configuration.

A CDD scheme

When the CDD is also used between the transmit antennas in the same cell, the cyclic delay \( \Delta_c^{(\mu)} = \Delta^{(\mu)} + \Delta^{(p)} \) will be inserted instead of the only cell-independent cyclic delay \( \Delta^{(\mu)} \), where \( \Delta^{(\mu)} = \mu \Delta_{\text{cell}} \), \( \mu, p \leq N_T - 1 \) is the antenna-dependent cyclic delay and its parameter \( \Delta_{\text{cell}} \) can be chosen within the range \([0, N_c/N_{\text{group}}/N_T] \). The signals transmitted from all the antennas are almost same except with the different cyclic delay so that the index of transmit antenna can be omitted, i.e. \( X_{i,k} = X_{i,k}^{(*)}, \forall p \leq N_T - 1 \). Therefore, the received signal on the \( k \)th subcarrier in the \( \mu \)th cell shown in (6) can be rewritten as

\[
Y_{i,k}^{(\mu)} = X_{i,k}^{(*)} \sum_{p=0}^{\frac{N_c}{N_{\text{group}}}-1} e^{-j2\pi \frac{p}{\frac{N_c}{N_{\text{group}}}}} \sum_{\mu=0}^{N_T-1} H_{i,j,k}^{[\mu,\mu]} e^{-j2\pi \frac{\mu p}{N_{\text{cell}}}} + W_{i,k}^{(\mu)} \tag{7}
\]

It can be seen that the cyclic delay diversity has transformed a MIMO channel into a SIMO channel with the increased frequency-selectivity, i.e. the spatial diversity is transformed into frequency diversity. Therefore, there is no improvement in the performance if without channel coding.

The receiver has the almost same structure as that for the conventional OFDM systems. We only have to estimate the equivalent SIMO channel frequency response \( H_{i,k}^{[\mu,\mu]} \) for coherent detection, not each separated CFR between the transmit antennas and receive antennas.

B STBC scheme

Due to the requirement of STBC principle, the quasi-static fading is assumed, i.e. the gains of the channels are constant over two OFDM block intervals. And the processes of STBC encoding and decoding is done with two OFDM block intervals. So here the time index for the effective CFR of an equivalent MIMO channel can be omitted for simplification, i.e. \( \tilde{H}_{i,k}^{(p,q)} = H_{i,k}^{(p)} = H_{i,k}^{(q)} \).

At the transmitter, the STBC encoding with \( N_T = 2 \) transmit antennas and code rate 1 is performed at each subcarrier. The STBC mapping scheme of the data symbol \( S_{i,k} \) to \( X_{i,k}^{(*)} \) at the \( k \)th, \( 0 \leq k \leq N_c - 1 \) subcarrier is shown in Table 1. After passing through the channel, the received signal on the \( k \)th subcarrier of the \( i \)th and \((i + 1)\)th OFDM block in the

\[
\begin{array}{c|c|c}
\text{time } i & \text{Antenna 0} & \text{Antenna 1} \\
\hline
S_{i,k} & S_{i+1,k} \\
\hline
-S_{i+1,k} & S_{i,k} \\
\end{array}
\]

\[
q^t \leq q \leq N_T - 1 , \text{ antenna branch as shown in (6) within 2 OFDM symbols intervals can be expressed as}
\[
[Y_{i,k}^{(q)}]_{i+1,k} = [\tilde{H}_{k}^{(q,\mu)}]_{i+1,k}^T [\tilde{S}_{i,k} \; \tilde{S}_{i+1,k}] + [W_{i,k}^{(q)} \; W_{i+1,k}^{(q)}] \tag{8}
\]

Then, (8) can be rewritten as follows:

\[
\begin{bmatrix}
Y_{i,k}^{(q)} & Y_{i+1,k}^{(q)}
\end{bmatrix} = \begin{bmatrix}
H_{k}^{(q,\mu)} & H_{k}^{(q,1)}
\end{bmatrix} \begin{bmatrix}
\tilde{S}_{i,k} \; \tilde{S}_{i+1,k}
\end{bmatrix} + \begin{bmatrix}
W_{i,k}^{(q)} \; W_{i+1,k}^{(q)}
\end{bmatrix} \tag{9}
\]

When the MRC is performed on the received signals, the resulting signal can be written as

\[
\tilde{S}_{k} = \tilde{H}_{k}^{(q)} Y_{k} = C_{k} S_{k} + \tilde{H}_{k}^{(q)\ast} W_{k} \tag{10}
\]

where

\[
C_{k} = \begin{bmatrix}
\sum_{p=0}^{1} |\tilde{H}_{k}^{(q,p)}|^2 & 0 \\
0 & \sum_{p=0}^{1} |\tilde{H}_{k}^{(q,p)}|^2
\end{bmatrix} \tag{11}
\]

Finally, the estimates of the transmit signal on the \( k \)th subcarrier is determined by the sum of the combined signals in all receive antennas, which results in

\[
\tilde{S}_{k} = \sum_{q=0}^{N_T} \tilde{S}_{k}^{(*)} = [\tilde{S}_{i,k} \; \tilde{S}_{i+1,k}]^T \tag{12}
\]

In case of STBC, each separated CFR between the transmit antennas and receive antennas should be estimated.

IV HIERARCHICAL TRANSMISSION FOR BROADCAST

It is known that the different bits in the broadcast stream could have different protection priorities. Therefore, the hierarchical transmission scheme with multi-level coding and multi-resolution modulation (MRM) can be used for the broadcast services, which provides different service quality for the mobile station with the different SNR. In the hierarchical transmission, two independent data streams are modulated onto a single stream. One data stream with lower-rate, called as high priority (HP) stream, is embedded within a low priority (LP) stream. It might be necessary that the bits of HP stream should be with a greater error protection than those of the LP stream. Using these error-technique techniques, the HP stream may require a relatively lower SNR in order to achieve the same bit-error-rate (BER) as the LP stream. Then, the receivers with good reception conditions can detect both streams successfully.
while those with poorer reception conditions may only receive the HP stream.

The modulation in the hierarchical transmission is based on a multi-resolution modulation which allows one to design a hierarchical protection scheme. Its constellation consists of clusters of points spaced by different distances. Each cluster may itself have sub-clusters, and so on. The minimal distance between two clusters is larger than the minimal distance between two sub-clusters. Then, the basic idea is to assign the HP bits to the clusters and LP bits to the sub-clusters.

Assume that the cluster and sub-cluster used to represent HP and LP information have $M_{HP}$ and $M_{LP}$ elements, respectively. The transmitted signal set is formed by adding all elements of the LP information set to each element of the HP information set. Here, the addition of two element means the addition of the respective coordinates in the complex plane. Consequently, the signal set has $M = M_{HP} \cdot M_{LP}$ signal points which are divided into $M_{HP}$ groups of $M_{LP}$ elements. As shown in Fig.2, the principle of multi-resolution modulation with 16 points is explained here as an simplest example. The hierarchical transmission system maps the data onto 16 points in such a way that there is effectively a QPSK stream embedded within 16QAM stream. Furthermore, the ratio $\lambda = \beta/\alpha$ can be adjusted to protect the HP stream at the expense of the LP stream, where $\alpha$ is the distance between HP symbols and $\beta$ is the distance between centroid of the LP symbols. In general, $\lambda$ should be less than 0.5 for a 16QAM constellation in the hierarchical transmission since the constellation becomes symmetric when $\lambda = 0.5$.

Since the transmit diversity is applied not only between the cells but also within one cell, the variance of received SNR will be quite large. The application of hierarchical transmission in this proposed scheme can eliminate the sharp threshold effect in the broadcast area.

V Simulation Results

The performances of the proposed transmission scheme in downlink MIMO-OFDM system for broadcast are evaluated in this section. In our simulations, the cyclic delay diversity (CDD) scheme is applied between the $N_{gpp} = 3$ cells, while STBC or CDD deployed in one cell. The basic transmission parameters are specified in Table 2 [1]. The selective fading channels between different transmit and receive antenna pair are independent. Under the assumption of a quasi-stationary channel, the channel is constant during at least two OFDM symbol intervals in case of STBC. At the receiver, perfect symbol/corner synchronization and channel state information are assumed to be available.

A With common modulation scheme

In Fig.3 and Fig.4, the performances of the proposed broadcast system applying intra-cell STBC/CDD and inter-cell CDD principle with the different number of receive antennas under PB3 channel are compared, whereas QPSK or 16QAM modulation is used respectively. Also the system with inter-cell non-CDD scheme (i.e. simple macro-diversity) are investigated as reference. It is clear that the inter-cell CDD principle can make better use of the macro-diversity and achieve the better BER performance than the reference system. On the other hand, STBC scheme as the intra-cell transmit diversity principle can achieve little better BER performance than CDD scheme because it can better exploit the spatial diversity gain through space-time coding than CDD principle. And this effect becomes more obvious with higher order modulation, i.e. 16QAM. For example, if the target BER is assumed to be $10^{-5}$, the BER gain of STBC principle compared with CDD principle is about 0.5 or 1dB under $N_R = 2$ or $N_R = 1$ in case of 16QAM modulation. However, CDD scheme as the intra-cell multi-antenna scheme is simpler and has more flexibility to work under the different scenarios with various antenna configuration.

B With hierarchical modulation scheme

The hierarchical modulation (HM) scheme applied is assumed to have two resolution levels and the HP to LP information ratio is 1:1. For the purpose of comparison, the reference system

<table>
<thead>
<tr>
<th>Table 2: System Parameters</th>
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<tbody>
<tr>
<td>Parameter</td>
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<tr>
<td>Bandwidth (MHz)</td>
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<tr>
<td>Carrier (GHz)</td>
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<tr>
<td>Frame duration (ms)</td>
</tr>
<tr>
<td>DFT size</td>
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<tr>
<td>Cyclic Prefix interval (samples/$\mu$s)</td>
</tr>
<tr>
<td>Subcarrier separation (kHz)</td>
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<tr>
<td>OFDM block duration ($\mu$s)</td>
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<tr>
<td>Number of OFDM symbols per frame</td>
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<tr>
<td>Number of useful data subcarriers</td>
</tr>
<tr>
<td>Channel coding/Decoding</td>
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<tr>
<td>Channel model</td>
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<tr>
<td>Antenna configuration ($N_T \times N_R$)</td>
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<tr>
<td>Cell-dependent parameter $\Delta_{\text{cell}}$</td>
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<td>Antenna-dependent parameter $\Delta_{\text{ant}}$</td>
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</table>
VI CONCLUSION

In this paper we have proposed the transmission diversity scheme with hierarchical modulation for broadcast in the evolutionary 3G cellular communication system, where CDD is applied between the different cells and STBC or CDD is used within the cell. Computer simulation results demonstrate that the proposed transmit diversity technique achieve better performance than the simple macro-diversity. Furthermore, with the hierarchical modulation scheme, the proposed transmit diversity scheme for broadcast outperforms the reference ILV system with the common modulation scheme when the HP and LP symbols with the different degree of prioritization are transmitted separately.

REFERENCES


