

An enhanced multi-antenna solution through beamforming to 3G long-term evolution

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Abstract—Beamforming has been greatly applied in TD-SCDMA, but in the 3G long-term evolution (LTE), multi-antenna solution aims to use multi-input-multi-output (MIMO). Usually MIMO requires enough large antenna space to ensure uncorrelated multi-channels, whereas beamforming antennas need small antenna space. But this years' research has shown the combination feasibility of beamforming and MIMO. In this paper, the 3GPP special channel model (SCM) has been researched and the beamforming is added to the LTE. Because of the beamforming combination, the number of transmitted antennas can not be restricted by 3GPP specification about LTE. Simulation results validate the efficiency. This gives a smooth evolution path from TD-SCDMA to LTE, and the advantage of beamforming can be inherited.

Keywords—Beamforming, MiMO, LTE, TD-SCDMA

I. INTRODUCTION

In order to maintain the future competitiveness of 3G technology, LTE concerns to increase data rates, improve spectrum efficiency, improve coverage and so on. Beamforming is one of the competitive technologies in TD-SCDMA, which contribute to the large coverage of TD-SCDMA. But in LTE, for the target of high data rates, MIMO is adopted. On the side of MIMO, the antenna spacing is usually required to be large enough, such as 10 times wavelength of the carrier for a uniform linear array (ULA) in small angle spread (AS) environments, in order to get low-correlation or independent fading channels. On the other side of beamforming, the antennas need to be closely correlated. Usually the spacing is half wavelength for ULA. Because of this conflicted character, beamforming and MIMO seem to be hardly combined, but actually not. In 3GPP LTE [2], antenna distance has been set to half wavelength and not beyond 10 times wavelength. On base station (BS) side for downlink, because scatters usually locate far away from the base station, the environment is small angular spread. In 3GPP [1] the AS is set to 2 degrees at angular of departure (AoD) 50 degrees or 5 degrees at AoD 20 degrees. Same time, large antenna distance will cause large antenna size in engineer application. All these disadvantages may block MIMO's application in LTE. Although precoding has been proposed in LTE to suit correlated channels, it will abandon weak sub-channels that

can cause channel capacity decrease. Beamforming has shown great advantage in TD-SCDMA, and smart antenna production has been largely commercial used. On the way from TD-SCDMA to LTE, how to get a smooth evolution, how to bring the advantage technology of TD-SCDMA into LTE, and how to solve the problems that MIMO meet in LTE, all lead to the combination of beamforming and MIMO.

Some research articles have discussed the combination of BF and MIMO. For example, [5], the author proposed a downlink transmission scheme combining space-time block coding (STBC) with adaptive beamforming techniques. Through the reconstruction of beamforming weights, correlated channels can be change to uncorrelated virtual channel. The multiple diversity antennas in STBC can equal to uncorrelated beamforming weights. So the key point is to get uncorrelated weights. In [3] [5] [7], the transmit beamforming weights are optimized by maximizing the cost function, but increasing the computing complexity. In TD-SCDMA, the DoA and DoD estimating technology is maturity, so in this paper, under the analysis of 3GPP SCM, the weights are feasibly set by the steering vector and allocated power according the uplink.

This paper is organized as follows. First in section 2, the 3GPP SCM is simply described. Through the analysis about the angular spread in 3GPP SCM, the power azimuth spectrum (PAS) can be modeled to be a Laplacian function. This is the theory foundation for the combination of beamforming and MIMO. In section3, the frame of combining beamforming in the 3GPP LTE multiple-antenna solution has been proposed. How to get the beamforming weights is introduced. Simulation results will be done in section 4 according the 3GPP SCM environment and the multi-antenna scheme. Contrasting result is shown. Finally the paper is concluded in section 5.

II. CHANNEL MODEL IN 3GPP SCM

Realistic radio channel model is important to the design and analysis. Whether the performance evaluates the system performance depends on the accurate channel model. In this paper, we focus on the wideband outdoor channel models for 3GPP LTE. In traditional channel models, the parameters almost focus on the time dispersion of radio

channels. But for the purpose of exploiting the spatial or directional channels in LTE, 3GPP presents the spatial channel model that is the output of the combined 3GPP-3GPP2 spatial channel model (SCM) ad-hoc group (AHG).

A. Angle spread and PAS

Angular spread and PAS are the main important spatial channel parameters in SCM. In [4], the investigation presented the measurement results in urban and rural areas for various base station antenna heights. It gave an analytical model with a Laplacian function for PAS. For the similar outdoor environments, the model about PAS has been inherited in 3G SCM [1].

In [1], the per-path BS PAS is:

$$P(\theta, \sigma, \bar{\theta}) = N_o \exp\left[-\frac{\sqrt{2}|\theta - \bar{\theta}|}{\sigma}\right] G(\theta) \quad (1)$$

Here θ is the angle in PAS, $\bar{\theta}$ is the AOD of path, RMS angle-spread σ controls the spread of function. P is the average received power and G is the numeric base station antenna gain, N_o is the normalization constant.

$$N_o^{-1} = \int_{-\pi + \bar{\theta}}^{\pi + \bar{\theta}} \exp\left[-\frac{\sqrt{2}|\theta - \bar{\theta}|}{\sigma}\right] G(\theta) d\theta \quad (2)$$

At BS side, antennas are usually high enough that scatters are far away from the BS. It will cause small RMS angle spread σ . In 3G SCM for link level simulation, it is set to 2 or 5 degree depending on AoD. Fig. 1 describes the PAS of different AoD and σ parameters according to [1]. It is obviously shown that due to the influence of small RMS angle-spread, the PAS of different paths can get orthogonal if choosing suitable AoDs. The orthogonal performance is the foundation for the combination of beamforming and MIMO.

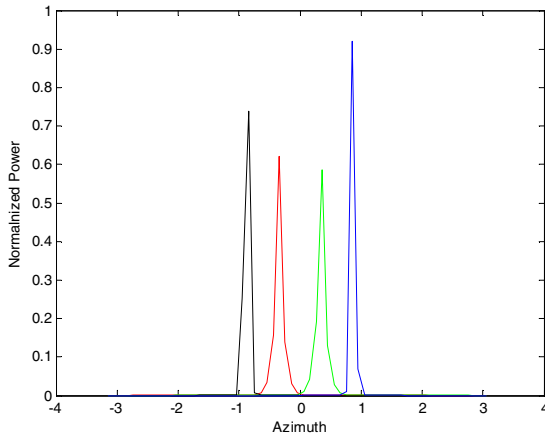


Figure 1. Example of PAS obtained in BS outdoor environment.

B. Channel model

There are N time-delayed multi paths between BS and MS. Each path consists of M subpaths [1]. For a simply analysis, we only consider the N main paths, and assume the array broadsides of BS and MS are superposition. But during the simulation next, the channel simulation is totally according to [1].

Channel can be simply modeled as figure 2. There are S elements in linear BS array and U elements in linear MS array. $\theta_{n,AoD}$ is the absolute AoD for the n th path at the BS that respects to the BS broadside and is similarly to $\theta_{n,AoA}$. Referring [1], the channel coefficients for N multipath components are given by a U -by- S matrix of complex amplitudes.

$$\mathbf{H}(t) = \sum_{n=1}^N (\sqrt{P_n} \cdot \sqrt{G_{BS}(\theta_{n,AoD})} \cdot \sqrt{G_{MS}(\theta_{n,AoA})} \quad (3)$$

$$\cdot \exp(jk \|\mathbf{v}\| \cos(\theta_{n,AoA} - \theta_n) t) \exp(j\phi_n) \mathbf{a}((\theta_{n,AoD}) \mathbf{a}^T(\theta_{n,AoA})))$$

$$\mathbf{a}(\theta_n) = \begin{bmatrix} 1 & e^{j\pi \sin(\theta_n)} & \dots & e^{j(M-1)\pi \sin(\theta_n)} \end{bmatrix}^T \quad (4)$$

Where P_n is the power of the n th path, G_{BS} and G_{MS} are the antenna gains, k is the wave number $2\pi/\lambda$, λ is the carrier wavelength in meters, $\|\mathbf{v}\|$ is the magnitude of the MS velocity vector, ϕ_n is the phase of the n th path, $\mathbf{a}(\theta_{n,AoD})$ and $\mathbf{a}(\theta_{n,AoA})$ are $M \times 1$ steering vector ant AoD or AoA. M is equal to S or U . $(\cdot)^T$ and $(\cdot)^H$ denote matrix transpose and Hermitian transpose.

For simply analysis, assuming the receiving element is single. The channel coefficients can be shorten as

$$\mathbf{H}(t) = \sum_{n=1}^N \alpha_n(t) \mathbf{a}(\theta_{n,AoD}) \quad (5)$$

$$\alpha_n(t) = \sqrt{P_n} \cdot \sqrt{G_{BS}(\theta_{n,AoD})} \cdot \sqrt{G_{MS}(\theta_{n,AoA})} \cdot \exp(jk \|\mathbf{v}\| \cos(\theta_{n,AoA} - \theta_n) t) \exp(j\phi_n) \quad (6)$$

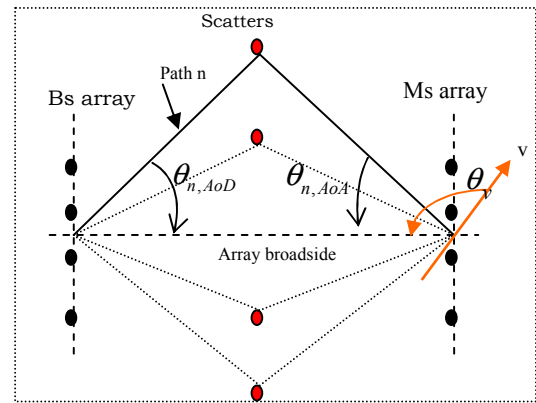


Figure 2. Channel model for beamforming combination.

Through the above analysis of channel model, the signals that should be transmitted at the BS elements can be transmitted from different orthogonal paths, so the scheme used in [5] [6] is useful for LTE multiple antennas. The received signals can virtual seem to be transmitted from the scatters that usually far away each other. Through this way, the correlated channels can be reconstructed as virtual uncorrelated channels.

III. COMBINATION OF BEAMFORMING AND MIMO IN LTE

In 3GPP specification [2], no matter multi-antenna is used for spatial multiplexing or transmitting diversity, after the signal generation of layer mapping and OFDM, the signal is sent to antenna ports. Beamforming is added here for the purpose to reconstruct uncorrelated channel. The frame is described as the following in Fig. 3.

If without beamforming in specification [2], the block of vectors $\mathbf{y} = [y_0 \dots y_{P-1}]^T$ should be map on each of the antenna ports. Using the channel model in section 2, the received signal should be:

$$\mathbf{r} = \mathbf{y}^T \cdot \mathbf{H} + \mathbf{n}$$

(7)

$\mathbf{H}$ is the channel coefficients denoted in (5), $\mathbf{n}$ is complex random variable representing receiver noise, and $\mathbf{r}$ is the received signal vector. After beamforming combination, the received signal is:

$$\begin{aligned} \mathbf{r} &= (y_i \cdot \mathbf{w}_1 + \dots + y_{P-1} \cdot \mathbf{w}_{P-1}) \cdot \mathbf{H} + \mathbf{n} \\ &= \mathbf{y}^T \cdot \mathbf{W} \cdot \mathbf{H} + \mathbf{n} \\ &= \mathbf{y}^T \cdot \mathbf{H}_2 + \mathbf{n} \end{aligned} \quad (8)$$

Where $\mathbf{W} = (\mathbf{w}_1, \dots, \mathbf{w}_{P-1})^H$, $\mathbf{w}_i$ is the $M \times 1$ beamforming weight for y_i . With the help of beamforming weights, the block of vectors $\mathbf{y}$ can be mapped to orthogonal paths, and the correlated channel $\mathbf{H}$ is reconstructed to virtual uncorrelated channel $\mathbf{H}_2$. The decoding process can remain unchanged if take $\mathbf{H}_2$ as channel coefficients.

The next key point is how to get beamforming weights. In [5], it gave optimal eigen-beamformer pertaining to minimizing a tight bound on the symbol error rate (SER), and loaded beamforming according to statistical water-filling approaches. These approaches are superiority when only getting knowledge of the channel correlations. In [3], the transmit beamforming weights can be optimized by maximizing the cost function to guarantee statistically uncorrelated. But these approaches cause to increase processing complexity.

In TD-SCDMA, DOA estimation is applied maturely. In this paper, suppose the AoD and power fading amplitude of different path can be estimated from the uplink at base

station. Referring [6] and adding water-filling power allocation, the beamforming weight $\mathbf{w}_i$ can be set as steering vector $\mathbf{w}_i = k_i \mathbf{a}(\theta_i, A_{oD})$, where k_i is associated with the power fading amplitude of path, $\mathbf{a}(\theta_i, A_{oD})$ is the steering vector of selected i th path. The beamforming weights are subjected to the following:

$$\sum_{i=1}^P \mathbf{w}_i^H \cdot \mathbf{w}_i = \sum_{i=1}^P k_i^2 \cdot M = 1 \quad (9)$$

Where P is the transmitted ports of $\mathbf{y}$, M is the number of transmitted antennas, α_i is the power fading amplitude of i th path estimated from uplink.

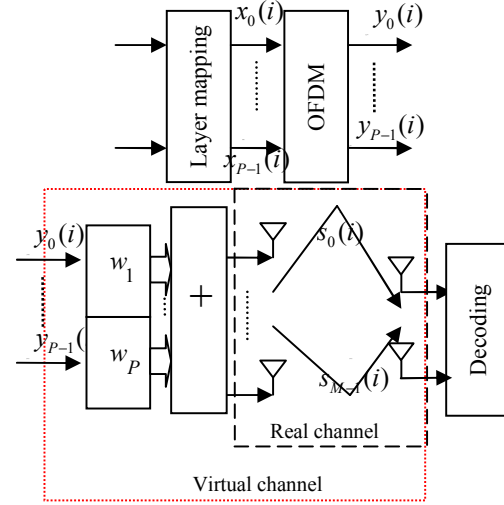


Figure 3. Combination frame of beamforming and MIMO.

IV. SIMULATION RESULTS

The simulation is under the channel model [1], according the steps to generating parameters of user and coefficients. Urban macrocell environment is selected. The detail parameters are set in table 1. We consider a linear array of $M=2, 4$ or 6 equispaced antennas at the transmitter, and single antenna at the receiver.

TABLE I. SIMULATION PARAMETERS OF URBAN MACROCELL

Parameters	Values
Modulation schemes	QPSK
Layer mapping	Spatial Multiplexing
Transmission rank	2
The number of antenna ports P	2
Actual transmit antennas M	2,4,6
Number of paths (N)	6
Number of sub-paths (M) per-path	20
Mean AS at BS	$E(\sigma_{AS}) = 8^\circ, 15^\circ$
Per-path AS at BS (Fixed)	2 deg
BS per-path AoD Distribution standard distribution	$\eta(0, \sigma_{AoD}^2)$ where $\sigma_{AoD} = r_{AS} \sigma_{AS}$

Parameters	Values
Lognormal shadowing standard deviation, σ_{SF}	8dB
Pathloss model (dB),	$34.5 + 35\log_{10}(d)$

Fig. 4 illustrates the average bit error rate (BER) performance of the proposed combination scheme vs. signal-to-noise ratio (SNR). For comparison, the conventional scheme without beamforming in LTE is also included. Fig. 5 illustrates the BER vs. SNR performance of the combination scheme under different M.

In Fig. 4, M is set to 2 in order to equal P. It can be seen that under the same BS antennas, the superiority of the proposed combination scheme can get 4dB plus at 10^{-3} than the conventional scheme in LTE. In Fig. 5, obviously when increasing the transmitted antennas M, the performance can get more increase, about 1dB of one antenna. In conventional scheme in LTE, the transmitted antennas are limited by the transmission rank or layers. But when combining beamforming, the number of antenna ports P is mapped to orthogonal beams, the actual number of antennas can be set flexibly and the antennas which used in TD-SCDMA can be applied in LTE. It is easy for engineering improvement.

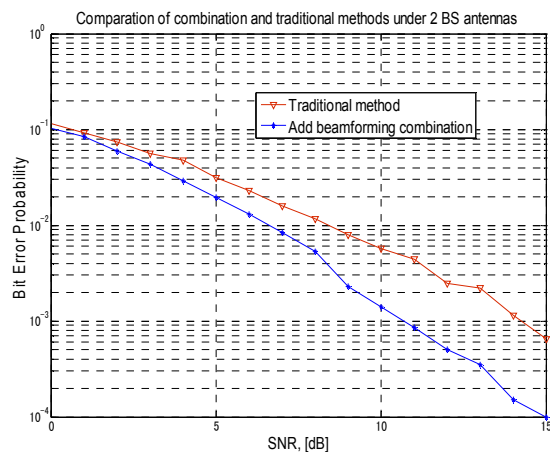


Figure 4. BER performance comparison of traditional and combination methods under 2 BS antennas.

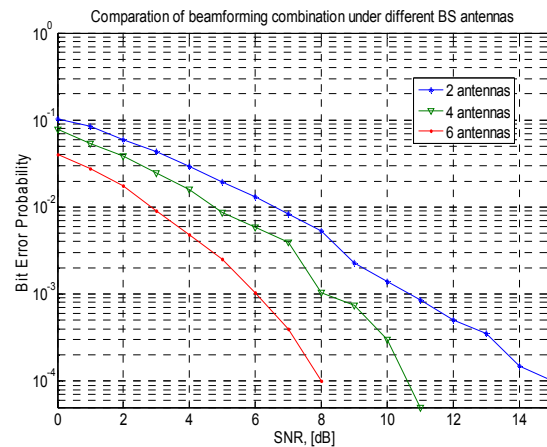


Figure 5. BER performance comparison of beamforming combination under different BS antennas.

V. CONCLUSIONS

In the paper, a downlink transmit beamforming scheme is combined in LTE to achieve performance under correlated channels. It outperforms the conventional scheme in LTE when the AoD and power fading amplitude of multipath are best estimated from uplink. It is justified in various simulations. Because of the beamforming combination, the number of transmitted antenna can not be restricted by specification. The antennas used in TD-SCDMA can be reused in LTE to ensure a smooth evolution from TD-SCDMA to LTE. The next research should focus on how to get the best estimated AoD and fading amplitude and how to improving the performance when channel coefficients change rapidly.

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