РАДІОЕЛЕКТРОННІ ПРИСТРОЇ, СИСТЕМИ ТА НВЧ ТЕХНІКА

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ЕФЕКТИВНІСТЬ МЕТОДІВ ФОРМУВАННЯ ДІАГРАМИ СПРЯМОВАНОСТІ ТА ПРОСТОРОВОГО РОЗНЕСЕННЯ ПЕРЕДАВАННЯ В ПРИМІЩЕННЯХ І НА ВІДКРИТІЙ МІСЦЕВОСТІ

У сучасних безпровідних мережах важливу роль у забезпеченні високих пропускних здатностей каналів відіграють методи діаграмоутворення та просторового рознесення каналів передавання. В сукупності з технологією ортогонального частотного мультиплексування OFDM, вони дають змогу досягти прийнятних значень коефіцієнта бітових помилок BER за меншого співвідношення сигнал/завада SNR. Ефективність зазначених компонентів широкосмугових безпровідних мереж змінюється залежно від того, де розташовані абоненти відносно базових станцій – у приміщеннях чи на відкритій місцевості. У статті запропоновано результати дослідження та аналізу різних способів розширення кута випромінювання антен базових станцій у процесі передавання та приймання сигналів. Подано порівняльну характеристику методів просторового рознесення передавальних антен (transmit diversity) та діаграмоутворення (beamforming). Отримано результати моделювання системи LTE із застосуванням двох зазначених методів. Доведено, що із використанням способів розширення кута випромінювання антен базової станції зменшується значення коефіцієнта бітових помилок за незмінного співвідношення сигнал/завада для обох випадків взаємного розміщення базової станції та обладнання користувача. У процесі моделювання враховано основні параметри сигналу, що формується шляхом ортогонального частотного мультиплексування. Вибрані значення ширини смуги каналу відповідають стандарту LTE. Враховано, що для боротьби з частотно-селективним федінгом застосовується циклічний префікс. Також у процесі моделювання відображено, що для закритих приміщень розширення кута випромінювання є великим за рахунок розсіювання, а для відкритої місцевості це значення на порядок менше. Показано, що для закритих приміщень доцільніше використовувати просторово-часове кодування блоків.

Ключові слова: splines, Savitsky-Golay filter, LSS- decomposition.

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EFFECTED ANGULAR SPREAD ON BEAMFORMING AND TRANSMIT DIVERSITY FOR INDOOR AND OUTDOOR

The implementation of beamforming and spatial diversity in Orthogonal Frequency Division Multiplexing (OFDM) systems reveals challenges in terms of complexity, feedback, and scenario dependencies. In this paper we discuss the differences and limitations of OFDM transmission over scenarios with different angular spread, which can viewed clearly from the base station antenna (BSA), signals departing to or arriving from the UE appear to be spread over a range of angle and evaluate the issues arising from the implementation of beam-forming and spatial diversity in OFDM systems.

Key words: OFDM, BER, Beamforming, Transmit Diversity, STBC, SFBC.

Introduction. OFDM (Orthogonal Frequency Division Multiplexing) is a modulation technique that is very effective in mitigating adverse multipath effects of a broadband wireless channel [1]. The robustness against frequency selective fading, as well as narrowband interference, combined with an efficiently use of spectrum, have pushed OFDM to be the primary physical layer adopted in several standards. Moreover, afford able implementation complexity of OFDM became a reality following the latest developments in integration technology that made the FFT (fast Fourier transform) chips economic to apply in receivers and transmitters. There are many techniques used with transmit diversity one of these techniques are Space-Time Block Coding (STBC) [2] is an open loop transmit diversity scheme where the diversity is achieved at the receiver without the knowledge of the channel at the transmitter. A complementary to this kind of transmit diversity scheme is beamforming (BF) [3]. When the wireless channels between transmit and receive antennas are correlated to each other, then transmit diversity scheme is not expected to perform well, i.e. if independent fading among the antenna signals cannot be achieved, BF is preferred over transmit diversity. In BF we exploit the fact that the antenna elements are close together so that appreciable coherence between the antenna signals is present. In both transmit diversity and beamforming, data rates are mainly bandwidth limited when SNR reaches a certain level [4]. In downlink of a cellular system Beamforming is the closed-loop transmit diversity and considered as a particular case of spatial multiplexing with only one code word and one layer [5].

Transmit diversity consists of applying an space-frequency block coding (SFBC) scheme according to the number of antennas of the eNodeB. We consider a MISO configuration of the spatial link, with N_t transmit antennas, and a single receive antenna N_r. It is a reasonable choice for downlink cellular systems to place the complexity of handling multiple antennas at the transmitter side, especially for portable receivers, where current drain and physical size are important constraints.

Beamforming. Beamforming uses antenna arrays to increase the signal power for different direction and array of antenna elements is weighted in order to shape the radiation diagram of the antenna pattern. Here, we focus on transmit beamforming. Thus, the Direction of Departure (DoD), i.e., the direction of spread wave from the transmitter, is the angle of interest. In a multi antenna transmission, data symbols are mapped to the antennas, and the signal at each antenna is weighted by a certain factor. In beamforming, the choice of weights depends on the algorithm used to optimize the radiation pattern. Here, the Minimum Mean Square Error (MMSE) criterion is used to compute the optimal weights of the Beamformer as shown in equation (1) below.

$$w_{opt} = R_{yy}^{-1} r_{yd} , \tag{1}$$

where R_{yy} – is the correlation matrix [Nr ×Nr] of the received signal, and r_{yd} is the cross correlation vector between the transmitted data and the received signal.

The computation of weights in beamforming requires the knowledge of the channel coefficients. In slowly time-variant fading, the channel of a downlink Time Division Duplex (TDD) system is estimated in the uplink frame without loss of performance. On the other hand, Frequency Division Duplex (FDD) systems require a feedback channel to obtain the channel estimate at the transmitter side, since the array response is frequency dependent.

In OFDM, downlink beamforming can be implemented either before or after the Inverse Discrete Fourier Transform (IDFT) operation, i.e., either in the frequency or time domain, respectively. The first scheme is referred to as a pre-IDFT downlink beamforming, and the latter scheme is referred to as a post-IDFT downlink beamforming.

The implementation of a beamforming system that tracks each terminal individually in an OFDM system has several constraints in terms of complexity. FDD systems require feedback to obtain the channel knowledge at the transmitter, and the frequency domain beamforming, the antenna weights are computed for group of subcarriers or each subcarrier, greatly increasing the complexity.

Spatial Diversity. While beamforming boosts the signal strength in a particular direction using an antenna array, antennas that are physically separated by a few wavelengths experience independent fading channels that can be used for diversity or multiplexing. For 3Gpp Transmit diversity used SFBC technique with better from STBC technique special when channels increased therefore we can say that special diversity used when link adaptation is weakly and so when low (SINR).

Space Time Block Coding (STBC). First we must talk brief of STC which is representing a hybrid technique that applies both space and time diversity in a combined way [6]. The most common form of STC used for diversity is STBC. STC was first introduced by Alamouti [7] when presenting a two branch transmitter diversity scheme that achieves full diversity.

The STBC proposed in [7] transmits two symbols over two antennas and two symbol durations according to the transmit matrix:

$$S = \begin{pmatrix} s_n & s_{n+1} \\ s_{n+1}^* & s_n^* \end{pmatrix} \tag{2}$$

Under the assumption of constant fading over two consecutive symbols, the scheme achieves diversity order of two. Extending the concept of STBC, Tarokh [8] proposed transmission blocks for more than two transmit antennas that achieve full diversity, such as the code for four antennas and spatial rate 3/4 periods:

$$S = \begin{pmatrix} s_n & s_{n+1} & \frac{s_{n+2}}{\sqrt{2}} & \frac{s_{n+2}}{\sqrt{2}} \\ s_{n+1}^* & s_n^* & \frac{s_{n+2}}{\sqrt{2}} & -\frac{s_{n+2}}{\sqrt{2}} \\ \frac{s_{n+2}^*}{\sqrt{2}} & \frac{s_{n+2}^*}{\sqrt{2}} & \frac{-s_n - s_n^* + s_{n+1} - s_{n+1}^*}{2} & \frac{-s_{n+1} - s_{n+1}^* + s_n - s_n^*}{2} \\ \frac{s_{n+2}^*}{\sqrt{2}} & -\frac{s_{n+2}^*}{\sqrt{2}} & \frac{s_{n+1} + s_{n+1}^* + s_n - s_n^*}{2} & -\frac{s_n + s_n^* + s_{n+1} - s_{n+1}^*}{2} \end{pmatrix} \tag{3}$$

Space Frequency Block Coding (SFBC). Space frequency block coding was first proposed in Dehghani as an extension of traditional space-time block coding for OFDM systems. In SFBC, the basic idea of the Alamouti scheme is applied in frequency domain instead of time domain. Figure 1 illustrates the SFBC operation for the particular two-antenna configuration. SFBC operation is performed on pairs of complex valued modulation symbols. Hence, each pair of symbols has an associated pair of frequency resources (i.e., a pair of OFDM subcarriers). Modulation symbols are mapped directly onto the available resources of the first antenna. However, mapping of each pair on the second antenna is reversely ordered, sign reversed, and complex conjugated, as illustrated in Figure 1.

For a proper reception of the transmitted modulation symbols, the mobile terminal must be informed about SFBC transmission and a simple linear operation has to be applied to the received signal. Contrarily to cyclic delay diversity, SFBC provides diversity on the level of modulation symbols.

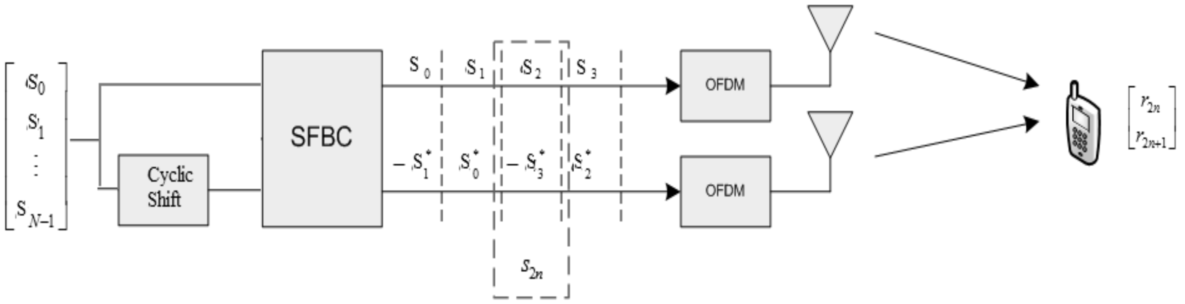

Fig. 1. Cyclic delay diversity for SFBC for two-antenna configuration

Space-Frequency or Space-Time Processing and Scheduling. This section discusses feasibility issues of the resource allocation of the OFDM frame in multiuser systems, combined with beamforming and spatial diversity. The scheduler assigns the OFDM subcarriers and symbols to the users based on the channel conditions

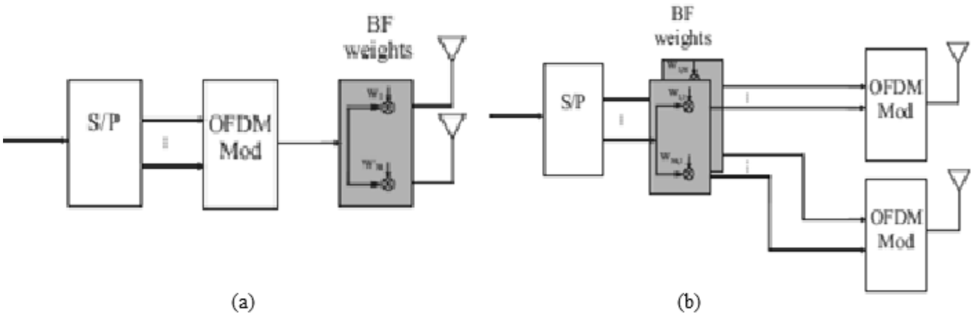

Fig. 2. Time domain beamforming in OFDM (a),
Frequency domain beamforming in OFDM (b)

In time domain scheduling, each OFDM symbol is allocated to one user at a time, Time Division Multiple Access (TDMA). The beamformer determines the radiation pattern to the user allocated to that time slot. In such system, all the subcarriers are used by one user at a given OFDM symbol, thus, a post-IDFT beamformer is recommended.

Figure 2.(a) shows the block diagram of the time domain beamforming. After the IDFT operation in the transmitter, the time domain signal is transmitted through a wideband Beamformer, e.g., a multi-tap beamformer. In order to implement spatial diversity in a TDMA system, the STBC requires that the block of symbols is allocated to one user only.

For codes with high number of channel uses, the SFBC permits more flexibility, as it is implemented across OFDM subcarriers [9]. In an Orthogonal Frequency Division Multiple Access (OFDMA) system, the scheduler allocates the available subcarriers to the users at each OFDM symbol. The pre-IDFT beamformer allows the system to steer the beams to each user independently in OFDMA.

Figure 2 (b) shows the frequency domain beamforming implemented on the OFDM subcarriers with blocks of weights for each antenna. Since in OFDM each subcarrier experiences a narrowband single-tap channel, narrowband beamformers can be applied. However, the number of beams is constrained by the number of transmit antennas that dictate the degrees of freedom of the beamformer. If a large number of users is uniformly distributed over the cell, then the beamforming technique fails at steering the beams toward each user. A possible solution is to create clusters of users who are collocated by spatially grouping the users that are close to each other. In addition to spatial clustering, the scheduling algorithm can also constrain the number of users allocated per time slot, and separate the allocation in frequency and time domains. The BS steers the beam that covers the users in that set and avoids interference to other directions in the cell.

If the subcarrier allocation is kept static for at least T OFDM symbols, STBC can be implemented for each narrowband subcarrier. Otherwise, SFBC can also be applied, if the users are allocated contiguous subcarriers, and the number of subcarriers assigned to one user is a multiple of the code block size. Figure 3 depicts the implementation of STBC or SFBC encoding in the transmitter of OFDM.

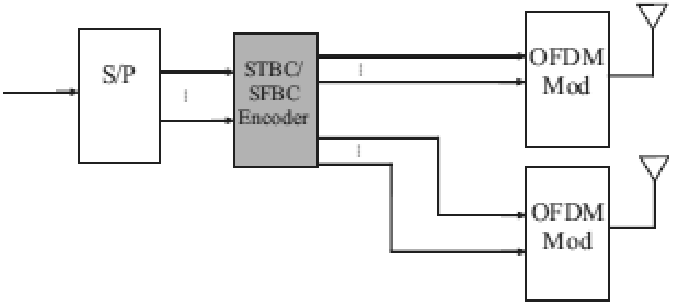

Fig. 3. STBC and SFBC in OFDM

Results. To compare beamforming and spatial diversity, indoor micro-cell and outdoor macro-cell scenarios are considered for the downlink of a single-user scenario. The simulator was developed as an extension of the MATLAB software for OFDM performance simulation provided in [10].Table (1) shows the parameters for these scenarios.

Table 1

Parameters used in simulation

Parameters	Indoor	Outdoor
No. of sub-carrier	64	1024
User velocity	3km/h	40km/h
Max delay spread	0.5 us	5us
Angular spread	240°	20°
Bandwidth	20MHz	20 MHz
frequency	5GHz	5 GHz
Symbol duration	4 us	4 us
Coherence time Tc ms	30	1.5
CP length, Ng	16	200

We assume that the synchronization requirement of the OFDM receiver is perfectly met, and the transmit beamforming weights are computed based on the uplink frame of a TDD system or via a delay and error-free feedback channel in an FDD system. Spatial Correlation Angular spread is a measure of the angular depressiveness of the wave front of the signal between the transmitter and the receiver. The angular spread is usually high in an indoor scenario, owing to the proximity of scatters, and low in an urban scenario.

A low angular spread limits the available spatial diversity, therefore beamforming is more appropriate to use. On the other hand, in indoor channels, due to a broader angular spread, spatial diversity can effectively exploit the uncorrelated signals.

For transmit diversity, the physical separation between antenna elements is assumed five times the wavelength, 5λ. A large separation makes the antenna elements uncorrelated, and it is feasible at the BS due to lower constraints on size. The implementation of beamforming requires the antenna elements to be placed closely, i.e., the wave front should be phase-coherent over the antenna aperture. Hence, we use a spacing of λ/4, which is a common value considered in literature within the correlation condition of $d < \lambda/2$.

In the wideband signal, the L multipath signals depart from the array with different angles. The signal vector representation is the sum of all signals shaped by the steering vector, $a(\theta_l)$.

The spatial-temporal fading channel is modeled with the correlated fading coefficients of the N_t antenna elements of the l tap in accord with [11]

$$h_l^R = R^{1/2} h_l , \tag{4}$$

where h_1 is the channel vector with N_t independent coefficients. The spatial covariance matrix R is given by

$$R = \frac{1}{L} \sum_{l=1}^{L} a^H (q_l) a(q_l) \tag{5}$$

$$a(q_l) = \left[1, \exp(j a_l), \ldots, \exp\left(j(N_t - 1) a_l\right)\right]$$

$$a_l = \frac{2p}{l} d \sin q_l ,$$

where $a(\theta_1)$ is the steering vector dependent on azimuth direction θ_1 of the 1th signal.

The steering vector is the N_t-dimensional complex vector containing the responses of the antenna elements to a narrowband source of unit power.

Performance and Effect angular spread on BER. The results of un-coded BER for transmit diversity and frequency domain beamforming for various values of angular spread in a single-user OFDM system.

Spatial diversity is obtained with the orthogonal half rate STBC for four antennas. STBC is used in the indoor scenario, while the diversity for outdoor scenario is obtained with SFBC. Here we can modulate using QPSK. The Figure 4 illustrates the BER curves for the transmit diversity configuration in outdoor (SFBC) and indoor (STBC) scenarios, shows the BER performance of transmit diversity and beamforming techniques in indoor scenario, while present the results for outdoor scenario.

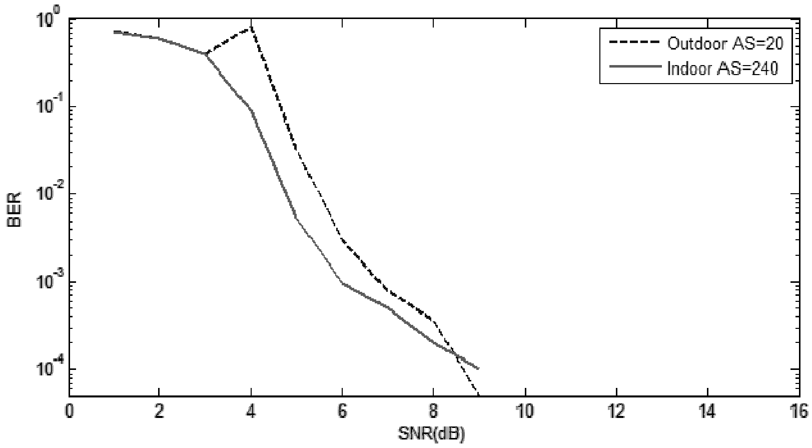

Fig. 4. BER performance of transmit diversity for different angular spread

The high angular spread of indoor scenarios, combined with the low mobility, presents STBC as the best technique. In fact, the high angular spread induces a low correlation of the antennas, and the low mobility makes the channel quasi-static, necessary conditions for the STBC to exploit diversity. In outdoor scenario, owing to a high mobility of the MS, STBC is not effective due to the loss of quasi-static characteristic of the channel. Therefore, SFBC is used for outdoor. In outdoor, the BER curve presents an error floor at high SNR on account of the high frequency selectivity of the channel.

Beamforming provides a robust performance at lower angular spread values. The spatial diversity increases consistently the performance in terms of BER as the angular spread widens both in indoor and outdoor environments. Transmit diversity outperforms beamforming in indoor scenarios with very high angular spread, but otherwise the array gain of beamforming delivers better performance. Although the strength of beamforming comes at the cost of a higher complexity, the advantage in outdoor scenario suggests its implementation in macro cells.

Conclusion. In this paper provided an insight into the performance of spatial diversity and beamforming in different wireless environments. The comparison is based on BER performance for various spatial channel correlations, as a result of angular spread conditions. We have discussed frequency and time domain approaches for transmit diversity and beamforming in OFDM-based systems. Results show that STBC is more suitable for indoor environments with high angular spread, whereas in outdoor scenario, the array gain of beamforming is more effective than diversity. SFBC provides diversity over frequency in time selective scenario where the STBC proves inefficient. The performance of SFBC erodes when the transmitted block is longer than the coherence bandwidth of the channel. However, due to the flexibility of the OFDM design, the subcarrier spacing can be shortened, according to the frequency selectivity of the scenario, by increasing the number of subcarriers.

1. Nee R. V. and Prasad R. OFDM for Wireless Multimedia Communications / Norwood, MA, USA: Artech House, Inc., 2000. 2. Luis Miguel Cortes-Pena, "MIMO Space-Time Block Coding (STBC): Simulations and Results // DESIGN PROJECT: PERSONAL AND MOBILE COMMUNICATIONS, GEORGIA TECH (ECE6604), April, 2009. 3. Friedlander B. and Scherzer S. Beamforming vs. Transmit Diversity in the Downlink of a Cellular Communications System // in Proc. Of 35th Asilomar Conference on Signals, Systems and Computers, vol. 2. 4. Kevin Linehan, Julius Robson. What base station antenna configuration is best for LTE-Advanced? // WP-106096-EN (9/12) 2012 CommScope, Inc. 5. Maximizing LTE Performance through MIMO Optimization // PCTEL Inc., RFS Solutions, April 2011, Retrieved from http://rfsolutions.pctel.com/artifacts/MIMOWhitePaperRevB-FINAL.pdf. 6. Paulraj A. J., Nabar R. and Gore D. Introduction to Space-Time Wireless Communications. – New York, NY, USA: Cambridge University Press, 2003. 7. Alamouti S. M. A simple transmit diversity technique for wireless communications // IEEE Journal on Selected Areas in Communications, vol. 16, no. 8, pp. 1451–1458, 1998. 8. Tarokh V., Jafarkhani H., and A. Calderbank R. Space-time block coding for wireless communications: performance results // IEEE Journal on Selected Areas in Communications, vol. 17, no. 3, pp. 451–460, 1999. 9. Rohling H. and Gruneid R. Performance comparison of different multiple access schemes for the downlink of an OFDM communication system // in Proc. IEEE Vehicular Technology Conference (VTC), vol. 3, Phoenix, AZ, USA, May 1997, pp. 1365–1369. 10. Heiskala J. and Terry J. OFDM Wireless Lans: A Theoretical and Practical Guide / Indianapolis, IN, USA: Sams Publishing, 2001. 11. Seeger A., Lobinger A., Wiedmann R., and Raaf B. Downlink eigenbeamformer with combining of eigenbeams // in Proc. IEEE Global Communications Conference GLOBECOM), vol. 5, San Antonio, TX, USA, November 2001, pp. 1269–1273.