LTE є одним із стандартів зв'язку для мобільних телефонів наступного покоління, тому в статті зроблено огляд основних методів еквалізації в технології LTE з MIMO та SC-FDMA в каналах, де максимальна затримка перевищує довжину Захисного інтервалу. Розглянули три методи корекції: часовий інтервал, область частоти і турбо вирівнювання

Ключові слова: LTE, SC-FDMA, OFDM, MIMO, корекції, MMSE-BLE, RNN

LTE является одним из стандартов связи для мобильных телефонов следующего поколения, поэтому в статье сделан обзор основных методов эквализции в технологии LTE с MIMO и SC-FDMA в каналах, где максимальная задержка превышает длину Защитного интервала. Рассмотрены три метода коррекции: временной интервал, область частоты и турбо выравнивание

Ключевые слова: LTE, SC-FDMA, OFDMA, MIMO, коррекции , MMSE-BLE, RNN

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FEATURES OF EQUALIZATION IN LTE TECHNOLOGY WITH MIMO AND SC-FDMA

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1. Introduction

Mobile broadband access and high data rates for mobile data services are becoming more and more important. Long Term Evolution (LTE), the 4G successor of Universal Mobile Telecommunications (UMTS) 3G standard, offers both. It is the upcoming technique for mobile internet access. The idea of this work is to improve the performance of single carrier frequency division multiple access (SC-FDMA), used in the LTE uplink [1]. SC-FDMA employs frequency domain equalization [1], which is compared with an iterative equalization in the time domain, using the recurrent neural network (RNN) equalizer [2]. In a third approach a combination of equalization and decoding for coded transmission, known as turbo equalization, is presented [3]. In a first step we considered bit error rates and packet error rates, but only minor improvement could be realized. But when implementing hybrid automatic repeat request (HARQ) [4] and having a closer look at the throughput, defined by the ratio of the number of received packets to the number of transmitted packets, the gain of time domain equalization can be easily seen. LTE standard was started as a project in 2004 by telecommunication body known as the Third Generation Partnership Project (3GPP). SAE (System Architecture Evolution) is the corresponding evolution of the GPRS/3G packet core network evolution. The term LTE is typically used to represent both LTE and SAE LTE evolved from an earlier 3GPP system known as the Universal Mobile Telecommunication System (UMTS), which in turn evolved from the Global System for Mobile Communications (GSM). The main goal of LTE is to provide a high data rate, low latency and packet optimized radio access technology supporting flexible bandwidth deployments. Same time its network architecture has been designed with the goal to support packet-switched traffic with seamless mobility and great quality of service. The primary advantage e of OFDM over sing le-carrier schemes is its ability to cope with severe channel conditions without complex equalization filters. In this report we overview the fundamental techniques of MIMO OFDM equalization in channels where the maximum delay exceeds the length of the Guard Interval. The are considering three main parts explaining frequency domain, time domain and turbo equalization.

2. Analysis of published data and problem statement

Data communication volume of mobile phones is rapidly increasing at present due to dissemination of smart phones and mobile communication.

Wireless communications based on multiple antennas have initially gained popularity due to the capacity increase in flat-fading channels [5]. In frequency-selective channels, this feature can be maintained by enabling OFDM, so that each subcarrier experiences a separate flat-fading MIMO channel. Notably, in frequency selective channels, spatial multiplexing MIMO-OFDM is able to offer both a rate increase and a diversity gain with respect to single-antenna OFDM [6].

The Long Term Evolution (LTE) is one of communication standards for next-generation mobile phones, which has evolved the high-speed data communication standard HSDPA for the mainstream 3G (third generation) mobile phone system W-CDMA at present. The LTE specifications have been standardized by 3G (W-CDMA) Standardization Organization 3GPP (3rd Generation Partnership Project) as “3GPP Release 8”. The long term evolution (LTE) standard adopts OFDM in the downlink and single carrier-FDMA (SC-FDMA) for uplink transmission [7]. With usage of MIMO, the LTE downlink can support up to 300 Mbps transmission rate and uplink can reach 75 Mbps. The advanced version LTE-A can support up to 1 Gbps in downlink and 500 Mbps in uplink. Compared to the OFDM used in downlink, SC-FDMA has lower peak-to-average power ratio for the transmitter. This provides higher power efficiency for the mobile device. Although, the usage of MIMO increases data rate tremendously, it also introduces inter-antenna interference. Besides this interference, the multi-path fading channels result in inter-symbol interference. With the help of cyclic prefix, the inter-symbol interference between SC-FDMA symbols can be minimized very well. However, the intersymbol interference between symbols inside the same SCFDMA symbol still remains significant. Minimum mean square error (MMSE) frequency domain equalizers (FDE) are usually adopted to reduce both inter-antenna and intersymbol interference [8]. However, in multi-path channels, MMSE-FDE can not remove the interference completely. Both residual inter-symbol interference and inter-antenna interference still exist. They are especially strong in equal tap channels. As a result, they will degrade the receiver performance. In recent years, several schemes were proposed to perform interference cancellation in LTE downlink [9] and uplink [10]. However, few papers exist on low complexity implementation for software defined radio (SDR).

3. The purpose and objectives of the study

The main objective of the equalization in LTE technology to improve the performance of the Long Term Evolution, (LTE) is one of communication standards for next-generation mobile phones.

Expansion of communication band (capacity) is a critical issue for communication carriers. We thought at work of equalization in LTE technology with MIMO and SC-FDMA for the following reasons:

1. Because the LTE that allows high-speed data communication with low delay is superior in terms of the radio wave use efficiency, many of major communication carriers in the world have indicated a policy of adopting the LTE. The rapid dissemination of the LTE in the future is expected.
2. In this work, we analyze this integrated network in order to increase the communication capacity. We take into account multi-parametric stochastic approach that combines the statistical description of the terrain and the built-up overlay with description of the signal intensity spatial distribution, taking into account the channel multipath effects from various natural and artificial obstructions located in the urban scene.
3. The LTE mobile phone system adopts the MIMO system having multiple antennas to allow high-speed communication. If noise generated in a mobile phone interferes with the antenna, the radio sensitivity lowers and the communication quality is degraded. Therefore, such interference must be suppressed by noise suppression. (Intra-system EMC) Noise must be suppressed for all antennas because the LTE allows high-speed communication using multiple antennas.

4. Main differences between OFDMA and SC-FDMA of LTE

OFDMA is a multiple access scheme based on the well-known orthogonal frequency-division multiplexing (OFDM) modulation technique. Its main principle is to split the data stream to be transmitted onto a high number of narrowband orthogonal subcarriers by means of an inverse fast Fourier transform (IFFT) operation, which allows for an increased symbol period. The latter, together with the use of a guard interval appended at the beginning of each OFDM symbol, provides this technology great robustness against multipath transmission [11]. A realization of this guard interval is the so-called cyclic prefix (CP), which consists of a repetition of the last part of an OFDM symbol. As long as the CP is longer than the maximum excess delay of the channel, degradations due to inter symbol interference (ISI) and inter carrier interference (ICI) are avoided. Furthermore, the goal of employing narrowband subcarriers is to obtain a channel that is roughly constant over each given sub band, which makes equalization much simpler at the receiver. Finally, since these subcarriers are mutually orthogonal, overlapping between them is allowed, yielding a highly spectral efficient system. Despite all these benefits, OFDM also presents some drawbacks: sensitivity to Doppler shift, synchronization problems, and inefficient power consumption due to high PAPR [11]. SC-FDMA is a multiple access scheme based on the single-carrier frequency-division multiplexing (SC-FDM) modulation technique, sometimes also referred to as discrete Fourier transform (DFT)-spread OFDM. Its main principle is the same as for OFDM; thus, the same benefits in terms of multipath mitigation and low-complexity equalization are achievable [12]. The difference though is that a DFT is performed prior to the IFFT operation, which spreads the data symbols over all the subcarriers carrying information and produces a virtual single- carrier structure. As a consequence, SC-FDM presents a lower PAPR than OFDM [13]. This property makes SC-FDM attractive for uplink transmissions, as the user equipment (UE) benefits in terms of transmitted power efficiency. On one hand, DFT spreading allows the frequency selectivity of the channel to be exploited, since all symbols are present in all subcarriers. Therefore, if some subcarriers are in deep fade, the information can still be recovered from other subcarriers experiencing better channel conditions. On the other hand, when DFT dispreading is performed at the receiver, the noise is spread over all the subcarriers and generates an effect called noise enhancement, which degrades the SC-FDM performance and requires the use of a more complex equalization based on a minimum mean square error (MMSE) receiver [12].

5. Optimal Equalization

In general, there are three categories of equalization techniques. Our technique is the time–frequency domain equalization with channel shortening. A time-domain equalizer is inserted to reduce the MIMO channels to the ones with the channel length shorter than or equal to the CP length, and then, a one-tap frequency-domain equalizer is applied to each subcarrier. When the MIMO channels are shortened by the time-domain equalizer, residual inter carrier interference and inter symbol interference are introduced. They cannot be eliminated by the subsequent frequency-domain equalizer and, thus, limit the performance. In report briefly are considering different equalization techniques. In particular very effectively is the time domain equalization (TEQ).It is using a short FIR filter at the receiver input that is designed to shorten the duration of the channel impulse response (L). Thus it allows a reduction in the guard interval length. Using a filter with up to 20 coefficients, the effective channel impulse response of a typical AWGN channel can easily be reduced by a factor of 10. Different cost functions such as minimum mean squared error, maximum shortening signal-to-noise ratio (SNR), and minimum intersymbol interference (ISI), and maximum bit rate have been proposed to design the (TEQ). Each received symbol y_i of a block can be written as a sum of the useful part of the symbol, interference and noise In (1) r_{ij} are the elements of the discrete-time channel matrix [14].

$$\tilde{y}_i = r_{ii} y_i + \sum_{i=1, i\neq j}^{N} r_{ij} y_i + n_{ci}. \tag{1}$$

The idea of the (recurrent neural network) RNN equalizer [2] is to estimate the interference and subtract it from the received symbol.

$$\tilde{y}_k^{(l)} = yk - \sum_{j=1}^{K} \frac{r_{kj}}{r_{kk}} \tilde{y}_k^{(l-1)}, \tag{2}$$

$$\tilde{y}_k^{(l)} = \theta(\tilde{y}_k^{(l)}). \tag{3}$$

After the final iteration step log likelihood ratios (LLRs) [15], [16] are calculated and passed to the turbo decoder. The activation function θ (·) builds the core of the RNN equalizer. The optimum activation function for complex-valued symbol alphabets has been derived by Sgraja et al. For binary phase shift keying the well-known hyperbolic tangent function is obtained. Based on the remaining interference power and the noise power the optimum activation function is calculated in each iteration step. For the tangent hyperbolic function the remaining degree of freedom to be adjusted is the slope at the point of inflection. Generally the steepness of the function will increase with increasing iteration number. This reflects the improving reliability of the soft symbol estimates due to the successive interference cancellation. The updating of the subchannels is also of great influence on the recurrent neural networks RNN's performance.

6. Simulation results equalization in LTE

The transmission bandwidth of 5 MHz translates to a total number of M=512 subcarriers available in the OFDMA subsystem. The number of subcarriers occupied for the transmission is fixed to K=300. For all simulations the extended vehicular A (EVA) model from the LTE standard is used. The power delay profile is assumed to be known perfectly at the receiver. The channel impulse response is assumed to be time invariant within one slot, i. e. for seven SC-FDMA symbols. The cyclic prefix is chosen sufficiently long. The output of the turbo coder is always punctured to a code rate of 1/2. The modulation alphabet used is the 16QAM alphabet. The following parameters are used in the receiver: a fixed number of eight iterations are performed in is used for the RNN, if implemented in a conventional receiver structure. For both the MMSEBLE and conventionally implemented RNN eight iterations are performed in the turbo decoder. The turbo equalizer uses two inner iterations, each with four RNN and four turbo decoder iterations. Fig. 1 shows the transport block error rate (TBER) for the three equalizers. Both implementations of the RNN equalizer show a very good performance for a low signal to noise ratio and both significantly outperform the MMSE-BLE.

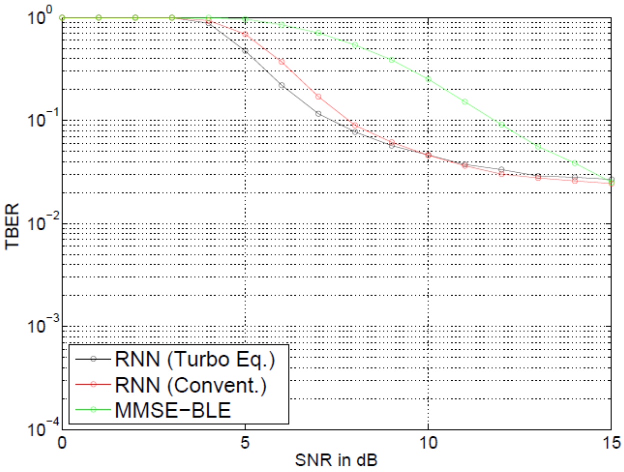

Fig. 1. Transport block error rates for the 16QAM modulation and a code rate of rc=0:5 for the EVA channel model for different equalizers

The turbo equalization shows slight advantages compared to the conventional receiver structure. For a higher SNR the MMSE-BLE outperforms the RNN equalizer due to an error floor. This error floor is caused by the RNNs tendency to converge against a wrong solution in case of very poor representatives of the channel impulse response. Due to the statistical channel model used some channels exhibit a very high frequency selectivity and thus create a vast amount of interference. Simulations carried out for different code rates and other LTE channel models show similar results. In Fig. 2 the throughput η for the time and frequency domain equalizers is shown. Considerable performance gains can be realized by the application of time domain equalization. At a throughput of η=0:9 a gain of roughly 5 dB is realized by the RNN equalizer. The time domain equalization shows superior performance compared to the MMSE-BLE until a SNR of about 15dB. Then the influence of the error floor makes the MMSE-BLE outperform the RNN equalizer. When comparing the turbo equalizer with the conventional RNN equalizer, a gain of roughly 1dB may be realized in the SNR region between 4 to 8dB. Overall the benefits from the time domain equalization may become more apparent if throughput rates are studied.

The total throughput for 16QAM on the EVA channel model are shown in Fig. 3. A larger gain in the lower SNR regions can be achieved using the RNN equalizer.

Until a SNR of 15dB, the RNN equalizer, implemented in a turbo or conventional receiver structure, can improve the throughput by up to 30 %. For higher SNRs the MMSE-BLE outperforms the RNN equalizer. Especially using the turbo equalization implementation of the RNN, after 9 Mbit=s the throughput does not improve any further. However, modifying the scheduling of the multidimensional turbo iteration process, further performance gains are possible. This can be seen form the fact that the conventionally implemented RNN equalizer achieves a throughput of up to 10 Mbit=s.

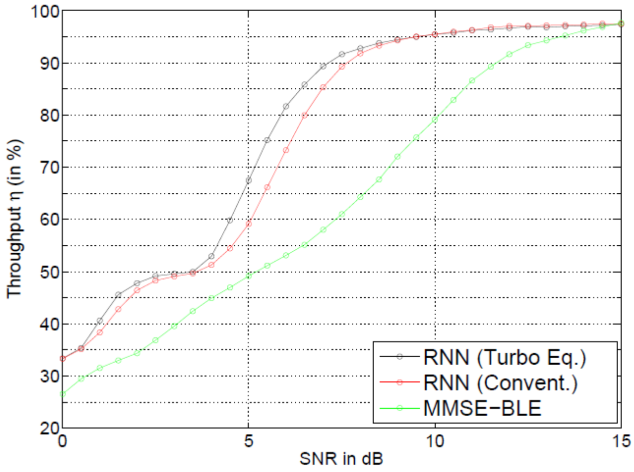

Fig. 2. Throughput for the EVA model with a code rate of rc=0:5 using a 16QAM alphabet for different equalizers

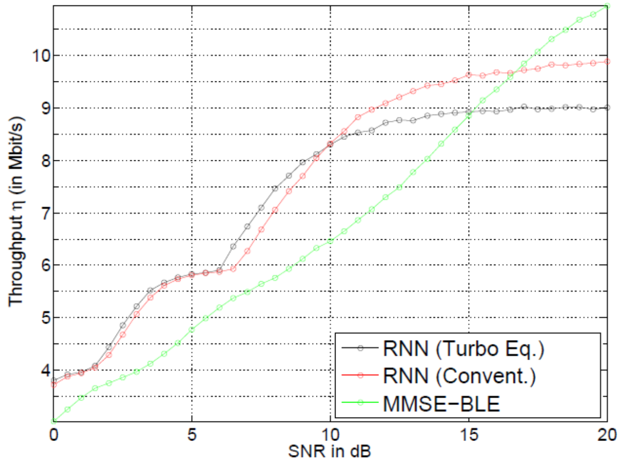

Fig. 3. Maximum throughput of different equalizers using the 16QAM modulation and the EVA channel model

7. Conclusion

The LTE allows high-speed data communication (reception: 100 Mbps or higher and transmission: 50 Mbps or higher). Since the frequency band is expanded up to 20 MHz, the logical maximum transmission rate is 326.4 Mbps in reception and 86.4 Mbps in transmission. The data communication rate is higher than that of 3G/3.5G even at the same frequency band, which allows acceptance of a lot of users. Furthermore, the LTE achieves low-delay transmission with a connection delay of 100 ms or less and a radio section transmission delay of 5 ms or less. Thus the LTE is suited for audio communication, moving picture distribution, and online games. The best performance is introduced by turbo equalization due to the improvement of the equalized signal estimation on the each iteration and better cancelation of the ISI component. OFDMA and SC-FDMA has several benefits over other transmission schemes like high spectral efficiency due to the orthogonality between subcarriers it is possible to pack them closely together (15kHz subcarrier spacing). Robustness in multi-path environments thanks to the cyclic prefix as mentioned before. On basis of the simulated results, it was concluded that the structure has low bit error rate when MLSE equalizer is used. It is shown through numerical simulations that high performance gain is achieved in equalized MIMO OFDM system. A broad frequency range (700 MHz to 2.7 GHz) is adopted for the LTE and frequency bands are allocated to communication carriers in each country.

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ВПЛИВ ПОМИЛОК НА ТОЧНІСТЬ РЕЗУЛЬТАТІВ ПРОСТОРОВОГО МОНІТОРИНГУ В УМОВАХ НАДЛИШКОВОСТІ ІНФОРМАЦІЇ

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В умовах інформаційної надмірності рішення задачі оптимального використання оцінок одного і того ж вектора стану, отриманих різними вимірювачами одночасно, передбачає їх вагове підсумовування. Але матриця вагових коефіцієнтів, що входить у вираз для визначення результуючої оцінки, залежить від значень параметрів, які вимірюються, і апріорно не завжди відомі. Проведено аналіз впливу помилок визначення матриці вагових коефіцієнтів на точність результуючої оцінки

Ключові слова: об'єднання інформації, вимірювання параметрів, незалежні вимірювачі, фільтрація оцінок, матриця вагових коефіцієнтів

В условиях информационной избыточности решение задачи оптимального использования оценок одного и того же вектора состояния, полученного различными измерителями одновременно, предполагает их весовое суммирование. Однако матрица весовых коэффициентов, входящая в выражение определения результирующей оценки, зависит от значений измеряемого параметра и априорно не всегда известна. Проведен анализ влияния ошибок матрицы весовых коэффициентов на точность результирующей оценки

Ключевые слова: объединение информации, измерение параметров, независимые измерители, фильтрация оценок, матрица весовых коэффициентов

1. Вступ

Виявлення небезпечних факторів надзвичайних ситуацій здійснюється за допомогою систем моніторингу різного рівня. Реалізація завдань моніторингу потребує наявності комплексу даних, які обґрунтовують прийняття рішень щодо забезпечення безпеки життя і діяльності населення, що мешкає та працює на територіях, які підпадають під вплив небезпечних і шкідливих факторів аварій, катастроф та стихійних лих. Причому, йдеться не про окремі спостереження, а про їхній комплекс, оскільки тільки інформація про відповідні параметри може надати правдиву картину подій, що відбуваються, умов розвитку і як наслідок забезпечити прийняття адекватних заходів щодо попередження їхнього виникнення.

2. Аналіз досліджень літератури та постановка задачі

До числа найбільш важливих джерел отримання достовірної інформації відносяться вимірювання по-