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Description	

Towards Less-than-One Reuse Factor: Space-Time MIMO Turbo Equalizers System-Level Simulation Results

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Abstract

Current advances in multi-dimensional channel sounding techniques make it possible to evaluate performances of signal processing algorithms in realistic conditions. By using channel impulse response measurement data collected in the real fields, link-level performances of the signal processing algorithms in the fields such as bit error rate (BER) and frame error rate (FER) performances can be evaluated. This technique is called link-level simulation. Through statistical analysis of link-level simulation results, system-level performances of S/T-equalizers such as SINR and BER distributions in the area of interest can also be evaluated. This technique is called system-level simulation.

This paper focuses on link- and system-level performances of Space/Time- (S/T-) and MIMO Turbo Equalizers in real fields. Methodologies for the link- and system-level simulations using field measurement data are first presented. Results of link- and system-level simulations using two-dimensional channel sounding field measurement data collected in Tokyo are then presented. The assumption made in this paper is that multiple users aim to transmit their signals using the same time- and frequency-slots without spreading their signals in the frequency domain, which is an ultimate goal of cellular mobile communication engineering. It is shown that S/T- and MIMO Turbo Equalizers make this ultimate goal realistic.

1. Introduction

Tremendous effort is currently being made to exploit the spatial dimension of channels with the aim that the multiple-input multiple-output (MIMO) system concept can really be in place [1]-[3]. An enormous number of research papers have been published that introduce joint space/time- (S/T-) signal processing algorithms for MIMO communications. The obvious purpose of S/T-equalization is to endow receivers with immunity against inter-symbol interference (ISI) and co-channel interference (CCI). Refs. [4] and [5] survey the historical background of the technology, and summarize current trends in S/T-equalizer algorithm development. Despite the volume of efforts made on algorithm development, few papers have examined in-field performance.

Discovery of the Turbo codes has motivated the research for the creation of new signal detection concepts that are, in general, referred to as Turbo principle. Ref. [6] presented a new signal detection scheme, soft-canceller followed by minimum mean square error (SC/MMSE) filter, which can be seen as a Turbo principle-based technique. Recently, we have applied the SC/MMSE technique to MIMO signal detection [7], of which device is referred to as SC/MMSE MIMO Turbo equalizer. Although the computational complexity of SC/MMSE MIMO Turbo equalizer is only in proportion to the 3rd power of the total paths number existing in the MIMO radio link topology, its performances are almost equivalent to the optimal detector based on the multi-user maximum likelihood sequence estimation (MLSE). This low complexity of SC/MMSE MIMO Turbo equalizer invokes research for single carrier broadband MIMO system where all users use the same time- and the same frequency-slots without relying on multi-carrier or spread spectrum techniques.

Parameter design for practical systems should, in general, reflect the radio environments wherein the systems are to operate. In design of S/T-equalizer as well as MIMO Turbo equalizer, the key factors that determine overall performance are the *spatial* and *temporal* properties of the radio channels. Unlike the third-generation (3G) and prior systems, which mainly exploit the received signal's *temporal* structure [8], future broadband mobile communication systems must well exploit the received signal's *temporal* and *spatial* structures. In fact, the received signal's directional spread provides us with another dimensionality that can be used to resolve the received signal components, and then recombining them. Unfortunately, however, the majority of papers dealing with S/T-equalization techniques use idealistic channel models such as the exponential-temporal and Gaussian-spatial distribution model. These idealistic models are too simple, and so cannot well predict the performances of S/T-equalizers in the field.

Current advances in multi-dimensional channel sounding techniques make it possible to evaluate performances of signal processing algorithms in realistic conditions [9]. Channel impulse response (CIR) sequences from a transmitter to each of the antenna elements can be recorded. Recorded real-time channel sounding measurement data can be used for realistic off-line simulations. Since the data represents a real propagation scenario, performances of S/T-equalizer as well as MIMO Turbo equalizer in the field can be accurately evaluated by running the measurement data through the S/T- and/or MIMO Turbo equalization algorithm of interest. This technique provides us with much more realistic estimates of S/T-equalizer performance than model-based simulations.

The purpose of this paper is to evaluate system-level performances of S/T- and MIMO Turbo equalizers in fields. This paper is organized as follows: Section 2 describes methodologies for the link- and system-level simulations using two-dimensional channel sounding field measurement data. Section 3 shows results of the simulations conducted to evaluate link- and system-level performances of S/T-equalizer as well as SC/MMSE MIMO Turbo equalizer in real fields. A major conclusion of this paper, which is given in Section 3.4, is that even if multiple users use the same time- and frequency-slots without spreading their signals in the frequency domain, an acceptable Signal-to-Interference *plus* Noise power ratio (SINR) at the Spatial equalizer output can be achieved at more than 99% of the areas. This strongly advances the achievement of the ultimate cellular system configuration.

2. Link- and System-Level Simulations

2.1 Objectives

Both link- and system-level simulations are off-line simulations using multidimensional channel sounding field measurement data, but their objectives are different. They are defined as follows:

(1) Link-level simulation aims to evaluate S/T- and MIMO Turbo equalizers' link-level performance in terms of bit error rate (BER) in various radio environments. It focuses on analyzing/evaluating the impact of S/T-equalizer configurations, parameters, and algorithms on performance.

(2) System-level simulation aims to obtain system-level performance figures such as SINR and BER geographical distributions in the areas of interest as well as outage probability. Main focus is on interference scenarios, which depend on cell design including frequency reuse and user distribution.

2.2 Field Measurements

To conduct link- and system-level simulations, sets of impulse response data have to be gathered in the area of interest. A series of two-dimensional channel sounding measurements was conducted in a typical urban area of Tokyo. A two-dimensional channel sounder [9] was used in the field measurements. Table 1 summarizes major specifications of the field measurement. The channel sounder receiver's eight-element uniform linear array (ULA) was located on top of a building whose height was approximately 40 meters. Other surrounding buildings had almost the same height. The transmitter was moved along a street. The propagation paths between the sounder's transmitter and receiver were all non-line-of-sight. The output of the field measurement was sets of data indicating the measured impulse responses of the radio channels between the transmitter's omni-directional antenna and each of the 8 elements of the receiver antenna array. For the evaluation of average performance, simulation results obtained by using channel impulse response data collected in the vicinity of the measurement area of interest had to be averaged. For this purpose the channel impulse responses were calculated every 200 milliseconds in succession.

2.3 Link-Level Simulations

Figure 1 shows a schematic diagram of the link-level simulations. Since the CIRs between the omni-directional transmitter antenna and each of the L antenna elements have been obtained through the two-dimensional channel sounding field measurements, the snapshot vector sequence representing each element's received signal waveform can be calculated by convoluting the transmitted waveform with the measured CIR samples.

Received waveforms of co-channel interference signals can also be calculated in the same way from the CIR data measured at different transmitter positions. The calculated received waveforms of the desired and interference signals are added together element-by-element. Statistically independent additive white Gaussian noise (AWGN) samples are then added, and the snapshot sequences corrupted by AWGN are further convolved with the root roll-off filter's impulse response to obtain output waveforms of the L antenna elements. Signal processing for calculating element output sample sequences as well as for running S/T- and MIMO Turbo equalizer algorithms can all be conducted on a PC platform.

2.4 System-Level Simulation

System-level simulation aims to evaluate system-level performance attributes such as outage probability of a system using S/T- and/or MIMO Turbo equalizers, for which geographical distributions of parameters in a certain area of interest have to be calculated. Figure 2, a map of the measurement area, shows that there were two hexagonal adjacent cells (250 meter cell radius) that are referred to as Cell A and Cell B for convenience. Each cell was divided into six 60-degree sectors. The channel sounder receiver's eight-element ULA was located at the center of Cell A, paralleling the centerline of one of the six 60-degree sectors, which is referred to as Sector A_1. There are three 60-degree sectors in Cell B that belong to Sector A_1's 60-degree coverage extension. They are referred to as Sectors B_1, B_2, and B_3, respectively.

Channel sounding signals were transmitted from the points belonging to Sectors A_1, B_1, B_2, or B_3 at different times, and sets of CIR data between the transmitter's omni-directional antenna and the receiver's antenna elements were collected. Obviously, one ultimate goal of cellular system engineering is that every user can use the same time- and frequency-slots without spreading signal bandwidth. To envisage the possibility of achieving this goal by using S/T-equalization, interferers in Sectors B_1, B_2, and B_3 were made active, and the desired users were placed in A_1.

The desired users were assumed to communicate with the base station in Cell A, and the interferers with the base station in Cell B. Path-losses due to distance were first calculated corresponding to the distances between the users' locations and their communicating base stations. The loss incurred by shadowing was then computer-generated for each of the users, and the shadowing losses were multiplied by the distance-based path losses user-by-user. It was assumed that the attenuation of signal strength due to the path-loss was proportional to the fourth power of distance, and that shadowing variation followed a Log-Normal distribution with standard deviation of 8.0 dB.

The users were assumed to be power-controlled by their home sector's base stations to compensate the path-loss and shadowing. The effect of the power control on signal strengths of the interferers in Sectors B_1, B_2, and B_3, received by Sector A_1's receiver, was then taken into account.

3. Simulations Results

3.1 MIMO Turbo Equalizer Link-Level Simulation Results

A two-user MIMO communication environment was first simulated. Major specification of the simulation is summarized in Table 2. The measurement run took place over 8 seconds in succession for the each user's location, and the CIR data was corrected every 200 mille seconds. The collected sets of data were run to perform the SC/MMSE MIMO Turbo equalizer algorithm for the two users, and the average BER performances curves were obtained. The iterative channel estimation technique presented in Ref. [10] was used. Figures 3 (A) and (B) show average bit error rate (BER) performance obtained as a result of MIMO link-level simulation: Fig. 3 (A) is for the first user, and Fig. 3 (B) for the second user. Solid lines in the figures are the performance curves corresponding to the case where there is only one user, and the channel is assumed to be known. Hence, the solid curve indicates the performance limit of the MIMO channel. It is found that for the both users the difference between the MIMO and single user curves is roughly 1 dB after the third iteration.

Figure 4 shows in a three-user MIMO communication environment BER performance after the 5[th] iteration, averaged over the three users. Major specification of the simulation is the same as in Fig. 3, but the three users' positions are fixed in this case. The SC/MMSE Turbo MIMO equalizer algorithm was run assuming the complex gains with the paths in this MIMO radio topology are assumed to be known. It is found that the difference between the MIMO and single curves is, again, roughly 1 dB.

3.2 S/T-Equalizer System-Level Simulation Results

Figure 5 shows a block diagram of the S/T-equalizer considered. It consists of a cascaded connection of adaptive array antenna and adaptive equalizer [11], [12]: each of the adaptive array antenna elements is equipped with a fractionally spaced tapped delay line (FTDL), and the Time-equalizer has taps covering a portion of the channel delay profile. The maximum likelihood sequence estimator (MLSE) is used to estimate the sequence considered most likely to have been transmitted.

Key parameters are the numbers L, M, and N of the antenna elements, the FTDL taps, and feedback taps in the MLSE equalizer, respectively; these are expressed as (L, M, N) for notation convenience. The tap weights were determined adaptively using the recursive least square (RLS) algorithm. As a result of the field measurement, we obtained 45 sets of CIR data. 10000 combinations were taken by randomly choosing the desired and three interference users' locations corresponding to 45 field measurement points within the sector A1, B1, B2, and B3 (In this case, one desired and three interferers were considered). For each of the 10000 combinations, the S/T-equalization signal processing was performed using the measured CIR data for the S/T-equalizer. Cumulative distribution of Spatial-equalizer's output signal-to-interference plus noise power ratio (SINR) defined as SINR=(*Total of Combinable Path Energies*)/ (*Mean Square Error After Convergence of RLS Algorithm*) was evaluated as a S/T-equalizer's system-level performance figure.

Figure 6 shows spatial equalizer output SINR (=MLSE input SINR) distribution curves with L, M, and N values as parameters. It is found from the figure that even without the MLSE feedback taps, (8, 11, 0) configuration can achieve higher than 8 dB SINR at the Spatial-equalizer's output in 99% of Sector A_1.

With 5 feedback taps in MLSE, the SINR distribution can further be enhanced: with (L, M, N)=(8, 11, 5) the Spatial-equalizer's output SINR is higher than or equal to 10 dB in 99% of Sector A_1.

3.3 MIMO Turbo Equalizer System-Level Simulation Results

As a MIMO Turbo equalizer's system level performance figure, cumulative distribution of bit error rate (BER) in Sector A_1 was evaluated. Two users were located in Sector A_1, and they simultaneously transmitted their signals to the base station. As a result of the field measurement, we obtained 75 sets of CIR data. 1250 combinations were taken by randomly choosing two locations from the 75 field measurement points within the sector A_1 for the two users. (In this case, the two users are both desired, and no interferers were considered).

At the base station, the SC/MMSE MIMO Turbo equalization algorithm was performed. Other simulation conditions are summarized in the table in Fig. 7. Result of the system level simulation is shown in Fig. 7. The parameter is Fig. 7 the iteration times of the MIMO Turbo equalizer. It is found that after 4^{th} iteration, 10^{-5} BER can be achieved at more than 97 % of the A_1 area.

4. Conclusions

In this paper we have focused on link- and system-level performances of Space/Time- (S/T-) and MIMO Turbo Equalizers in real fields. Roles of the link- and system-level simulations were fisrt defined, and methodologies for them using field measurement data were presented. The assumption made in this paper is that multiple users aim to transmit their signals using the same time- and frequency-slots without spreading their signals in the frequency domain. Results of link- and system-level simulations using two-dimensional channel sounding field measurement data collected in Tokyo indicate that S/T- and MIMO Turbo Equalizers make this ultimate goal quite realistic.

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Table 1 Major Specifications of Field Measurement

Bandwidth	100 MHz
Radio Frequency	5.2 GHz
Transmitter	Omnidirectional
Receiver	8 elements of ULA
Tx/Rx Synchronization	Rubidium Reference
Sounding Signal	Multi-Tone

Table 2 Major Specification of MIMO Turbo Equalizer Simulations

MIMO Structure	2 Users (Moving) / 2 Receive Antennas
Encoder	Convolutional Code (Rate: 1/2, Const.Length:3)
Modulation	BPSK
Decoder	Max-Log-Map
RF	5.2 GHz
Data Rate	12Mbps
Tx/Rx Filter	Root Roll Off Filter (Roll Off Factor = 0.5)
Synchronization	Correlation Based

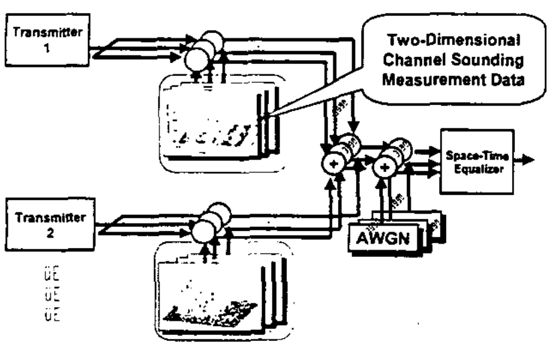

Fig. 1: Schematic Diagram of Link-Level Simulations

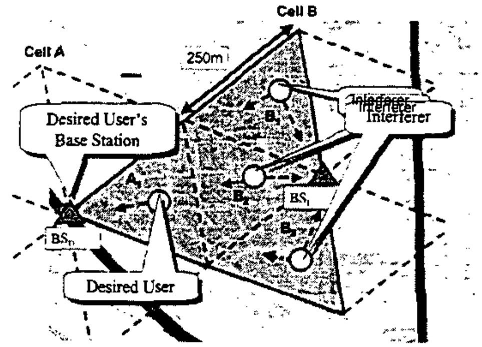

Fig. 2 Map of the Field Measurement Area

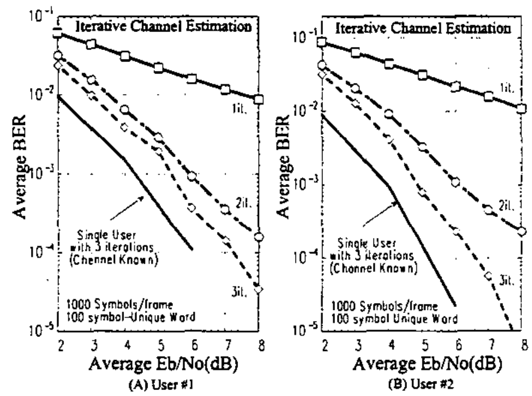

Fig. 3 BER Performances with MIMO Turbo Equalizer

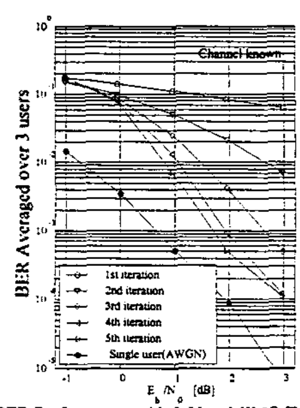

Fig. 4 BER Performance with 3-User MIMO Turbo Equalizer

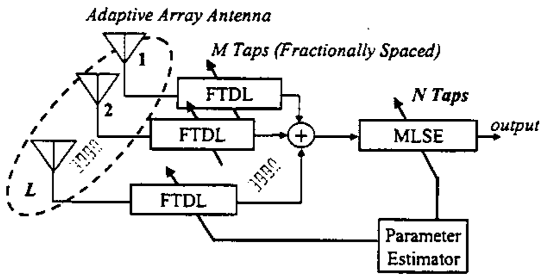

Fig. 5 Block Diagram of S/T-Equalizer

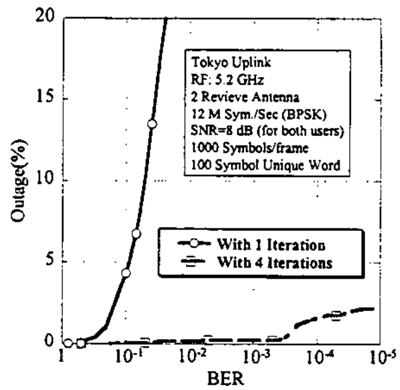

Fig. 7 cdf of BER in A_1 Area

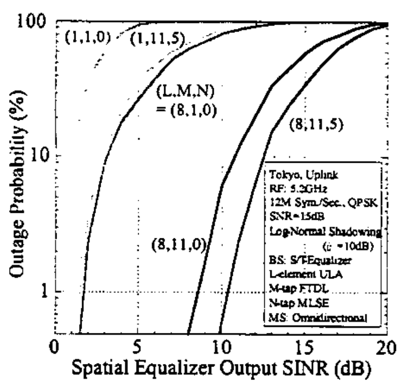

Fig. 6 Cdf of Spatial Equalizer Output SINR