Performance Evaluation for FTDL-Spatial/MLSE-Temporal Equalizer Using Field Measurement Data

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Abstract — **This paper shows results of link level simulations conducted to evaluate performances of spatial and temporal equalizers (S/T-Equalizers) using field measurement data. The spatial and temporal equalizer discussed in this paper have a configuration expressed as a cascaded connection of adaptive array antenna and maximum likelihood sequence estimator (MLSE): each of the antenna elements has a fractionally spaced tapped delay line (FTDL), and the MLSE has taps covering a portion of channel delay profile. Bit error rate (BER) performances of the S/T-Equalizers, including the in the presence of Co-channel Interference (CCI) are presented. Performance sensitivity to symbol timing offset is also investigated. Major conclusions of this paper are that allocating more taps to spatial domain is more effective than to time domain when the total number of taps is fixed, and that increasing the FTDL length is effective in reducing performance sensitivity to timing offset.**

I. Introduction

A goal of this paper is to show effectiveness of spatial and temporal equalization (S/T-Equalization) under real mobile radio propagation environments. The methodological basis of this paper is link-level simulations using a two-dimensional (spatial and temporal) channel sounding technique. Channel impulse response data gathered through field measurements are used in the link-level simulations to estimate real performances of S/T-Equalizers. Type of S/T-Equalizer investigated in this paper is an L-element adaptive array antenna followed by a maximum likelihood sequence estimator (MLSE). Each of the L antenna elements is equipped with a fractionally spaced tapped delay line (FTDL).

Link-level simulation itself is merely an off-line simulation, but makes it possible to compare performances on a fair and practical basis since it uses the same field measurement data for different equalization schemes and algorithms. This paper first evaluates performances of the FTDL/MLSE S/T-Equalizer through link-level simulations using field measurement data gathered in an urbane area of Tokyo. Simulations were also conducted using the same data for other two types of S/T-Equalizer: one is an L-element FDTL adaptive array antenna followed by a DFE; the other an L-element FDTL adaptive array antenna alone (the former referred to as L-FTDL/DFE, and the latter L-FTDL). Account is taken of the presence of a Co-Channel Interferer (CCI).

Another discussion topic of this paper is performance sensitivity to timing offset from its optimal position. It is well known that MLSE equalizer performances are relatively sensitive to timing offset and that the sensitivity can be significantly relaxed if the FTDL has a sufficient length [1]. It is shown that the same conclusion as Ref. [1] can be drawn for the L-FTDL/MLSE S/T-Equalizer.

This paper is organized as follows: Section II shows filed measurement data representing temporal and spatial characteristics of the channel. Section III describes the configuration of the S/T-Equalizers investigated in this letter. Section IV shows results of the link-level simulations using the field measurement data.

II. Field Measurement

The two-dimensional channel sounder system [2] used in the field measurement, and the signaling scheme assumed in the link-level simulations are mostly the same as those described in Ref. [3], [4], and [5]. Table 1 summarizes major specifications of the field measurement. The channel sounder system makes it possible to identify channel impulse response with a reasonable accuracy for 12 $Msymbols/sec.$ signal transmission offline simulations.

A series of field measurements took place in a typical urban area of Tokyo prior to the link-level simulations. Output of the field measurement is a set of data indicating the impulse responses of the radio channels between the transmitter's omnidirectional antenna and each of the L elements of the receiver antenna array. The transmitted test signal is a chirp waveform with $100MHz$ bandwidth, of which carrier frequency is $5.2GHz$. The channel sounder employs FFT-based correlation processing at the receiver. A software utility of the channel sounder system can provide a two-dimensional (temporal and spatial) super-resolution signal analysis capability, with which a $6nsec.$ time-domain and a $2.5degree$ spatial-domain resolution can be achieved.

For the evaluation of average performances, simulation results obtained by using channel impulse response data collected in the vicinity of the measurement area of interest have to be averaged. For this purpose the channel impulse responses were calculated every 0.6 meters in succession. Fig. 1 (A) shows an example of the channel impulse response data gathered over 8 seconds of a measurement run. and Fig. 1 (B) an example of the two-dimensional profile of the received composite signal obtained as a result of the two-dimensional signal analysis.

III. S/T-Equalizer Configuration

Fig. 2 shows a block diagram of the S/T-Equalizers evaluated in this paper. Key parameters with the configurations in Fig. 2 are the numbers L and M of the antenna elements and the FTDL taps, respectively, which are expressed as (L, M) for notation convenience. Another important parameter is the number N of the feedback taps in MLSE. Fig. 3 (A) shows a block diagram of the MLSE equalizer, where the N feedback taps are used to generate the replicated signal at the array output corresponding to the symbol sequence considered most likely to have been transmitted. The number of the states used by the Viterbi algorithm for MLSE is $Q(N-1)$ for Q-level signaling. For quaternary phase shifted keying (QPSK), $Q = 4$. With L-FTDL/DFE and L-FTDL, the definitions of L, and M are the same as with L-FTDL/MLSE. Fig. 3 (B) shows a block diagram of the DFE equalizer.

Table 2 summarizes major specification of the signal format used in the link-level simulations. QPSK was used as a modulation scheme. Transfer function of a Nyquist filter with roll-off factor $\alpha = 0.5$ was shared equally by the transmitter and receiver. A $12 Msymbols/sec.$ QPSK signal was root roll-off filtered at both the transmitter and receiver for spectrum shaping and noise reduction, respectively. All the $LM+N$ weights are updated by using the recursive least squares (RLS) algorithm every symbol timing using the training sequence embedded periodically in the transmitted data frames. Signal processing for link-level simulations, including calculating waveforms of root roll-off filtered symbol sequences to be transmitted, convolving the transmitted waveforms with the channel impulse response data, and further convolving the channel output with the root roll-off filter's impulse response to obtain the output of the antenna elements, was all conducted on a PC platform.

IV. Results

A Performance Comparison

Off-line simulations were conducted using the Tokyo measurement data. For a fair comparison of performances among the three types of the S/T-Equalizers, the $L \times M$ value was kept constant at 24. For L-FTDL/MLSE and L-FTDL/DFE, $N = 3$, and for L-FTDL, $N = 0$. Fig. 4 shows average bit error rate (BER) performances for various values of (L, M). The BER curves shown in Fig. 4 were obtained for a symbol timing at which the channel impulse response exhibits its maximum point in magnitude. It is found that smaller BERs can be achieved with larger L values (hence smaller M values). This indicates that the dominant factor in determining the BER performance is the element numbers of the spatial equalizer. It is found also from Fig. 4 that the use of feedback taps can improve BERs, but the performance difference between L-FTDL/MLSE and L-FTDL/DFE is quite small. In fact, the level of significance of performance improvement should depend on how suitable the channel impulse response is to the S/T-equalizer configuration considered, and hence more significant performance improvement should be achieved by L-FTDL/MLSE under different two-dimensional channel characteristics.

B BER Performance of FTDL/MLSE S/T-Equalizer in the presence of CCI

Fig. 5 shows average BER performance curves of L-FTDL/MLSE S/T-Equalizer with (L, M) and average signal-to-interference power ratio (C/I) as parameters. It is found from Fig. 5 that smaller BERs can be achieved by increasing the antenna element number L. Increasing FTDL tap number can also improve the BER performance. However, under a constraint that $LM = constant$, allocating more taps to spatial domain is more effective than to time domain.

C Performance Sensitivity to Timing Offset

It is well known that MLSE equalizer performances are relatively sensitive to timing offset [1]. To evaluate L-FTDL/MLSE's performance sensitivity to timing offset, 8 times over-sampling with respect to the symbol rate T was performed in the link-level simulations. Fig. 6 shows results of simulations in a dynamic condition where measurement data were gathered while the transmitter was moving. Hence, the BER curves shown in Fig. 6 indicate average performances, averaged over the data gathered during the measurement run. BERs were then evaluated for different timing offset indices with the FTDL length M as a parameter. The zero offset in Fig. 6 is the timing at which the channel impulse response exhibits its maximum point in magnitude. It is found that increasing the FTDL length M is effective in reducing the performance sensitivity to timing offset.

V. Conclusions

This paper has shown results of a series of link level simulations conducted to evaluate performances of FTDL/MLSE, L-FTDL/DFE, L-FTDL S/T-equalizers without CCI and that of FTDL/MLSE S/T-Equalizer in the presence of CCI. Field measurement data gathered in an urbane area of Tokyo was used in the link-level simulations. It has been shown that L-FTDL/MLSE S/T-Equalizer has the best performance, but the performance difference between L-FTDL/MLSE and L-FTDL/DFE is quite small. It has also been shown that allocating more taps to spatial domain is more effective than to time domain when the total number of taps are fixed.

Another point in this paper has discussed is the performance sensitivity of the L-FTDL/MLSE S/T-equalizer to timing offset. It has been shown that increasing the FTDL length is effective in reducing the performance sensitivity to timing offset.

References

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[4] T. Yamada, S. Tomisato, U. Trautwein, and T. Matsumoto, "Results of Link-Level Simulations Using Field Measurement Data for an FTDL-Spatial/MLSE-Temporal Equalizer", submitted to IEICE Trans. COM.

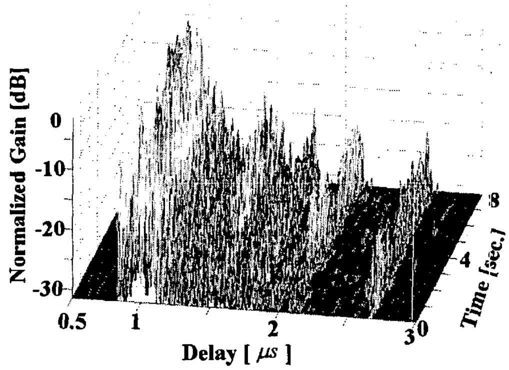
[5] T. Yamada, S. Tomisato, U. Trautwein, and T. Matsumoto, "Performance Evaluation of FTDL/MLSE-Temporal Equalizers in the Presence of Co-channel Interference" submitted to IEICE Trans. COM.

Table 1: Major Specifications of Field Measurement

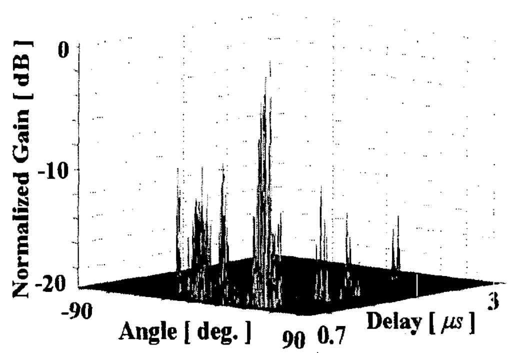
Bandwidth	100 MHz
Radio Frequency	5.2 GHz
Transmitter	Omnidirectional
Receiver	ULA, 8 elements
Tx/Rx Synchronization	Rubidium Reference
Time-domain Resolution	6 nsec.
Spatial-domain Resolution	2.5 deg.

Table 2: Major Specifications of Simulation

Modulation	QPSK
Symbol Rate	12 Msymbols/sec.
Tx/Rx Filter	Root Roll-off, $\alpha = 0.5$
Frame Format	Training: 450 symbols Data: 4960 symbols Guard: 40 symbols
S/T-Equalizer	ULA, L element(s) $T/2$ spaced FTDL, M tap(s) 16 state MLSE, DFE (3 taps)
Update Algorithm	RLS, $\lambda = 0.97$



(A) Measured Channel Impulse Response



(B) Delay-Angular Profile of Measured Channel Impulse Response

Fig. 1: Example of Measured Channel Impulse Response

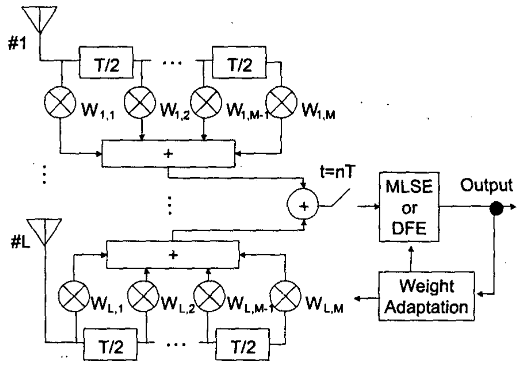
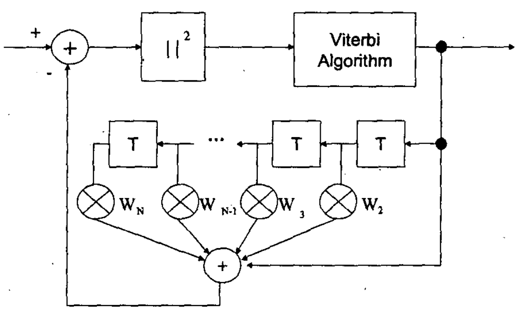
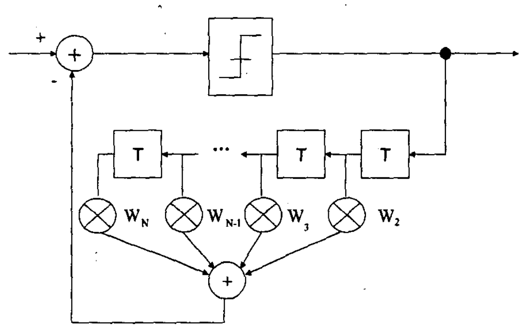


Fig. 2: Block Diagram of S/T-Equalizer



(A) Block Diagram of MLSE



(B) Block Diagram of DFE

Fig. 3: Block Diagrams of Temporal-Equalizer

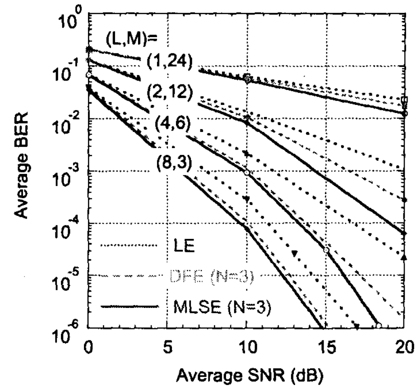


Fig. 4: L-FTDL/MLSE BER vs. Received Signal-to-Noise Power Ratio in Dynamic Condition

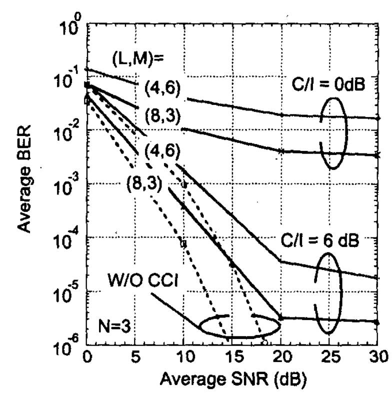


Fig. 5: Average BER vs. Average Received Signal-to-Noise Power Ratio in Dynamic Condition

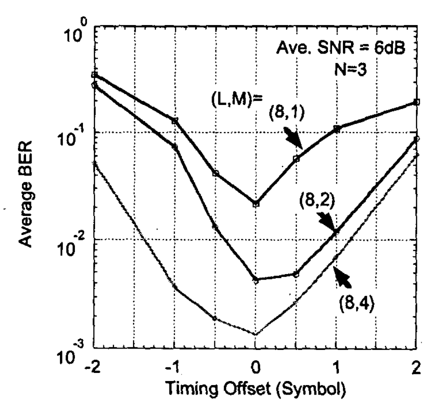


Fig. 6: Average BER vs. Timing Offset in Dynamic Condition