Efficient Link Quality Prediction for OFDM Systems

Wang Xiaoqin
FUJITSU R&D CENTER CO., LTD.
Beijing, China
wangxiaoqin@cn.fujitsu.com

Wang Xin
FUJITSU R&D CENTER CO., LTD.
Beijing, China
wangxin@cn.fujitsu.com

Abstract—**This paper presents an efficient link quality prediction method for OFDM systems. It is based on effective SINR mapping (ESM) approach. Being different from conventional ESM methods, the novel scheme employs constrained linear averaging to multiple instantaneous channel indicators. Its computation complexity is lower than conventional ones. Because there is no two-step mapping processing with invertible mapping functions. Its memory requirement is also much less because no additional off-line ESM look-up table is required. Finally, its performances in terms of BLER and throughput are evaluated in link adaption. Simulation results show that it is efficient.**

Keywords-link quality prediction; OFDM; ESINR

I. Introduction

Due to the good spectrum efficiency and tolerance of inter-symbol interface (ISI), orthogonal frequency division multiplexing (OFDM) is being considered as a modulation method for 4^{th} generation wireless communications.

In wireless communication systems, downlink transmission with channel quality information (CQI) is commonly used to provide higher link capacity and transmission reliability. Therefore, link quality prediction is an essential part in wireless receivers. And its accuracy has an important effect on the whole systems' performance and quality of service (QoS).

Previously, the average channel condition [1], which was quantified by physical (or average) signal to noise ratio (SNR), has usually been utilized. It was computationally simple. However, it is only effective for narrow band systems or static/quasi-static link condition, and there will be performance degradation for wide band systems such as OFDM systems with various fading link quality.

Currently, instantaneous link conditions are exploited for performance enhancement, especially in wide band wireless communication systems and fading channels. In earlier 3GPP contributions and standardization, several methods which are effective for OFDM systems have been proposed. Here, a novel concept named effective signal to interference and noise ratio (ESINR) is used. All of them map instantaneous multiple channel states, e.g. the post-processing SINR set of OFDM sub-carriers, into a scalar value called ESINR which is expected to an effective quality in additive white Gaussian noise (AWGN) condition. Then the CQI of current link is derived from basic AWGN link level performance. Among them, there are two popular effective SINR mapping (ESM) methods which are considered to have enough accuracy: Exponential Effective SINR Mapping (EESM) and Mutual Information based Effective SINR Mapping (MI-ESM). However, in the SINR compression, both of them require two-step mapping processing with an inverse non-linear mapping function. Besides, because of non-linear mapping functions, there will be high real-time computation complexity, or additional off-line ESM look-up table (LUT) is required. For wide band OFDM systems, the computation complexity and processing timing cost are high.

In this paper, a low complexity link quality prediction method called constrained linear ESINR mapping is proposed. It is such scheme in which the instantaneous post-processing SINR values of OFDM sub-carriers are limited to an effective range firstly, and then the average value of the above constrained SINRs is considered to be the final ESINR result. Its advantages include that there is no two-step mapping processing with invertible non-linear mapping functions, and no additional off-line ESM LUT is required. And it leads to implementation complexity reduction compared with conventional ones.

The remainder of this paper is organized as follows. In section II, conventional ESM models are described. The novel constrained linear ESINR mapping scheme is proposed in section III. Performance evaluation and analysis with link adaption are presented in section IV. Finally, conclusions are made in section V.

In the following, γ denotes SINR. $\{\gamma_k\}(k=0,1,\ldots,N-1)$ denots the vector of instantaneous post-processing SINR for N OFDM sub-carriers. Ant the ESINR is denoted by γ_{eff}.

II. Background: Conventional ESM Methods

A key issue for accurate ESM method is how to mapping multiple instantaneous channel states, such as the instantaneous SINR set $\{\gamma_k\}(k=0,1,\ldots,N-1)$ of OFDM sub-carriers, to a corresponding effective metric γ_{eff}. Its purpose is to predict the performance such as bloke error ratio (BLER) through finding an effective value based on AWGN conditions instead of collecting the performance for all kinds of channel conditions [2]-[3], which is shown in (1).

$$BLER(\{\gamma_k\}) \approx BLER_{AWGN}(\gamma_{eff}) \tag{1}$$

The procedure is described in Figure 1.

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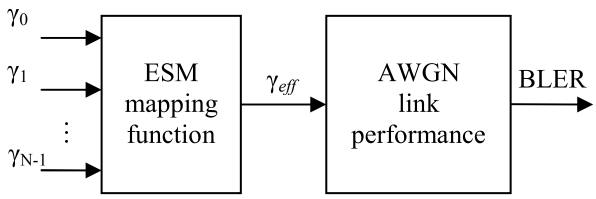

Figure 1. Principle of effective SINR mapping

Basically, current ESM methods can be summarized with (2).

$$\gamma_{eff} = \alpha_1 \Phi^{-1}\left[\frac{1}{N}\sum_{k=1}^{N}\Phi\left(\frac{\gamma_k}{\alpha_2}\right)\right] \quad (2)$$

Here, α_1 and α_2 are modulation and coding scheme (MCS) related adjustment factors. $\Phi(*)$ is an invertible mapping function, which is the main difference of different ESM methods, and $\Phi^{-1}(*)$ is its inverse.

A. *Exponential Effective SINR Mapping (EESM)*

In EESM [3]-[5], the following mapping function is used:

$$\Phi(x) = \exp\left(-\frac{x}{\beta}\right) \quad (3)$$

The inverse function of $\Phi(*)$ is:

$$\Phi^{-1}(x) = -\beta \ln(x) \quad (4)$$

Thus,

$$\gamma_{eff} = -\beta \ln\left[\frac{1}{N}\sum_{k=1}^{N}\exp\left(-\frac{\gamma_k}{\beta}\right)\right] \quad (5)$$

where, β is a MCS related scaling factor that is used to adjust the mapping function.

In real applications, if (5) is real-time computed, the complexity of the exponential function and the logarithm function is high. Otherwise, additional LUT is required.

B. *Mutual Information based Effective SINR Mapping (MI-ESM)*

MI-ESM is considered to be the one the performance of which is best among current popular ESM methods.

In MI-ESM [6]-[8], the mapping function that means symbol information is:

$$\Phi(\gamma) = SI(\gamma) = E_{XY}\left\{\log_2 \frac{P(Y/X,\gamma)}{\sum_X P(X)P(Y/X,\gamma)}\right\} \quad (6)$$

where, X is the transmitted symbol, and Y is the received symbol. $P(Y/X,\gamma)$ is the AWGN channel transition probability density, and $P(X)=1/M$ is the priori probability, where M is the number of points in modulation constellation.

Further, the closed-form expression of (6) is given in [7]-[8]. It is too complex to do real-time computation, so in real applications the LUT that contains the relationship between SINR and SI for each candidate modulation type is required. However, for implementation of real applications, the accuracy of the LUT is limited by memory size and processing timing requirements. Moreover, for wide band OFDM systems, large number of look-up operations leads to large processing timing cost.

Besides, lots of approximation methods are also introduced [7]. However, most of approximated mapping functions are also non-linear.

In the following, a low complexity solution that is real-time computable is proposed.

III. Constrained Linear ESINR Mapping Model

To reduce the real-time computation complexity, a novel ESM mapping function is introduced:

$$\Phi(x) = \alpha \log_{10}(x) + \beta \quad (7)$$

And the inverse function is:

$$\Phi^{-1}(x) = 10^{\frac{x-\beta}{\alpha}} \quad (8)$$

In (7) and (8), α and β are adjustment factors.

Substituting (7) and (8) into (2), the ESINR value is derived as follows:

$$\begin{aligned}\gamma_{eff} &= 10^{\frac{\frac{1}{N}\sum_{k=1}^{N}[\alpha\log_{10}(\gamma_k)+\beta]-\beta}{\alpha}} \\ &= 10^{\frac{1}{N}\sum_{k=1}^{N}[\log_{10}(\gamma_k)]}\end{aligned} \quad (9)$$

If SINR values are measured by decibel (dB), (9) is expressed as follows:

$$\begin{aligned}\gamma_{eff}[dB] &= 10\log_{10}(\gamma_{eff}) \\ &= \frac{1}{N}\sum_{k=1}^{N}10\log_{10}(\gamma_k) \\ &= \frac{1}{N}\sum_{k=1}^{N}\gamma_k[dB]\end{aligned} \quad (10)$$

From (10), it is derived that the ESINR is the linear average value of post-processing SINR set, where both ESINR and post-processing SINR values are measured in decibel domain. The advantage of (10) is that there is no MCS related adjustment factors in the mapping function, and that there is no two-step mapping operations.

Besides, in real application, extreme conditions are considered: One is the channel quality which is too bad to make the BLER equal to 1, and the other is the channel which is good enough to make the BLER equal to 0. Here, the extreme channel conditions are expressed as follows:

$$BLER(\gamma) \approx \begin{cases} 1 & (\gamma \le \gamma_{TH_L}) \\ 0 & (\gamma \ge \gamma_{TH_H}) \end{cases} \quad (11)$$

where, γ_{TH_L} and γ_{TH_H} denote channel quality thresholds.

For some applications, such as link adaption, the exact ESINR values in the above extreme conditions is not so important, and they can be represented by γ_{TH_L} and γ_{TH_H} .

Thus, the novel ESM method is proposed as follows:

$$\gamma_{eff}[dB] = \frac{1}{N}\sum_{k=1}^{N} \gamma'_k[dB] \quad (12)$$

$$\gamma'_k[dB] = \begin{cases} \gamma_{TH_L} & (\gamma_k < \gamma_{TH_L}) \\ \gamma_k & (\gamma_{TH_L} \le \gamma_k \le \gamma_{TH_H}) \\ \gamma_{TH_H} & (\gamma_k > \gamma_{TH_H}) \end{cases} \quad (13)$$

In (13), because of the constraint of the instantaneous post-processing SINR values, the above novel ESM method is called constrained linear ESINR mapping.

Combing the constrain conditions, (7) is expressed in decibel domain as follows.

$$\Phi(x) = \begin{cases} C_1 & (x < \gamma_{TH_L}) \\ \alpha' x + \beta & (\gamma_{TH_L} \le x \le \gamma_{TH_H}) \\ 0 & (x > \gamma_{TH_H}) \end{cases} \quad (14)$$

Here, C_1, α' and β are modulation scheme related parameters. The typical value for different modulation schemes are listed in Table I.

TABLE I: TYPICAL PARAMETERS FOR THE PROPOSED ESM FUNCTION

Parameter	QPSK	16QAM	64QAM
C_1	2	4	6
α	0.12	0.23	0.27
β	1.00	0.84	0.59
γ_{TH_L} (dB)	-8.4	-8.4	-8.4
γ_{TH_H} (dB)	8.4	11.5	20.0

Figure 2 shows the ESINR mapping function comparison between the proposal and MI-ESM for QPSK.

In conclusion, the advantages of the proposal include:

- There is no two-step mapping processing with invertible mapping functions in the SINR compression, which is shown in (12).
- The main operations are clipping and linear average. Therefore, it is simply computation.
- For some special applications, such as link adaption, no additional ESM LUT is required for (10).

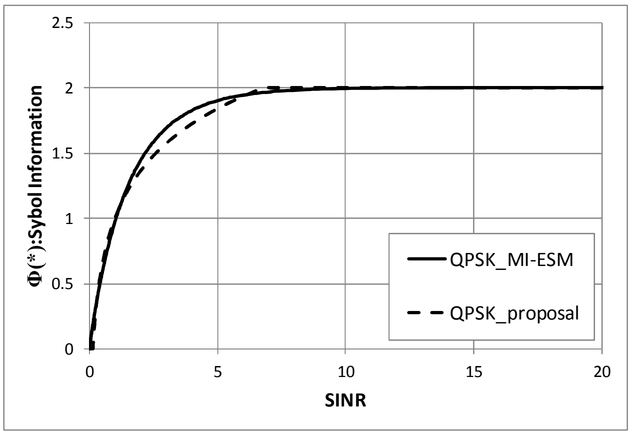

Figure 2. ESM funtion comparison with QPSK

IV. PERFORMANCE EVALUATION

In this section, complexity and performance comparison with MI-ESM based link adaption are discussed.

The system parameters relating to the OFDM symbol or frame structure are based on IEEE802.16e downlink systems, which are summarized in Table II.

TABLE II: SIMULATION SYSTEM PARAMETERS

Parameters	Specifications
Carrier frequency	3.5GHz
Sampling frequency	10MHz
Frame duration	5ms
OFDM symbol duration (including CP)	115.2µs
FFT size	1024
CP length	128
Number of transmitting antennas	1
Number of receiving antennas	2
Channel type	PB3
Number of MCS level candidates	11

Applying the proposal to link adaption, the procedure of MCS selection is explained in Figure 3. Basically, instantaneous pose-processing SINR values of all used OFDM subcarriers are clipped to a constrained range with (13). Then the average value of the clipped SINR set is calculated and used to be the ESINR value. Finally, suitable MCS is selected. In Figure 3, the MCS LUT is AWGN link level performance based MCS selection thresholds table, which is obtained by off-line experiments.

A. Complexity comparison

Table III shows the complexity comparison results.

In IEEE 802.16e, there are three modulation candidates: QPSK, 16QAM and 64QAM. If the dynamic SINR range is from -20dB to 25dB with 0.5dB step, and if the bit width of SINR values and $\Phi(\gamma)$ values is 8bit, the whole size of the required memory is (3[modulation_type]*451[steps]*8[bit]).

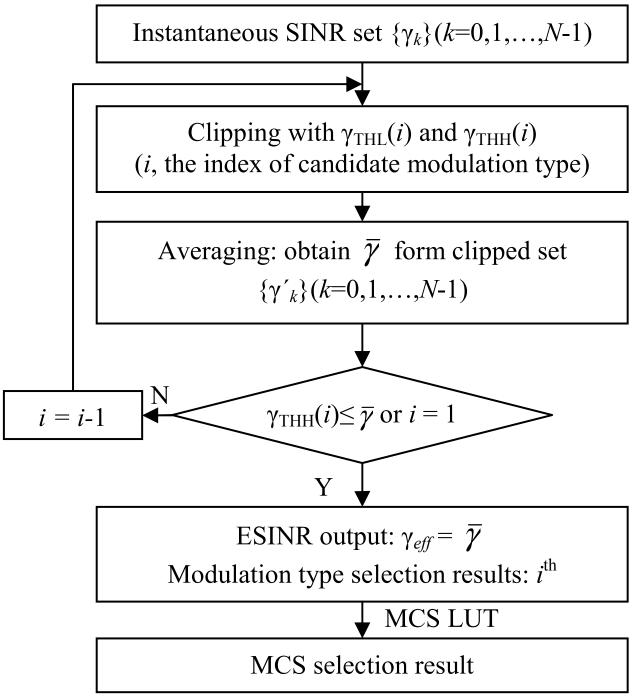

Figure 3. The flow chart of link adaption with the proposed ESM method

For MI-ESM, if there is N used OFDM subcarriers, (N+1) look-up operations are required for (2), and at the worst case the whole LUT should be scanned for once look-up operation, which means that ((N+1)*3*451) comparison operations are required for the whole mapping processing. Besides, there are (N-1) addition operations and 1 shift operation.

For the proposal, only six thresholds should be stored, and clipping operations for instantaneous SINR values are required. In a word, the complexity of the proposal is much lower.

TABLE III: COMPLEXITY COMPARISON

		MI-ESM	Proposal
Memory		3*451*8	3*8
operation	Look-up	N+1	0
	Addition	N-1	N-1
	Shift	1	1
	Clipping	0	≤N

B. Performance comparison

Figure 4 gives the ESINR mapping performance comparison between the proposal and MI-ESM. In the figure, the solid lines are the AWGN-link performance curves. The gray points are the effective performances with MI-ESM for PB3 channel. And the white points are the effective performance with the proposal for PB3 channel. It is indicates that the SINR-to-BLER performance of the proposal is very similar with that of MI-ESM.

Besides, the proposal is applied to WiMAX Forum™ Mobile Radio Conformance Tests (RCT). All the test cases related ESINR pass the RCT requirements. Figure 5 shows throughput performance comparison of one of them. In the figure, the dash line is the SNR-to-throughput curve with average SINR method. The solid line is with MI-ESM. And the white points are with the proposal. It is indicated that the performance of average method is worst, and that the SNR-to-throughput performance of the proposal is almost the same as MI-ESM.

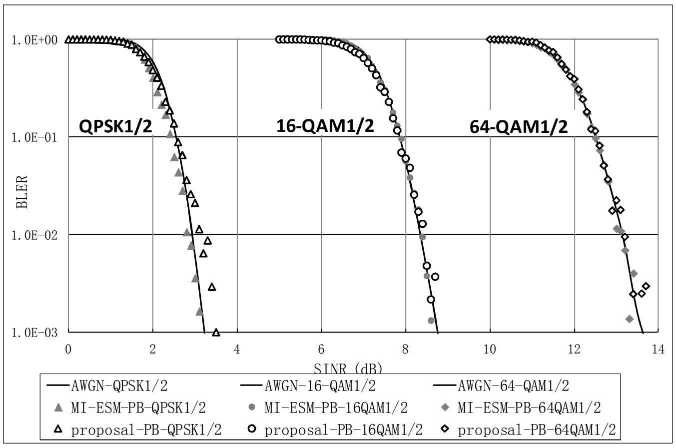

Figure 4. ESINR mapping performance comparison

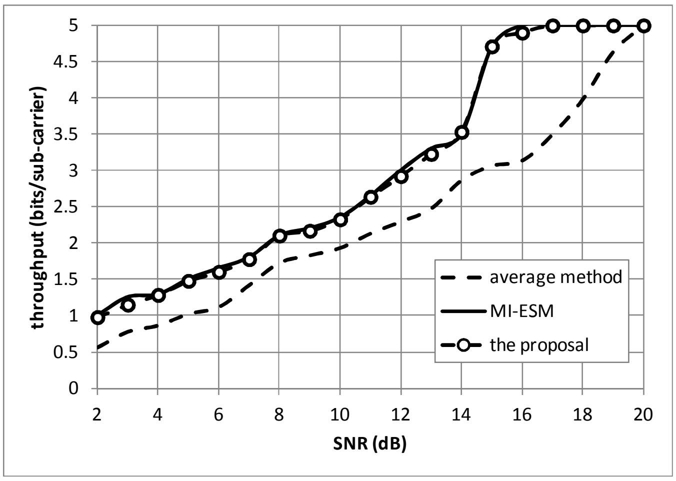

Figure 5. Throughput performance comparison

V. CONCLUSIONS

This paper introduced constrained linear average ESM method for OFDM systems. Through clipping operations, it constrained the post-processing SINR values of sub-carriers to a range. Then the linear average value of the clipped SINR set is used to be final ESINR estimation result. Its advantage is low computation complexity because there is no two-step non-linear mapping processing. And its memory requirement is also less than conventional methods because no additional off-line ESM LUT is required.

Potentially, this novel ESM method can be applied to other radio resource management such as power allocation.

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