

Link-to-System Interface for Estimating HSDPA System Performance for Interference Mitigating Receivers

Gregg Charlton and Vincent Roy
 InterDigital Communications Corporation
 781 3rd Ave., King of Prussia, PA, USA, 19406
 1000 Sherbrooke W., Montreal, Quebec, H3A 3G4
 E-mail: {gregg.charlton, vincent.roy}@interdigital.com

Abstract – This paper presents a link-to-system interface methodology used to estimate system throughput for receivers capable of interference mitigation. A relationship between receiver performance and the dominant interference ratios is identified. A sample space consisting of Ior/Ioc and the dominant interferer ratio is defined and serves as the basis for determining input parameters for link level simulations. The link level simulation results are then used to drive a system simulator capable of assessing system throughput for a variety of channels and network loads. Lastly, some results comparing interference mitigating receivers against non-interference mitigating receivers are presented.

Index Terms – HSDPA, modeling, interference cancellation

I. INTRODUCTION

Traditionally, link level simulation efforts modeled the desired signal as a digital source and treated interfering sources as AWGN. A system level simulator using a typical link-to-system interface to estimate system level performance of advanced wireless networks consists of the following:

1. A lookup table mapping quasi-instantaneous (averaged over a very short interval) SINR to quasi-instantaneous throughput. Different lookup tables are generated for different receiver types and different channel models.
2. A system level simulator that simulates mobile units operating in time-varying environments, collects SINR statistics, and maps these instantaneous SINR statistics to instantaneous throughputs using the lookup table described above.

Because the link-to-system interface described above is based on link level simulations in which interference is modeled as AWGN, it is not adequate to estimate the performance of receivers capable of exploiting structured interference (later referred to as interference mitigating receivers). For the system level simulations to reflect performance improvements yielded by interference mitigating receivers, the link-to-system interface must be based on link level simulations performed using structured interference. In these simulations, the interference sources are modeled as distinct digital sources.

This paper summarizes the development of a link-to-system interface that enables system performance for interference mitigation in 3G WCDMA/HSDPA systems to be evaluated. Consistent with 3GPP terminology, the term Ior/Ioc will be used in lieu of SINR, and the interference environment perceived by a mobile receiver will be characterized using a set of dominant interference profiles (DIP) as defined in [2].

DIP_i is defined as:

$$DIP_i = \frac{\hat{I}_{or,i+1}}{I_{oc}}; \quad i \geq 1,$$

where $\hat{I}_{or,2} \dots \hat{I}_{or,N}$ represent received signal power from the five most significant interference sources such that $\hat{I}_{or,2} > \hat{I}_{or,3} > \dots > \hat{I}_{or,N}$. It is straightforward to set the power levels of the interfering sources and conduct link level simulations; however, it is not clear how to use the results in a system level simulator to estimate performance. For the aforementioned case in which all interferers are treated as AWGN, the link-to-system interface typically consists of a single lookup table (i.e., one lookup table per channel model) of instantaneous throughput versus instantaneous Ior/Ioc. For the case in which interference is modeled using N structured interference sources, a direct extension of this methodology would become impractical, since a separate lookup table would have to be developed for all combinations of the N-element DIP sets. Instead, we propose an alternative that takes advantage of the performance characteristics of interference mitigating receivers and leads to a practical, two-step throughput interpolation scheme. With this approach, it is possible to estimate system throughput for interference mitigating receivers.

II. METHODOLOGY

Initial link-to-system interface development focused on a geographic approach in the hopes that the performance of interference mitigating receivers would be consistent within a limited number of cell areas. As no such contiguous cell areas were identified, a statistical approach based on the DIP ratios was subsequently pursued. While a strong correlation between throughput and Ior/Ioc was observed, link level simulations showed little correlation between throughput and any of the

interference ratios taken independently. However, given a specific Ior/Ioc value, there was a high level of correlation between throughput and the relative power of the strongest interferer (DIP_1). This suggested that a two-dimensional lookup table using the (Ior/Ioc, DIP_1) pair would be sufficient to accurately model the performance of interference mitigation receivers.

System simulations determined the range of Ior/Ioc and DIP_1 values that would be encountered in system simulations with the modeling assumptions widely adopted in 3GPP [1], [4]. Figure 1 shows the sample space of potential (Ior/Ioc, DIP_1) points.

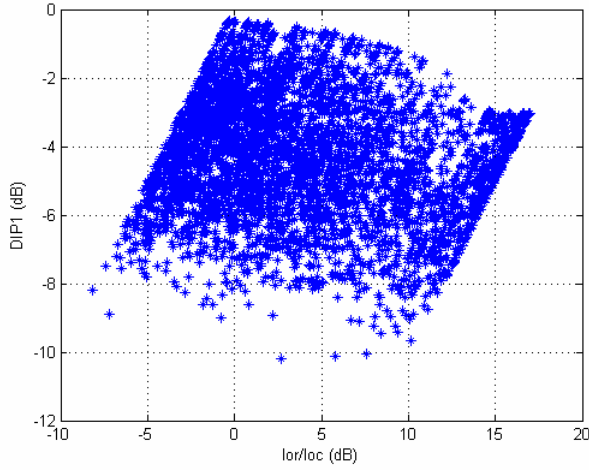


Figure 1. DIP_1 , Ior/Ioc Space

To develop an accurate link-to-system interface, it is necessary to conduct link level simulations covering the range of (Ior/Ioc, DIP_1) points shown in Figure 1. For example, a uniform grid of reference points could be defined so that the throughput for points lying between these reference locations could be estimated via interpolation.

In the process of analyzing the correlations between throughput and the different DIP_1 metrics, it was found that, for a fixed Ior/Ioc, the relationship between throughput and the Residual Interference Ratio for the strongest interferer (RIR_1 introduced in [3] and repeated below) is more linear than the relationship between throughput and DIP_1 . The RIR_1 metric is described below.

$$RIR_1 = 1 - 10^{DIP_1/10}$$

An interesting property of RIR_1 is that its inverse (i.e., $1/RIR_1$ in linear or $-RIR_1$ in dB) corresponds to the SINR gain that could theoretically be achieved if the strongest interferer was removed (i.e., perfectly cancelled).

The interpolation algorithm presented in this paper is based on Ior/Ioc and RIR_1 .

Figure 2 shows the Ior/Ioc vs. RIR_1 sample space, generated with a system level simulator, for both long-term statistics (i.e., without fast fading – shown in green) and instantaneous statistics (with fast fading – shown in red). The blue dots represent the 27 reference simulations necessary to generate the basis of the link-to-system interface.

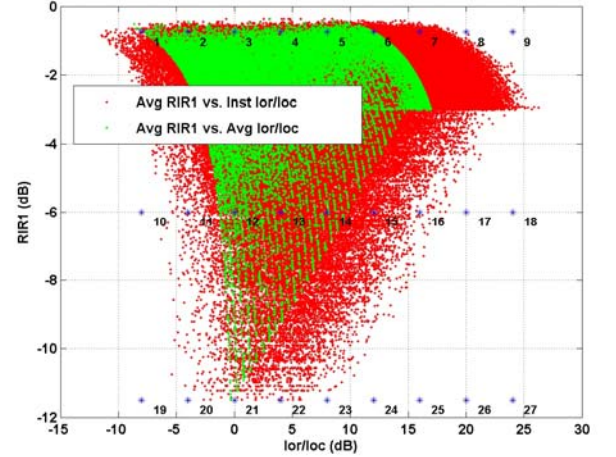


Figure 2. Sampling of RIR_1 vs. Ior/Ioc space

The 27 reference simulation points were chosen to cover the relevant range of possible Ior/Ioc and RIR_1 values. Ior/Ioc values were extended to cover the same range for each of the three RIR_1 values, even though some of the reference points did not correspond to realizable locations. The nature of Figure 2 suggests that throughput could best be estimated via standard two-dimensional interpolation routines. However, for cases in which the (Ior/Ioc, RIR_1) point falls at or near the boundary of possible values, a conventional 2D interpolation routine would typically assign the corresponding throughput in such a way that the more important parameter (Ior/Ioc) might not be given the greatest weight. Accordingly, we propose to employ a two-step, one-dimensional interpolation process. For points not at the boundaries in Figure 2, it is easy to demonstrate that the two-step interpolation method yields the same result as the conventional 2D method. For this process, three RIR_1 values were generated for each Ior/Ioc value, as illustrated in Figure 3. For example, at Ior/Ioc = 5 dB, the throughput would lie between 2.4 and 3.2 Mbps, depending upon the UE's RIR_1 value.

System simulations begin by specifying the number of active users in each cell. User positions are generated randomly from a uniform distribution. Lognormal shadowing, fast fading, and antenna gains are then added so that path losses can be calculated for all desired signals and interferers. For each user, the (Ior/Ioc, RIR_1) pair is calculated and the interpolation process (e.g., Figure 3 performance once tabulated) is used to find that user's expected instantaneous throughput. Based on the expected instantaneous throughput of each user, the system simulator will schedule UEs for each fading realization using a proportionally fair scheduler

(fairness exponent = 0.75). The mean throughput is then determined across multiple fading realizations for each of the active users. The entire process can then be repeated for a different number of active users. In this way, the individual user throughput and cell throughput can be estimated as a function of the network load.

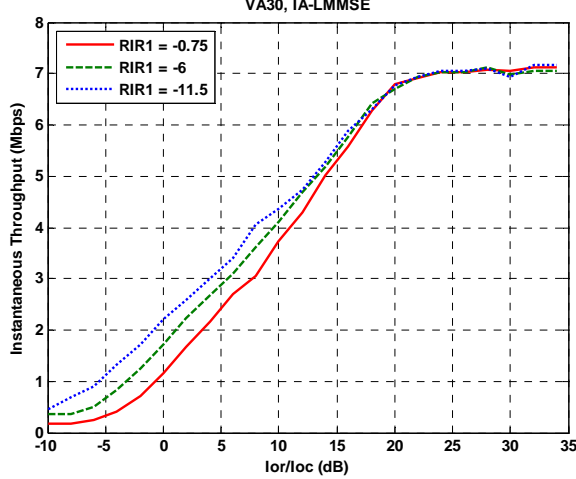


Figure 3. Instantaneous Throughput vs. Ior/Ioc Interpolation Curves

The methodology was used to compare the performance of an interference mitigating receiver against the performance of a receiver that is incapable of interference mitigation. The two receiver types can be thought of as LMMSE variants – a simple LMMSE and an interference aware LMMSE. Let the received signal r be expressed as $r = H_0 d_0 + \sum_{i=1}^M H_i d_i + n$, where H_0 is the channel impulse response matrix for the serving base station, $\{H_i, i = 1, \dots, M\}$ are the channel impulse response matrices for M interferers, d_0 is the transmitted signal from the serving base station, $\{d_i, i = 1, \dots, M\}$ are the transmitted signals from M interferers, and n is AWGN.

Assuming $E(d_0 d_0^H) = I$, the estimation of d_0 using the simple LMMSE receiver can be expressed as $\hat{d}_0 = H_0^H (H_0 H_0^H + \sigma_{i+n}^2 I)^{-1} r$, where σ_{i+n}^2 is the interference plus noise power. Using an interference aware LMMSE receiver, the estimation of d_0 can be expressed as

$$\hat{d}_0 = H_0^H \left(H_0 H_0^H + \sum_{i=1}^M \mu_i H_i H_i^H + \sigma_n^2 I \right)^{-1} r, \quad \text{where}$$

$$\{\mu_i^2 I = E(d_i d_i^H), i = 1, \dots, M\} \text{ and } \sigma_n^2 \text{ is the noise power.}$$

Section III compares the performance of the simple LMMSE and the interference aware LMMSE (IA-LMMSE).

III. SIMULATION RESULTS

Using the system simulation assumptions detailed in [1], the performance of the IA-LMMSE and the LMMSE receivers was compared. Both the pedestrian B and vehicular A channels, at 3 km/hr and 30 km/hr, respectively, were analyzed. Figure 4 shows the throughput comparison between the receivers for the case in which there is only a single user per cell. Examination of the figures reveals that, at the lower throughput range, IA-LMMSE receivers enjoy a measurable performance advantage. The advantage disappears, however, as one examines the higher throughput portions of the curves, where LMMSE and IA-LMMSE performance is identical. This indicates that the IA-LMMSE benefits are only observable at cell edge. The reason for this is that the interference perceived by users at cell edge tends to be characterized by one dominant interferer, whereas the interference perceived by users close to the base station tends to be characterized by a larger number of relatively weak interferers so that removing the dominant interferer would have little impact on performance.

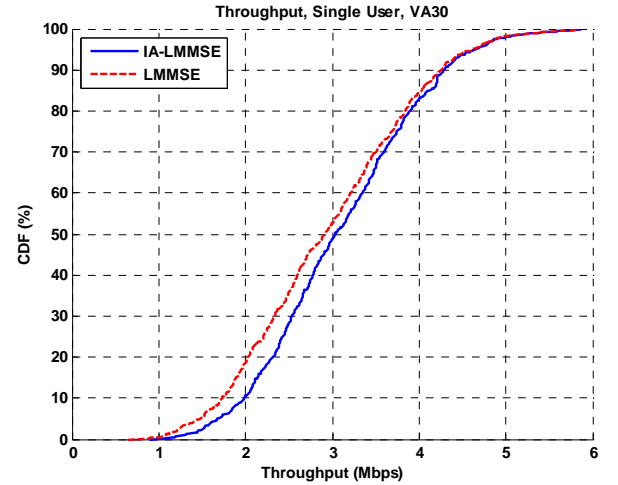


Figure 4. Single User Throughput, VA30 Channel

Throughput CDF curves for the case in which there are three active users per cell are shown in Figure 5. Again, the observations made earlier hold true, namely, IA-LMMSE receivers provide a throughput boost for cell edge users.

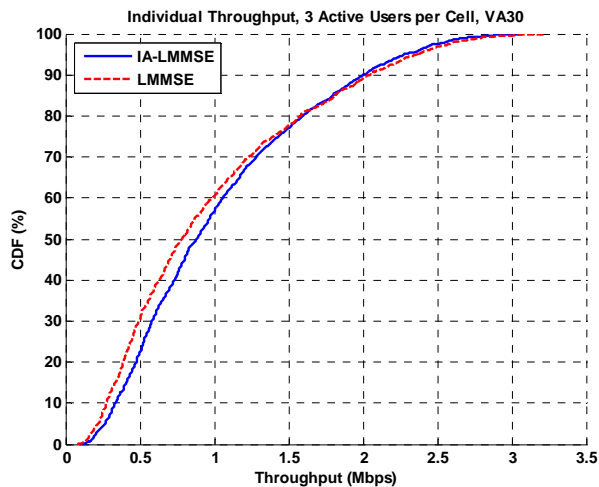


Figure 5. User Throughput with Three Users per Cell, VA30 Channel

It is possible to filter the throughput results and specifically examine only cell edge users. In this case, cell edge is defined as the region in which the user's $I_{or}/I_{oc} < 0$ dB. Using this criterion, a comparison between receivers is given in Figure 6. When considering only these users, the performance difference between the receivers becomes more dramatic. The median throughput is increased by nearly 16% in pedestrian B and by 21% in vehicular A. Table 1 summarizes the user throughput differences between the two receivers for the overall cell, cell edge, and cell center ($I_{or}/I_{oc} > 10$ dB). While the median overall improvement is not as impressive as the 21% improvement at cell edge, it remains a respectable 13%. Only at cell center do the receivers offer the same throughput performance. In ITU Pedestrian B conditions, the cell edge gains are smaller but still significant.

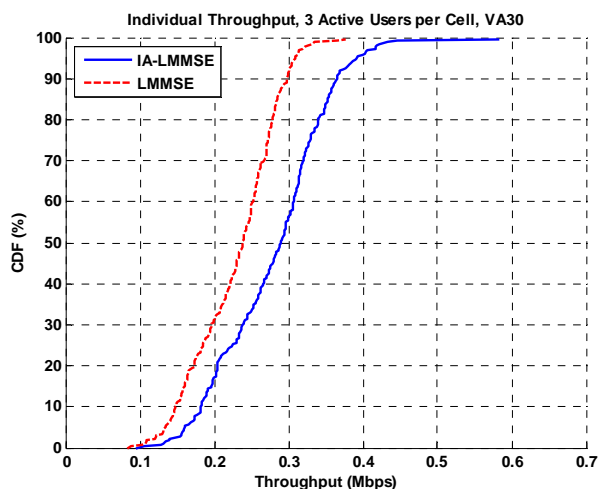


Figure 6. Cell Edge User Throughput with Three Users per Cell, VA30 Channel

Table 1. User Throughput Comparison (3 users/cell)

Receiver	User Throughput (Mbps)		
	Cell Edge	Overall	Cell Center
VA30			
LMMSE	0.24	0.78	1.86
IA-LMMSE	0.29	0.88	1.85
PB3			
LMMSE	0.35	0.97	2.08
IA-LMMSE	0.40	1.05	2.04

IV. SUMMARY AND CONCLUSIONS

Traditional link-to-system interfaces based on link level simulations in which interference is modeled as AWGN cannot evaluate the system level performance of receivers capable of mitigating interference. A framework has been presented to estimate user throughput for interference mitigating receivers. This framework includes a novel link-to-system interface and a methodology by which this interface is used in system level simulations. The proposed link-to-system interface is based on SINR (I_{or}/I_{oc}) and a novel metric RIR_I which characterizes the level of dominance of the strongest interferer perceived by a user. Basing the performance estimation only on these two variables allowed us to define a link-to-system interface that predicts performance with adequate accuracy and at a reasonable complexity.

A sampling methodology was also proposed to define the range of I_{or}/I_{oc} and RIR_I values over which the link level simulations need to be performed to create the requisite lookup tables. A proportionally fair scheduler was implemented in the system simulator and then used to schedule users over a large number of fast fading instances. The resultant statistics were then compiled to compare the performance of an interference mitigating receiver (IA-LMMSE) with a non-interference mitigating receiver (LMMSE). It was demonstrated that IA-LMMSE receivers provide a significant throughput advantage (15-20%) over LMMSE receivers in cell edge conditions.

V. REFERENCES

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