DOWNLINK QUALITY ESTIMATION IN UMTS-FDD SYSTEM : APPLICATION TO COGNITIVE RADIO

Lahouari Fathi
Télécom SudParis/Département CITI
Laboratoire SAMOVAR / CNRS UMR 5157
9 rue Charles Fourier, 91011 Évry, France
lahouari.fathi@it-sudparis.eu

Philippe Loubaton
Université Paris-Est Marne-la-Vallée
Cité Descartes, 5 bd Descartes
77454 Champs-sur-Marne, France
loubaton@univ-mlv.fr

ABSTRACT

In this paper, we consider user equipment which is not yet connected to a given UMTS-FDD network. We propose an algorithm which allows the user equipment to estimate bit error rate (BER) of a potential downlink in term of the spreading factor and of the power that could be allocated by a base station to this virtual link. This problem is motivated by the context of cognitive radio. Our approach is based on the estimation of the instantaneous signal-to-noise-plus-interference ratio (SINR) of the virtual link. For this, we derive a closed-form approximation of the SINR which only depends on the powers and on the channels between each active base station and the user equipment; these parameters can be estimated easily from the pilot channels transmitted by the active base stations.

Index Terms— Cognitive radio, downlink quality estimation, SINR, UMTS, virtual link

1. INTRODUCTION

In the context of future cognitive radio systems, a given user equipment may communicate with different possible systems (UMTS, GSM, WiFi, etc). In order to choose the most relevant system, the user equipment should be able to estimate the potential quality of the various links. In this paper, we address the downlink quality estimation between a given UMTS-FDD system and the user equipment. For this, we propose to estimate the instantaneous SINRs associated to a virtual link between one of the active base station of the UMTS network and the user equipment. This, of course, allows to evaluate long term criteria of quality.

We first derive a large system approximation of SINR between a given base station and the user equipment. This approximation only depends on the channels between the active base stations and the user equipment, the powers transmitted by these base stations, the virtual spreading factor and the virtual power that could be allocated to the link. The present SINR approximation is a generalization of the main result of Mouhouche et al. [1]. We next recall that the channels between the base stations and the user equipment can be easily estimated using pilot channels. We also propose a simple procedure to estimate the powers transmitted by the active base stations. We show how our results can be used at the user equipment side in order to predict the power that should be allocated to the virtual link to reach a certain target quality. We finally provide simulation results that demonstrate the performance of our estimation scheme.

2. SINR EXPRESSION

In the following, we assume that a virtual link is established between the base station 0 of the UMTS network and the user equipment. We also assume that Q − 1 interfering base stations of the same network are active at the user equipment location. The (virtual) signal so received at the user equipment, sampled at the chip rate, is denoted y(n), can be written as

\[ y(n) = \sum_{q=0}^{Q-1} \sum_{l=0}^{L_q-1} h_q(l)d_q(n-l) + w(n), \]  

where \( h_q(.) \) is the impulse response of the channel between the base station \( q \) and the user equipment, assumed to be time-invariant over the timeslot, and can be expressed in vector form as \( h_q = (h_q(0),...,h_q(L_q-1))^T \). \( d_q(n) \) is the chip sequence of power \( \mu_q^2 \), transmitted by the base station \( q \), and \( w(n) \) is complex, zero-mean, white and Gaussian noise of variance \( \sigma_w^2 \), independent of \( d_q(n) \), where \( q = 0,\ldots,Q-1 \).

For the sake of simplicity, we assume that the same spreading factor, say \( N \), is assigned to the \( K \) users controlled by the base station 0. The transmitted chip vector for the \( m \)th symbol time, \( \mathbf{d}_0(m) = (d_0(mN),\ldots,d_0((m+1)N-1))^T \), is obtained as

\[ \mathbf{d}_0(m) = \mathbf{S}_0(m) \mathbf{C} \sqrt{P_0} \mathbf{b}_0(m), \]  

where \( \mathbf{S}_0(m) \) is the \((N \times N)\) diagonal scrambling code matrix, \( \mathbf{C} \) is the \((N \times K)\) matrix whose columns are the channelization codes assigned to the \( K \) users, \( \sqrt{P_0} \mathbf{b}_0(m) \) is the \((K \times K)\) diagonal matrix whose diagonal elements are the square roots of the energy per symbol for the \( K \) users and \( \mathbf{b}_0(m) = (b_{0,1}(m),\ldots,b_{0,K}(m))^T \) is the transmitted symbol vector, where \( b_{0,1}(m) \) is the virtual symbol transmitted to the user of interest. The estimator of the symbol \( b_{0,1}(m) \) is given by

\[ \hat{b}_{0,1}(m) = \mathbf{C}_1^H \mathbf{S}_0^H(m) \mathbf{d}_0(m), \]  

where \( \mathbf{d}_0(m) = (\hat{d}_0(mN),\ldots,\hat{d}_0((m+1)N-1))^T \) is the estimated chip vector for symbol time \( m \). The estimate of the chip sequence \( \hat{d}_0(n) \) is obtained by linear filtering as

\[ \hat{d}_0(n) = \sum_{l=-N+1}^{N} g(l)\hat{y}(n-l), \]  

where \( g(.) \) is the impulse response of the receiver filter chosen of \( 2N \) chips length.
As mentioned in [2, 1], the SINR expressions are difficult to interpret because they depend in a complex manner on the spreading code and the channelization codes allocated to different users. To overcome this difficulty, it is now classical to model the scrambling code sequences as random i.i.d. sequences. The various SINRs can in this situation be interpreted as random variables, and it has been shown that, under certain conditions, they converge almost surely to deterministic quantities when the spreading factor $N$ and the number of users $K$ tend to infinity, while their ratio remains constant.

The forms of these limit SINRs become quite explicit, and allow to obtain more insight on the parameters that influence the downlink quality estimation. Here, we limit ourselves to the resulted limit SINR expression by omitting the details of its derivation which are some arduous. Hence, for user equipment with assigned virtual pilot channel (CPICH) [3], whose transmitted symbols are known synchronous with each detected base station to estimate the parameters required for SINR evaluation. We insist here on the fact that the user equipment does not connect to the detected base stations at all: the aim is to predict the link quality that the user equipment will have if connected to a base station.

The channel estimation is made possible thanks to the common pilot channel (CPICH) [3], whose transmitted symbols are known by the user equipment after identification of the scrambling code. A common used channel estimator exploits the good autocorrelation properties of the scrambling code. It consists to correlate the received signal and the scrambling code. However, there are alternative approaches that allow enhancing this estimation by incorporating statistical information of the channel [4].

### 3. Power Estimation

The powers transmitted by the base stations are assumed to be constant over the frame duration. Indeed, the number of users connected to a base station still constant over the frame duration since the users inputs/outputs are only allowed at the beginning of each frame [3]. Hence, the power estimation will be performed frame by frame. Again, we consider equation (1) under its matrix form

$$
\mathbf{y}(n) = \sum_{q=0}^{Q-1} \mathbf{H}_q \mathbf{d}_q(n) + \mathbf{w}(n),
$$

where $\mathbf{y}(n) = (y(n), \ldots, y(n + L - 1))^T$, and $\mathbf{H}_q$ is a $(L \times L + L - 1)$ channel matrix, where $L = Q + 1$. From (6), we show that the covariance matrix $\mathbf{R}_{yy} \triangleq \lim_{M \to +\infty} \frac{1}{M} \sum_{n=0}^{M-1} \mathbf{E} \left[ \mathbf{y}(n) \mathbf{y}(n)^H \right]$ is given by $\mathbf{R}_{yy} = \sum_{q=0}^{Q} \alpha_q \mathbf{B}_q$, where $\alpha_q = \mu^2_q$, with $\alpha Q = \sigma^2$, and $\mathbf{B}_q \triangleq \mathbf{H}_q \mathbf{H}_q^H$, with $\mathbf{B}_Q = \mathbf{I}_L$. Let $\mathbf{R}_{yy}$ and $\mathbf{B}_q$ be the estimates of $\mathbf{R}_{yy}$ and $\mathbf{B}_q$, respectively. Powers estimates are obtained by minimizing the criterion $J(\alpha) = \| \tilde{\mathbf{R}}_{yy} - \sum_{q=0}^{Q} \alpha_q \tilde{\mathbf{B}}_q \|^F$ with respect to $\alpha = (\alpha_0, \ldots, \alpha_Q)^T$, where $\| \cdot \|^F$ denotes the Frobenius norm. The solution $\hat{\alpha}$ is obtained by solving the system of linear equations

$$
\mathbf{\Gamma} \hat{\alpha} = \mathbf{F},
$$

where $\mathbf{F} = \mathbf{y}(n) \mathbf{y}(n)^H$, and $\mathbf{F} = \mathbf{y}(n) \mathbf{y}(n)^H$, for $i, j = 1, \ldots, Q + 1$. It is easy to show that $\mathbf{F}$ and $\mathbf{x}$ are both real. A simplified criterion of estimation (to be maximized) is obtained as $J(\hat{\alpha}) = \mathbf{x}^T \hat{\alpha}$. The covariance matrix is estimated as $\mathbf{R}_{yy} = \frac{1}{N_{\text{chips}}} \sum_{n=0}^{N_{\text{chips}}} \mathbf{y}(n) \mathbf{y}(n)^H$, where $N_{\text{chips}} = 2560$ chips is the number of chips contained in one slot.

We consider now the estimation of the powers from the 15 slots contained in one frame. Let $\mathbf{R}_{yy}$ (resp. $\mathbf{B}_q$) be the matrix formed by stacking the matrices $\mathbf{R}_{yy}$ (resp. $\mathbf{B}_q$) obtained for different slots. It is easy to show that the powers estimates are still given by (7) provided that $\mathbf{R}_{yy}$ and $\mathbf{B}_q$ are replaced by $\mathbf{R}_{yy}$ and $\mathbf{B}_q$, respectively. The same method is used for multi-antenna case.

Solving the system of linear equation (7) does not ensure obtaining positive solution, especially when the true values of powers are weak. However, by considering the Karush-Kuhn-Tucker (KKT) conditions [5], if a positive solution is obtained, it is the optimal one. If the obtained solution is unacceptable (i.e., at least one of its components is negative), we propose to use a combinatorial procedure to search a positive solution of lower order. This procedure consists to
solve systems of linear equations of lower order which are obtained by forcing some components of the solution to zero. The selected solution is the one among the acceptable solutions that maximizes the simplified criterion $J$.

4. POWER ALLOCATION

The channel estimate $\hat{h}_q$ is affected by a scale factor that corresponds to the square root of the pilot channel power, in other words, we have

$$\hat{h}_q = \sqrt{\eta_q}h_q, \quad \text{for } q = 0, \ldots, Q-1,$$

where $\eta_q$ is the power of the pilot channel transmitted by the base station $q$. In (8), we have considered perfect channel estimation for the sake of simplicity. Moreover, by substituting (8) in (7), we can show that the power estimate $\hat{\mu}_q^2$ is given by

$$\hat{\mu}_q^2 = \frac{\hat{h}_q^2}{\eta_q}, \quad \text{for } q = 0, \ldots, Q-1.$$  

(9)

It is worthwhile to note that the noise power estimate $\hat{\sigma}^2$ is not affected by the scale factor inherent to the channel estimation. From (8) and (9), and by considering the linearity of expression (5) with respect to $\rho$, we can show that $\beta(\rho) = \hat{\beta}(1)$, where $\hat{\beta} \triangleq \rho/\eta_0$ is the normalized virtual power, and $\hat{\beta}(1)$ is the estimated SINR for $\rho = 1$ (i.e., when the whole parameters are replaced by their estimates affected by the scale factor). Given that the pilot channel power is 10% of the base station total power [3], it is easy to compute the available normalized power $\hat{\mu}_q^2_{\text{available}} = 10 - \hat{\mu}_0^2$. Moreover, since the allocated power can not exceed the available power, we have $\hat{\rho} \leq \hat{\mu}_q^2_{\text{available}}$.

Let $BER_{\text{target}}$ be the desired quality of service. For each detected base station, we have first to determine the normalized virtual power $\hat{\rho}$ to be allocated to allow to the user equipment to reach $BER_{\text{target}}$, in other words, that satisfies the relationship

$$\frac{1}{N_{\text{slots}}} \sum_{k=1}^{N_{\text{slots}}} \left( \sqrt{\hat{\rho} \hat{\beta}_k(1)} \right) = BER_{\text{target}},$$

where $N_{\text{slots}}$ is the number of slots used to compute the mean. $\hat{\rho}$ is then compared to the available power $\hat{\mu}_q^2_{\text{available}}$. If $\hat{\rho} \leq \hat{\mu}_q^2_{\text{available}}$, then the $BER_{\text{target}}$ can be reached with allocated power $\rho = \hat{\rho}$. Otherwise the $BER_{\text{target}}$ is impossible and the best quality of service we can do with $\rho = \hat{\mu}_q^2_{\text{available}}\hat{\rho}$, is given by $BER_{\text{bound}} = \frac{1}{N_{\text{slots}}} \sum_{k=1}^{N_{\text{slots}}} \left( \sqrt{\hat{\mu}_q^2_{\text{available}} \hat{\beta}_k(1)} \right)$.

5. SIMULATION RESULTS

We consider the case of user equipment in an UMTS-FDD network with three active base stations, as illustrated in Figure 1. Base stations parameters are summarized in Table 1. A virtual spreading factor of 32 is assigned to the user equipment, which moves at speed of 30 km/h in vehicular-A environment [3]. The noise level is controlled by setting the pilot channel-to-noise ratio $P_{\text{CPICH}}/\sigma^2$ equal to 10 dB. This SNR is evaluated regarding the closest base station (i.e., BS-I in the case of Figure 1).

The obtained results for 100 frames (1500 slots) are given in Table 2, where Rake and MMSE with 1 and 5 antennas are considered. For comparison purposes, we give in Table 3 the theoretical results (obtained by using the true values of the parameters in the SINR expression). When $BER_{\text{target}}$ is possible, we give the required power to be allocated to the user equipment, otherwise we give $BER_{\text{bound}}$ and the available power. Powers are expressed in % regarding the pilot channel power. These results show a good behaviour of the proposed algorithm for the downlink quality estimation. The results in Table 2 are presented in more concise manner in Figure 2, where we give the evolution of the required $E_b/N_0$ as a function of $BER_{\text{target}}$.

6. CONCLUSION

A scheme for downlink quality estimation in UMTS-FDD system has been proposed in this paper. This scheme is based on the estimation of instantaneous values of SINR, and requires the operations of channel estimation, power estimation, and power allocation for the virtual link. The simulation results show that the proposed scheme performs very well; hence, it is well-suited in the context of cognitive radio. In fact, the proposed scheme provides the user equipment with information about its environment. This information can be used by the user equipment to choose a potential link, and select appropriate parameters, such spreading factor, modulation type and receiver structure, in order to reach a certain quality of service.
### Table 3. Theoretical results of power allocation.

<table>
<thead>
<tr>
<th>BER target</th>
<th>Rake-1</th>
<th>BS-I</th>
<th>BS-II</th>
<th>BS-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^{-1}</td>
<td>24.90%</td>
<td>1.10 \times 10^{-2}</td>
<td>2.46 \times 10^{-2}</td>
<td>200.10%</td>
</tr>
<tr>
<td>10^{-2}</td>
<td>119.50%</td>
<td>346.90%</td>
<td>616.90%</td>
<td>257.60%</td>
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<table>
<thead>
<tr>
<th>Rake-5</th>
<th>BS-I</th>
<th>BS-II</th>
<th>BS-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^{-1}</td>
<td>4.90%</td>
<td>13%</td>
<td>34.10%</td>
</tr>
<tr>
<td>10^{-2}</td>
<td>18.60%</td>
<td>49.30%</td>
<td>132.40%</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>MMSE-1</th>
<th>BS-I</th>
<th>BS-II</th>
<th>BS-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^{-1}</td>
<td>18.90%</td>
<td>93.50%</td>
<td>156.10%</td>
</tr>
<tr>
<td>10^{-2}</td>
<td>74.90%</td>
<td>276%</td>
<td>616.90%</td>
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</table>

<table>
<thead>
<tr>
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<th>BS-II</th>
<th>BS-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^{-1}</td>
<td>3.30%</td>
<td>12.40%</td>
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<tr>
<td>10^{-2}</td>
<td>12.40%</td>
<td>33%</td>
<td>88.50%</td>
</tr>
</tbody>
</table>

7. REFERENCES


Fig. 2. Required $E_b/N_0$ vs. $BER_{target}$. 

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