Co-Channel interference mitigation in GSM network using iterative QR layered space-time receiver

M.Sc.EE. Dabetić Rade, Telekom Srbija, MTS

[1]

Abstract – **In the multiple access wireless systems, like GSM-TDMA, users exploits same resources, which results in co-channel interference. In order to combat against co-channel interference, multi-user detection/interference suppression techniques can be used instead of single-user techniques that treat co-channel interference as noise. In this paper it will be presented and analyzed new receiver algorithm for co-channel interference mitigation. Analysis will be focused on adjacent cell co-channel interference in downlink. Presented technique, used as receiver algorithm in mobile station, is consisting of iterative channel coefficient estimation and subsequently interference suppression and data symbol detection using QR layered space-time receiver. In analysis it is assumed two transmit antennas (one for each base station (BS)-serving and adjacent), two receive antennas (for mobile station-MS), no cell synchronization and no frequency hopping. Simulation results will show performance of proposed receiver.**

Key words — **GSM co-channel interference mitigation, iterative receiver, QR layered space time receiver**

I. INTRODUCTION

Frequency planning in GSM network is the result of compromise of two opposite requirements: maximizing number of channels for traffic and minimizing co-channel interference. For that purpose cluster [1] is used. Cluster is the number of sites in which same frequency groups (groups of GSM frequency channels) are not used twice. For example 4/12 cluster means that 12 frequency groups are used in 4 sites. Adjacent cluster can use the same frequency groups again. Purpose of the cluster is to minimize co-channel interference between same frequencies by making large enough frequency reuse distance. Using large frequency reuse distance means bad spectral efficiency i.e. small number of traffic channels per frequency channel.

Purpose of this paper is to propose receiver algorithm in downlink that will allow that same frequency channel can be used in adjacent cells (small frequency reuse distance) which will result in significant spectral efficiency improvement. Presented algorithm is suitable for MS that have two or more receive antennas. Also algorithm could be implemented, with some changes, on co-channel interference mitigation in uplink. For sake of clarity analysis will be focused only on downlink transmission to MS with two receive antennas. In the chapter II, channel and simulation model in detail is described. In the chapter III proposed algorithm is described. In the chapter IV simulation results are presented. In the chapter V is summation of this paper.

First author, Dabetic Rade, Telekom Srbija a.d. MTS, Srbija (tel:+381 64 1243441, e-mail:raded@telekom.yu)

II. CHANNEL AND SIMULATION MODEL

In A. sub chapter signal and channel model for GSM system will be described. In sub chapter B. simulation model will be presented.

A. GSM signal and channel model

GSM frame is presented in Figure 1. In the middle of the frame is 26 bits of training sequence. On the left and right side there are 58 information bits. Altogether GSM frame has 142 bits. This is description of so called GSM ‘normal burst’ [1] which is used for traffic. Analysis will be based on this frame structure. There is also guard period – GP on each end of the frame and tail binary symbols – TB, but they both will be ignored in this analysis.

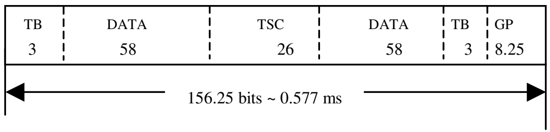

Figure 1. GSM ‘normal burst’

When signal propagates through radio environment it is subject to different distortions due to interference, fading and noise. It will be assumed that there is no ISI, which means that fading is flat Rayleigh fading. Apart from the white Gaussian additive noise impact on the signal there is also an obstruction on the signal amplitude described with coefficients with Rayleigh distribution. Summary the signal obstruction in simulation model is described with:

1. Path loss is the free space propagation loss. Path loss is described with:

$$\frac{P_s}{P_i} = \left(\frac{r_s}{r_i}\right)^{-\alpha}$$

where P_s, r_s are power strength and distance of the MS from serving BS and P_i, r_i are power strength and distance of the MS from interfering BS (Figure 2). In simulations, path loss will be analyzed according to C/I ratio i.e. how much signal strength is stronger than interference strength in dB in the MS position.

2. White noise, which is described through Eb/No – bit power per 1 Hz noise power.

3. Rayleigh fading coefficient matrix, which describes unknown signal amplitude changes between, transmits and receive antennas.

B. Simulation model

The scenario when co-channel interference is caused from adjacent cell is presented on Figure 2 and Figure 3.

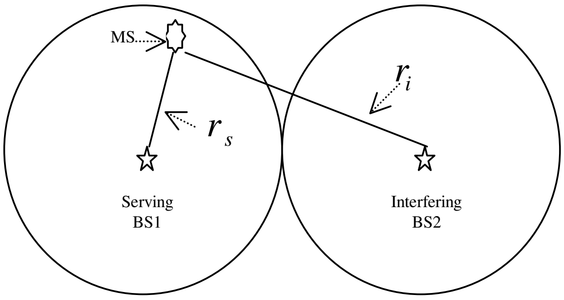

Figure 2. Simulation model

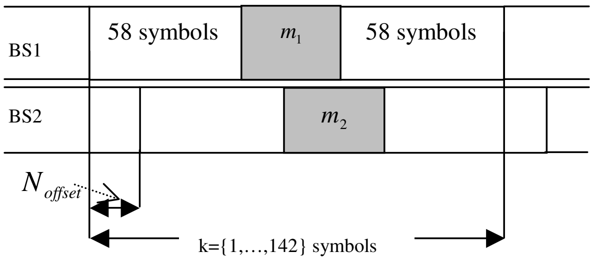

Figure 3. GSM frames

MS is under influence of downlink co-channel interference from BS2. In this paper co-channel interference is presented with C/I (carrier to interference) ratio expressed in dB. The C/I can be reliable estimated because MS already measure power on own and adjacent BCCH carrier in active mode [1]. Frames from BS1 and BS2 come unsynchronized to MS (Figure 3). Because of that, random offset T_{offset} exist between frames. Value of time offset can be estimated by measuring timing difference between frames on BCCH frequencies of serving and adjacent cells. It is assumed that BCCH frequencies are different for serving and adjacent cell. Rayleigh fading coefficients may change rapidly so they must be estimated for each frame. It is assumed that Rayleigh fading coefficients remains unchanged during one frame. Also it is necessary that training sequence in serving and adjacent cell is different because training sequences (m_1, m_2) are used for estimation of Rayleigh fading coefficients (this is the part of the proposed algorithm). Training sequences (m_1, m_2) are known because MS in idle mode reads BCCH information blocks (which includes training sequences) from own and adjacent cells. Training sequences are selected from GSM specification such that they have perfect cross-correlation [1]. Normalized offset is $N_{offset} = T_{offset} / T_s$, where symbol duration is T_s. It is assumed that N_{offset} >0, because results are the same as when N_{offset} is negative. Received signal in MS can be presented with:

$$y(k) = H * x(k) + n(k)$$

where $H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$ where h_{ij} is Rayleigh fading coefficient from BS i (base station i=1,2) to MS antenna j (j=1,2), $x(k) = \begin{bmatrix} x_1(k) \\ x_2(k) \end{bmatrix}$ where $x_1(k)$ is useful frame from BS1 and $x_2(k)$ is interfering symbol from BS2, $n(k) = \begin{bmatrix} n_1(k) \\ n_2(k) \end{bmatrix}$ where $n_1(k), n_2(k)$ are white gaussian noise samples for first and second MS receiving antennas respectively, $y(k) = \begin{bmatrix} y_1(k) \\ y_2(k) \end{bmatrix}$, $y_1(k), y_2(k)$ are received symbols for first and second MS receiving antennas respectively and $k \in \{1,...,142\}$. Signal strength is defined with *C/I=10**log(P_1 / P_2)), where P_i is x_i signal strength. Symbols contained in y(k) will be used in proposed algorithm described in the next chapter. Signal strength difference (in dB) of $x_1(k)$ and $x_2(k)$ is equal to C/I.

For the Rayleigh fading coefficient estimation, next equations are used:

$$Y_{m1} = H * \begin{bmatrix} m_1 \\ \hat{x}_2 \end{bmatrix} + n$$

$$Y_{m2} = H * \begin{bmatrix} \hat{x}_1 \\ m_2 \end{bmatrix} + n$$

where m_1, m_2 are training sequences of serving and interfering base stations respectively. If N_{offset} <26 (Figure 3) then:

$$\hat{x}_2 = \{x_2(59),...x_2(59+N_{offset}), m_2(1),..m_2(26-N_{offset})\}$$

and

$$\hat{x}_1 = \{m_1(N_{offset}),...,m_1(26), x_1(86),...,x_1(86+N_{offset})\}$$

else if $N_{offset} \geq 26$ then:

$$\hat{x}_2 = \{x_2(59),...,x_2(59+26)\}$$

and

$$\hat{x}_1 = \{x_1(59+N_{offset}),...,x_1(86+N_{offset})\}$$

In further analysis it will be assumed that $N_{offset} \leq 26$. These values are then used in the receiver algorithm described in the next chapter.

III. ALGORITHM

In GSM receiver, after receiving, detecting and de-interleaving data from 8 TDMA frames Viterby decoder is used to estimate two 20ms speech frames [1]. Proposed algorithm will estimate channel coefficients, suppress interference for each of 8 TDMA frames and detect useful data, de-interleave and estimate useful data. Previous steps then can be repeated in the multiple iterations in order to improve estimation of matrix *H* and consequently estimation of useful data.

First step in proposed algorithm is to estimate matrix *H*. Matrix *H* can be presented as *H=[h1 h2], h1,h2* are the first and the second column in matrix *H*. Estimation of *h1,h2* in the first iteration [2][3]:

$$h1 = 1/26 * m_1 * Y_{m1}$$

and

$$h2 = 1/26 * m_2 * Y_{m2}$$

and in the second and next iterations:

$$h1^{(j)} = 1/26 * m_1 * (Y_{m1} - h2^{(j-1)} * \hat{x}_2)$$

and

$$h2^{(j)} = 1/26 * m_2 * (Y_{m2} - h1^{(j)} * \hat{x}_1)$$

In this algorithm proposition, only *h2* will be estimated in the second and next iterations, because only values of useful data will be estimated (x_1). Interfering data (x_2) will be suppressed through QR algorithm. Channel coefficient estimation is calculated for 8 TDMA frames.

Second step in algorithm is interference suppression and detection of useful data. Two cases exist.

First case is the detection of useful symbols that do not overlap with training sequence m_2 (Fig. 3). This is achieved through QR decomposition (QR receiver) [4] applied on received signal *y(k)*:

$$y^{'}(k) = Q * y(k) = R * x(k) + Q * n(k)$$

where *H=Q*R* and $k \in \{1,...58,86 + N_{offset},...,142\}$. In case when *H* is 2x2 then matrix *R* has value $R = \begin{bmatrix} r_{11} & 0 \\ r_{21} & r_{22} \end{bmatrix}$. Then detection of useful data symbols can be performed with:

$$\tilde{x}_1(k) = 1/r_{11} * y^{'}(k)$$

On this way interference symbols from other base station are suppressed.

Second case is the detection of symbols that do overlap with training sequence m_2 (Fig. 2). Received symbols for this case are presented with:

$$\begin{bmatrix} y^1_{m2}(k) \\ y^2_{m2}(k) \end{bmatrix} = H * \begin{bmatrix} x_1(k) \\ m_2 \end{bmatrix} + n(k), k \in \{86,...,85 + N_{offset}\}$$

From previous equation two solutions can be found:

$$\tilde{x}_1(k) = 1/h_{11} * (y^1_{m2}(k) - h_{12} * m_2)$$

$$\tilde{x}_1(k) = 1/h_{21} * (y^2_{m2}(k) - h_{22} * m_2)$$

Detected value of $\tilde{x}_1(k)$ can be found as the mean value of previously calculated values. On this way we suppressed interference of known training sequence m_2. Described symbol detection is calculated for 8 TDMA frames.

Third step is data estimation. In the previous step useful symbols are detected for 8 TDMA frames. Detected symbols are first de-interleaved. For data estimation, proposed algorithm uses Viterby decoder on all detected data. If there is more iteration, estimated data are encoded, interleaved back to 8 TDMA frames and algorithm starts again when better estimation of channel matrix *H* is expected, better data estimation is expected etc. Simulation result will show that algorithm converges rapidly.

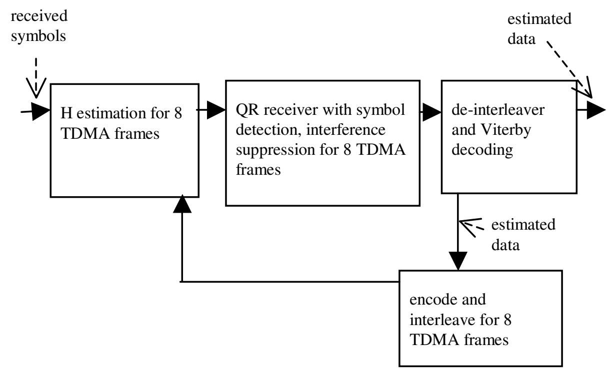

Figure 4. Receiver algorithm

Previous figure is schematic presentation of proposed receiver algorithm.

IV. SIMULATION RESULTS

Simulation results, produced in Matlab, presents previously described algorithm performance for different values of C/I and N_{offset}.

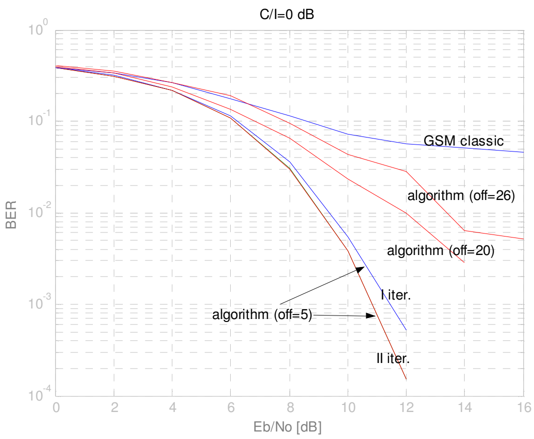

Figure 5. BER for C/I=0 dB

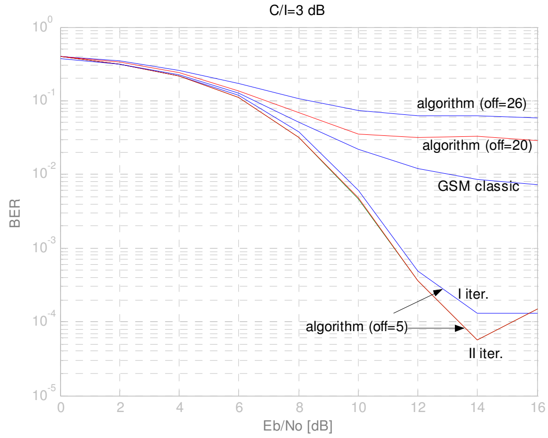

Figure 6. BER for C/I=3 dB

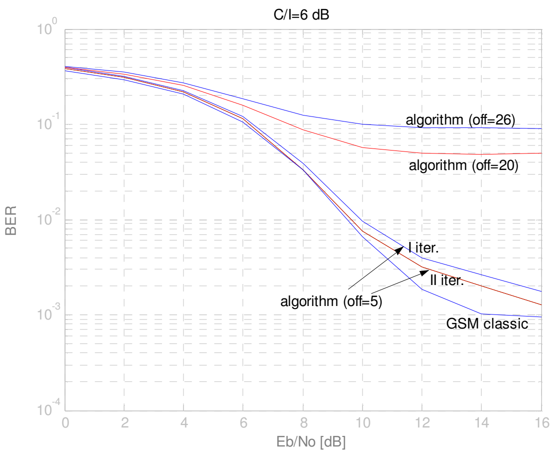

Figure 7. BER for C/I=6 dB

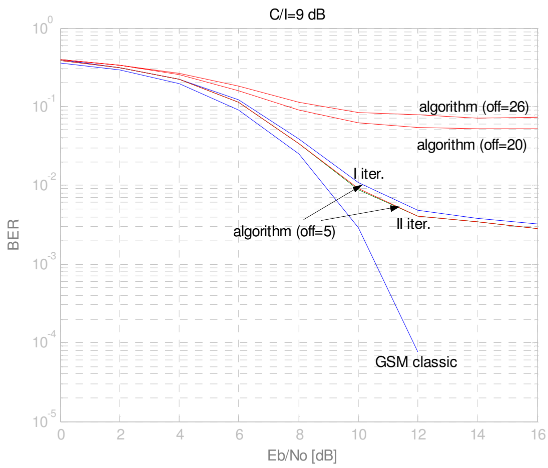

Figure 8. BER for C/I=9 dB

In the previous figures 'GSM classic' marks BER characteristic of classical GSM receiver (treats co-channel interference as white noise). BER characteristics marked with 'algorithm (off=x)' presents simulation results of proposed algorithm with N_{offset}=x. N_{offset} value has very great impact on algorithm performance, as N_{offset} increases BER becomes worse. The reason for that is that training sequences cross-correlation value gradually degrades as N_{offset} value increases [2]. Algorithm converges fast, so it isn't necessary to have more than two iteration, as can be seen from the previous figures (Figures 5-8). This is important fact since it minimizes time of processing which is very important for real time services (like voice service). As C/I value increases algorithm achieves less improvement in compare to classical GSM receiving algorithm. Again, bad estimation of matrix H as C/I increases is the reason for bad BER characteristic of proposed algorithm. At C/I=6 dB both receivers shows similar performance. At the C/I=9 dB classical GSM receiver is better (Figure 8). Algorithm usage should be limited to C/I values less than 6 dB.

V. Conclusion

Proposed algorithm shows very good results in cases when co-channel interference has substation values. Its usage is limited to $C/I \leq 6$ dB, since for bigger C/I values classical GSM receiver shows similar or better results. Also it isn't necessary for synchronization between GSM cells to be perfect. It is enough to be kept in the bound of $N_{offset} \leq 5$. It does not require too much processor power and time for processing, since it converges very rapidly (after 2 iterations). It is not hard to implement it since it uses several simple operations (for channel estimation and interference suppression – chapter IV) in addition to Viterby decoding block. In this paper algorithm is analyzed for GSM voice service, but it can be also implemented on GPRS/EDGE downlink data transfer.

References

[1] Ericsson documentation: "GSM air interface" , 1998
[2] H. Trigui and D. Slock Training sequence based mulituser channel identification for cochannel interference cancellation in GSM. In IEEE Workshop on Signal Processing Advances in Wireless Communications, pages 102.105, 1999
[3] Q. Li, N. Georghiades X. Wang. An iterative receiver for turbo-coded pilot-assisted modulation in fading channels *IEEE Communications Letters*, Vol. 5, No. 4, pages 145.147, Apr. 2001
[4] Branka Vučetić, Jinhong Yuan: "Space-time coding", 2003