Multirate/Multiclass Overlapped FFH-CDMA System: Performance Evaluation and Cutoff Rate Analysis

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***Abstract*: In this paper, a new method is proposed to achieve a multi-class multirate fast frequency hopping code division multiple access system (FFH-CDMA) based on a novel code overlapping procedure. We investigate the signal-to-interference ratio (SIR) performance for such system. A channel model that allows multirate overlapped transmission is presented base on which a closed form solution for the SIR has been derived. A comparison between the exact value of the SIR and the approximated one assuming random sequences is also discussed. On the other hand, the cutoff rate for each class of users is analyzed. It is shown that for a required quality of service (QoS) guarantee, a number of active users, and a given probability of hit, the data rate for each class can be increased beyond the nominal rate imposed by the un-overlapped constraint used in classical systems.**

1. Introduction

Lately, there is a growing interest in the development of broadband wireless communication networks for multimedia applications. The communication services in such networks can be high-speed and low-speed data, video, and many others with different performance and traffic requirements [1]-[6]. Since the output interference in a large CDMA system can be approximated as Gaussian [5][6], it is reasonable to take the quality of service (QoS) requirement as meeting the signal-to-interference power ratio SIR constraint.

Classical fast frequency hopping CDMA (FFH-CDMA) has been discussed in many works [7]-[10]. A multirate FFH-CDMA system using variable processing gain (PG) has been proposed in [4][6]. The intention was to guarantee the one-to-one correspondence between the PG and the source transmission rate. The drawback of this system is the drastic decrease in the transmitted signal power especially for higher rate users for which the PG becomes very small. The solution to this problem is the use of power control [5]. On the other hand, *Kwong* in [1][2] considered the multilength frequency hopping codes. Using these codes, rate and QoS are now dynamically matched to users' needs. The cutoff rate of the system is still limited by the physical constraints of the codes.

In this work, the general problem we consider is by how much we can increase the transmission rates of different classes of traffic beyond the nominal permitted rates so as to optimize performance to meet the QoS requirements, given a fixed PG for each class, a fixed number of users in the network, and a multimedia distribution. We will show that for an optimized family of codes, it is possible to increase a class bit rate beyond the nominal rate without decreasing the PG of the desired user as in [5][6] or allowing any time delay between the data symbols as proposed in [1].

Following the introduction, the paper is organized as follows. Section II presents the system model. In Section III, we derive an expression for the SIR. In addition, we quantify the effective increase in the number of hits as a function of the transmission rate. In Section IV, a service curve is introduced and derived, which relates the cutoff rates of the offered multimedia classes in a multi-class system. Section V contains numerical results. Finally, the conclusion is presented in Section VI.

2. Multi-class System Model

Consider a multirate FFH-CDMA communication network that supports M users in N different classes, which share the same medium [6]. The corresponding PGs for each class are given by $G_0 > G_1 > \ldots > G_{N-1}$. The nominal bit duration is given by $T_s = G_s T_c$ with T_c being the chip duration. The corresponding nominal rate is $R_{n\_s} = 1/T_s$. When the data rate increases beyond R_{n_s}, multi-bits can be coded during the time period T_s and transmitted together as revealed in Fig 1. At a given receiver the decoder observes practically multicode, which are delayed according to the transmission rate of the source as shown in Fig. 1. When user k transmits using rate $R_s > R_{n\_s}$, it introduces a bit overlap coefficient ε_s according to which the new rate is related to the nominal rate through the following equation

$$R_s = \frac{G_s}{G_s - \varepsilon_s} R_{n\_s} \tag{1}$$

In this paper we assume 1) a chip synchronous system and a discrete rate variation, 2) all users in the *class-s*, $s \in \{0,1,\ldots,N-1\}$, have the same bit overlap coefficient $0 \le \varepsilon_s < G_s - 1$, thus each class is characterized by $(G_s, \varepsilon_s, \beta_s)$, where β_s is the QoS requirement, and 3) a unit transmission power for all the users.

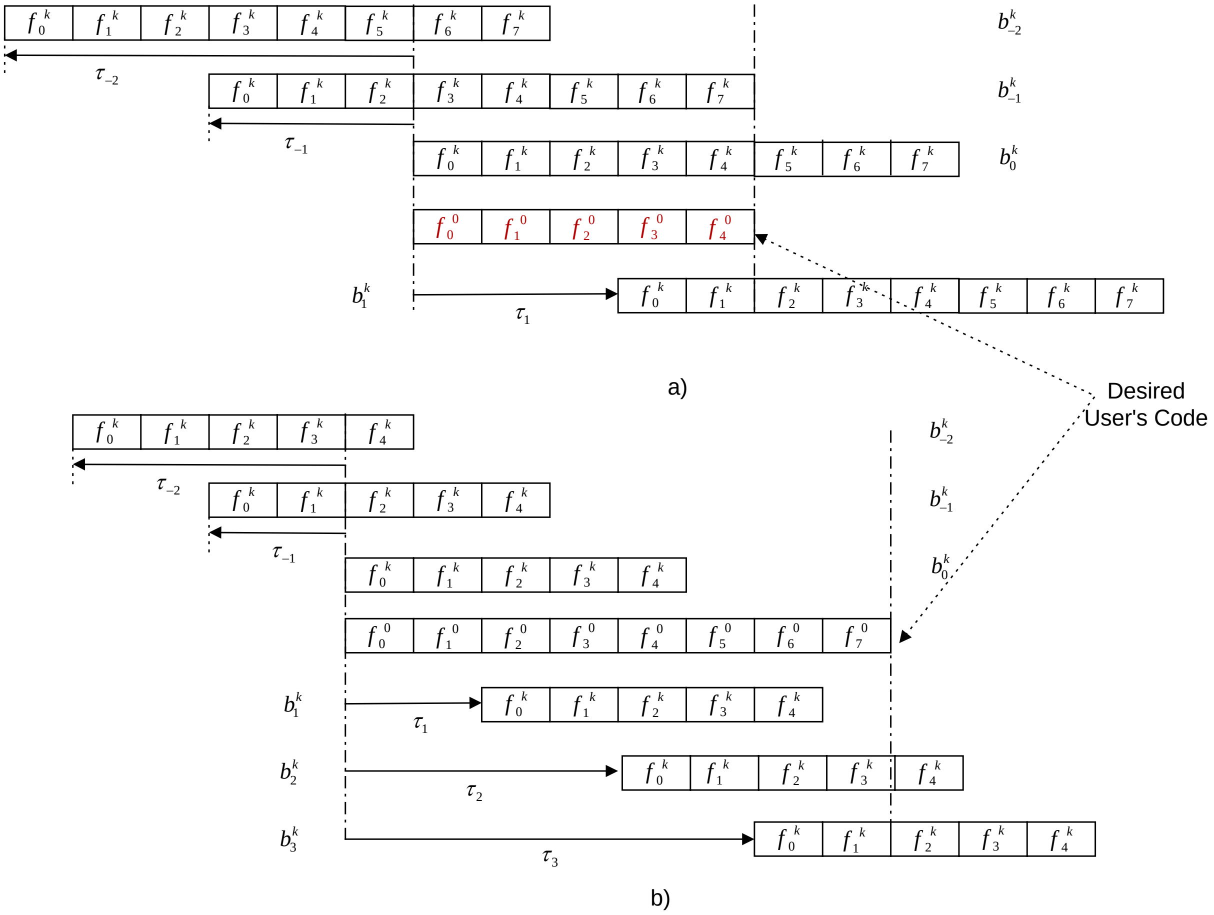

Fig. 1: Bandwidth of the proposed system.

2.1. Signal Structure

We define $a_k^{(s)}(t,f)$ and $b_k^{(s)}(t)$ as the hopping pattern and the baseband signal, respectively, where t and f represent the time and frequency dimensions. From Fig. 1, the bit stream can be seen to be serial-to parallel converted to v pulses. Assuming that the desired user is using the *class-m*, which is characterized by a PG G_m and an overlapping coefficient ε_m. Since the desired user nominal time period is $T_m = G_m T_c$, we are interested only in modeling the k^{th} interfering channel during a time period T_m. Because the bit b_X^k from the v-bits is delayed by $\tau_X = X\left(G_s - \varepsilon_s\right)T_c$, this suggests that the channel model, as seen by the desired receiver, can be represented as a tapped delay line with tap spacing of $\tau_{-1} = -\left(G_s - \varepsilon_s\right)T_c$ from left and $\tau_1 = \left(G_s - \varepsilon_s\right)T_c$ from right. The tap weight coefficients $b_X^k \in \{-1,1\}$ depending on whether the transmitted bit is zero or one. The truncated tapped delay line model as seen by the desired receiver is shown in Fig. 2. Accordingly the transmitted signal is given by

$$S_k\left(t,f\right) = \sum_v b_v^k a_k^{(s)}\left(t - \tau_v, f\right) \qquad (2)$$

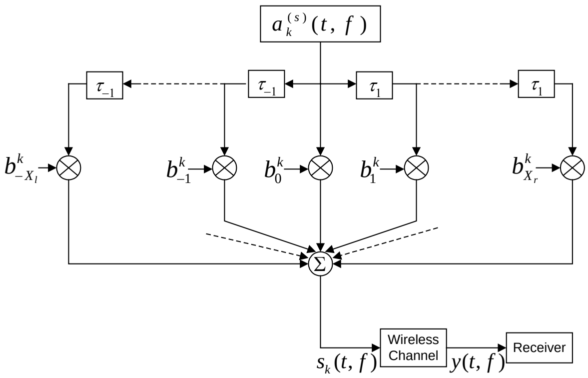

Fig. 2: Channel model.

Lemma 1: *Given an interferer k with* $\left(G_s, \varepsilon_s\right)$ *and the desired user with* $\left(G_m, \varepsilon_m\right)$ $\forall\, s, m \in \{0,1,\ldots,N-1\}$. *At the desired receiver end, during the nominal time period* T_m*, the observed total number of taps in channel k is given by*

$$N_k\left(G_m, G_s, \varepsilon_s\right) = \left\lceil \frac{\varepsilon_s}{G_s - \varepsilon_s} \right\rceil + \left\lceil \frac{\Delta G + \varepsilon_s}{G_s - \varepsilon_s} \right\rceil + 1 \qquad (3)$$

where $\Delta G = G_m - G_s$

Proof: For a given transmission rate R_s, which corresponds to $0 \le \varepsilon_s \le G_s - 1$ through (1) we can notice that in order for any transmitted bit b_X^k not to correlate with the desired user code during the time period T_m, the following inequalities must be satisfied

1) Preceding bits from the right

$$X \ge \frac{G_m}{G_s - \varepsilon_s} \quad (4)$$

If we use the fact that we consider discrete chip overlap, the smallest integer that satisfies (4) is

$$X = \left\lceil \frac{G_m}{G_s - \varepsilon_s} \right\rceil$$

Thus, we can define the final bit $b_{X_r}^k$ that correlates with the desired decoder from the right as follows

$$X_r = \left\lceil \frac{G_m}{G_s - \varepsilon_s} \right\rceil - 1 = \left\lceil \frac{G_m - G_s + \varepsilon_s}{G_s - \varepsilon_s} \right\rceil = \left\lceil \frac{\Delta G + \varepsilon_s}{G_s - \varepsilon_s} \right\rceil$$

2) Upcoming bits from the left

The same analysis can be applied for the upcoming bits but with the following inequality that must be satisfied

$$X \ge \frac{G_s}{G_s - \varepsilon_s} \quad (5)$$

The smallest integer that satisfies (5) is

$$X = \left\lceil \frac{G_s}{G_s - \varepsilon_s} \right\rceil$$

Therefore, the final bit $b_{X_l}^k$ that correlates with the desired decoder from left is given by

$$X_l = \left\lceil \frac{G_s}{G_s - \varepsilon_s} \right\rceil - 1 = \left\lceil \frac{\varepsilon_s}{G_s - \varepsilon_s} \right\rceil$$

Hence, the total number of observed transmitted codes is equal to X_r plus X_l in addition to the normal bit b_0^k, which proves (3). ¦

Lemma 2: *Given an interferer k with* (G_s, ε_s) *and the desired user with* (G_m, ε_m), *the observed total number of transmitted codes from transmitter k that undergo a total overlap with the desired correlator during* T_m *and excluding the normal bit* b_0^k, *is given by*

$$X_t = \left\lfloor \frac{|\Delta G|}{G_s - \varepsilon_s} \right\rfloor \quad (6)$$

where $\lfloor x \rfloor$ *is the highest integer smaller than x and* $|\Delta G|$ *is given by*

$$|\Delta G| = \begin{cases} G_m - G_s, & \text{if } G_m > G_s \\ G_s - G_m, & \text{if } G_m \le G_s \end{cases} \quad (7)$$

Proof: The proof is divided into two parts *1)* $G_m > G_s$ and *2)* $G_m \le G_s$.

1) $G_m > G_s$

In order to have a total overlap from the right, a bit b_X^k must satisfy the following inequality

$$G_s + X(G_s - \varepsilon_s) \le G_m$$

which means

$$X \le \frac{G_m - G_s}{G_s - \varepsilon_s}$$

The highest integer that satisfies the above inequality is

$$X_t = \left\lfloor \frac{G_m - G_s}{G_s - \varepsilon_s} \right\rfloor \quad (8)$$

2) $G_m \le G_s$

On the other hand, b_X^k has full overlap when $G_m \le G_s$, if

$$G_s - X(G_s - \varepsilon_s) \ge G_m$$

Therefore,

$$X \le \frac{G_s - G_m}{G_s - \varepsilon_s}$$

Thus, the final bit that has a total overlap is given by

$$X_t = \left\lfloor \frac{G_s - G_m}{G_s - \varepsilon_s} \right\rfloor \quad (9)$$

Having (8) and (9), we can easily deduce (6), which completes the proof of the Lemma. ¦

The received signal at the input of the decoder is therefore given by

$$y(t, f) = n(t) + \sum_{k=0}^{M-1} \sum_{v=-X_l}^{X_r} b_v^k a_k^{(s)}(t - \tau_v, f)$$

where $n(t)$ is an additive white Gaussian noise (AWGN) with two-sided power spectral density $\Gamma_0/2$.

2.2. Decoder's Output

Without loss of generality, we assume that the correlation-matched filter is matched to the zeroth signal with class-*m*. The output of the noncoherent matched filter correlator will be

$$Z_0^{(m)} = \Gamma + \int_0^{T_m} \sum_{k=0}^{M-1} S_k(t - \tau_v, f) a_0^{(m)}(t, f) dt$$

where Γ is a zero-mean AWGN with variance $\sigma_n^2 = \Gamma T_m / 4$. The multiple access interference (MAI) I_k from user k that transmits data with rate R_s can be written as

$$\begin{aligned} I_k = & \sum_{v=-X_l}^{-1} \int_0^{\tau_v} b_v^k h\left(a_k^{(s)}(t - \tau_v), a_0^{(m)}(t)\right) dt \\ & + \sum_{v=0}^{X_t} \int_{\tau_v}^{\tau_v + T_s} b_v^k h\left(a_k^{(s)}(t - \tau_v), a_0^{(m)}(t)\right) dt \\ & + \sum_{v=X_t+1}^{X_r} \int_{\tau_v}^{T_m} b_v^k h\left(a_k^{(s)}(t - \tau_v), a_0^{(m)}(t)\right) dt, \quad G_m > G_s \end{aligned} \quad (10)$$

and

$$\begin{aligned} I_k = & \sum_{v=-X_l}^{1-X_t} \int_0^{\tau_v} b_v^k h\left(a_k^{(s)}(t - \tau_v), a_0^{(m)}(t)\right) dt \\ & + \sum_{v=-X_t}^{0} \int_0^{T_m} b_v^k h\left(a_k^{(s)}(t - \tau_v), a_0^{(m)}(t)\right) dt \\ & + \sum_{v=1}^{X_r} \int_{\tau_v}^{T_m} b_v^k h\left(a_k^{(s)}(t - \tau_v), a_0^{(m)}(t)\right) dt, \quad G_m \le G_s \end{aligned} \quad (11)$$

$\forall \; k \ne 0$.$h(.)$ is the Hamming function [6]. The sequences $a_k^{(s)}(t)$ and $a_0^{(m)}(t)$ are numbers representing frequencies used at time t for the k^{th} interferer and the desired user, respectively. Notice that $a_k^{(s)}(i) = a_k^{(s)}(i + T_s)$. In addition, we define a new performance parameter called the auto-interference, I_0, caused by the desired user's signal and it is given by

$$I_0 = \sum_{v=-X_r}^{-1} \int_0^{\tau_v} b_v^0 h\left(a_0^{(m)}(t-\tau_v), a_0^{(m)}(t)\right)dt + \sum_{v=1}^{X_r} \int_{\tau_v}^{T_m} b_v^0 h\left(a_0^{(m)}(t-\tau_v), a_0^{(m)}(t)\right)dt \quad (12)$$

3. SIR Performance Evaluation

Since the user may set a connection for a particular multimedia class and modify it dynamically, the index *s* is a discrete random variable with a certain prior probability

$$p_k^{(i)} = \Pr(\text{user } k \text{ chooses class-}i) = \Pr(s=i) \qquad \forall\, i \in \{0,1,...,N-1\} \quad (13)$$

with $\sum_{s=0}^{N-1} p_k^{(s)} = 1$ and we call $p_k^{(s)}$ the multimedia probability mass function (pmf) for user *k*. I_k, $\forall\ 0 \le k \le M-1$, is assumed to be an independent random variable. Hence, the variance of the decision variable $Z_0^{(m)}$ is

$$\operatorname{var}\left[Z_0^{(m)}\right] = \sum_{k=1}^{M-1}\sum_{s=0}^{N-1} p_k^{(s)} \sigma_{I_k/s}^2 + \sigma_{I_0}^2 + \sigma_n^2 \quad (14)$$

$\sigma_{I_k/s}^2$ and $\sigma_{I_0}^2$ represent the interference power caused by an active user *k* using class-*s* and the auto-interference power caused by the desired user due to overlapping, respectively and they are given by

$$\sigma_{I_k/s}^2 = E(I_k^2/s) - E^2(I_k/s) \quad (15)$$

$$\sigma_{I_0}^2 = E(I_0^2) - E^2(I_0) \quad (16)$$

where *E*(.) is the expectation operator over all possible values of the overlapping bits b_X^k for $X \in \{-X_l, ..., X_r\}$ assuming that $\Pr\left(b_X^k = 1\right) = \Pr\left(b_X^k = -1\right) = 1/2$. $E(I_k/s)$ and the cross terms generated from squaring the summation in $E\left(I_k^2/s\right)$ become zeros because the average over the bit is zero, which enables us to write

$$E\left(I_k^2/s\right) = R_k\left(T_m, T_s, \varepsilon_s\right) = \begin{cases} \dfrac{1}{2}\left[\displaystyle\sum_{v=-X_l}^{-1} H_{k,0}^2(0,\tau_v) + \sum_{v=0}^{X_t} H_{k,0}^2(\tau_v, \tau_v + T_s) + \sum_{v=X_t+1}^{X_r} H_{k,0}^2(\tau_v, T_m)\right], & G_m > G_s \\ \dfrac{1}{2}\left[\displaystyle\sum_{v=-X_l}^{1-X_t} H_{k,0}^2(0,\tau_v) + \sum_{v=-X_t}^{0} H_{k,0}^2(0, T_m) + \sum_{v=1}^{X_r} H_{k,0}^2(\tau_v, T_m)\right], & G_m \le G_s \end{cases} \quad (17)$$

$$E\left(I_0^2\right) = R_0\left(T_m, \varepsilon_m\right) = \frac{1}{2}\left[\sum_{v=-X_r}^{-1} H_{0,0}^2(0,\tau_v) + \sum_{v=1}^{X_r} H_{0,0}^2(\tau_v, T_m)\right] \quad (18)$$

where,

$$H_{k,0}\left(\tau_i, \tau_j\right) = \int_{\tau_i}^{\tau_j} h\left(a_k(t-\tau_v), a_0(t)\right)dt \quad (19)$$

Let $q_v = \tau_v / T_c$, we can write

$$H_{k,0}(0,\tau_v) = T_c H_v(0,q_v) = T_c \sum_{j=0}^{q_v-1} h(a_{j-q_v}^k, a_j^0) \quad (20)$$

$$H_{k,0}\left(\tau_v, T_m\right) = T_c H_v\left(q_v, G_m\right) = T_c \sum_{j=q_v}^{G_m-1} h\left(a_{j-q_v}^k, a_j^0\right) \quad (21)$$

$$H_{k,0}\left(\tau_v, \tau_v + T_s\right) = T_c H_v\left(q_v, q_v + G_s\right) = T_c \sum_{j=q_v}^{q_v+G_s-1} h\left(a_{j-q_v}^k, a_j^0\right) \quad (22)$$

Using (20)-(22), $R_k\left(T_m, T_s, \varepsilon_s\right)$ and $R_0\left(T_m, \varepsilon_m\right)$ can be written as

$$R_k\left(T_m, T_s, \varepsilon_s\right) = \begin{cases} \dfrac{T_c^2}{2}\left[\displaystyle\sum_{v=-X_l}^{-1} H_v^2(0,q_v) + \sum_{v=0}^{X_t} H_v^2(q_v, q_v+G_s) + \sum_{v=X_t+1}^{X_r} H_v^2(q_v, G_m)\right], & G_m > G_s \\ \dfrac{T_c^2}{2}\left[\displaystyle\sum_{v=-X_l}^{1-X_t} H_v^2(0,q_v) + \sum_{v=-X_t}^{0} H_v^2(0, G_m) + \sum_{v=1}^{X_r} H_v^2(q_v, G_m)\right], & G_m \le G_s \end{cases} \quad (23)$$

$$R_0\left(T_m, \varepsilon_m\right) = \frac{T_c^2}{2}\left[\sum_{v=-X_r}^{-1} H_v^2(0,q_v) + \sum_{v=1}^{X_r} H_v^2(q_v, G_m)\right] \quad (24)$$

If we define

$$R_k\left(G_m, G_s, \varepsilon_s\right) = R_k\left(T_m, T_s, \varepsilon_s\right) \Big/ \left(T_c^2/2\right)$$

and $R_0\left(G_m, \varepsilon_m\right) = R_0\left(T_m, \varepsilon_m\right) \Big/ \left(T_c^2/2\right)$, then we substitute into (15) and (16), the SIR experienced by any active user that uses class-*m* is

$$\text{SIR}_m = \frac{G_m^2}{\displaystyle\sum_{k=1}^{M-1}\sum_{s=0}^{N-1} p_k^{(s)} R_k\left(G_m, G_s, \varepsilon_s\right) + R_0\left(G_m, \varepsilon_m\right) + \sigma_n^2} \quad (25)$$

3.1. Effective Increase in the Number of Hits

Proposition 1: For one-coincidence sequences with non-repeating frequencies [9][10], the expected value of the increase in the number of hits caused by any active interferer with $\left(G_s, \varepsilon_s\right)$ on a desired user with $\left(G_m, \varepsilon_m\right)$ is given by (28). In addition, the effective increase of the number of hits due to the auto-interference is

$$I_H^0\left(G_m, \varepsilon_m\right) = 0 \quad (27)$$

where X_r, X_l, X_t, and $|\Delta G|$ are given throughout Lemma 1 and Lemma 2 and *F* is the total number of available frequencies.

$$I_H^k\left(G_m,G_s,\varepsilon_s\right)=\frac{1}{F}\left[\left(G_s-\frac{\left(G_s-\varepsilon_s\right)}{2}\right)X_l-\frac{\left(G_s-\varepsilon_s\right)}{2}X_l^2+\left(G_m-\frac{\left(G_s-\varepsilon_s\right)}{2}\right)X_r-\frac{\left(G_s-\varepsilon_s\right)}{2}X_r^2+\left(\frac{\left(G_s-\varepsilon_s\right)}{2}-\left|\Delta G\right|\right)X_t+\frac{\left(G_s-\varepsilon_s\right)}{2}X_t^2\right] \quad (28)$$

***Proof*:** Is omitted due the lake of permitted space. ¦

In Fig. 3, we plot the position of hits between two Extended Hyperbolic Congruential (EHC) [9] codes with $G_s = G_m = 40$ and for $\varepsilon_s = 35$.

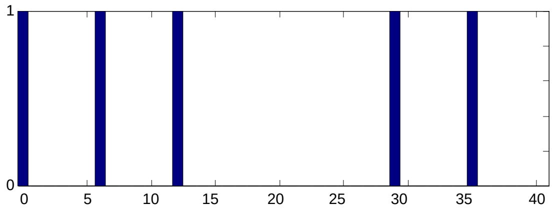

Fig. 3: Hit positions between two EHC codes for 35 chips overlap ($\varepsilon_s = 35$).

3.2. Average SIR

Assuming that the overlapping codes are independent virtual active users and one-coincidence sequences, we can compute the average correlations given in (23) and (24). In addition, if we assume that the multimedia pmf is the same for every user, $p_k^{(s)} = p^{(s)}$, the average SIR for the desired user with $\left(G_m,\varepsilon_m\right)$ will be

$$\mathrm{SIR}_m = \frac{G_m^2}{\frac{(M-1)}{2}\left\{\sum_{s=0}^{N-1}\frac{\left[p^{(s)}\cdot G_s\right]}{F}+\sum_{s=0}^{N-1}\left[p^{(s)}\cdot I_H^k\left(G_m,G_s,\varepsilon_s\right)\right]\right\}+\sigma_n^2} \quad (29)$$

In (29), we have been able to separate the interference power into the normal MAI power caused by active users when $R_s = R_{n\_s}$ and the one caused by virtual users that overlap with the desired user's code when $R_s > R_{n\_s}$.

4. Cutoff Rate Analysis

The main objective of this part is to analyze the cutoff rate for each working class in the system given *M*, *G_s*, $p^{(s)}$, and the QoS guarantee β_s for every $s \in \{0,1,\ldots,N-1\}$. For the clarity of the method and for mathematical convenience, we will present the case of a two-class system. In addition, we assume that all the classes have the same PG $\left(G_s = G\right)$. In this case, $X_l = X_r = X = \left\lfloor\frac{\varepsilon_s}{G-\varepsilon_s}\right\rfloor$. Therefore, (28)is simplified to

$$I_H^k\left(G,\varepsilon_s\right)=\frac{1}{F}\left[\left(G+\varepsilon_s\right)X-\left(G-\varepsilon_s\right)X^2\right] \quad (30)$$

Knowing that X is bounded by $\frac{\varepsilon_s}{G-\varepsilon_s} \le X = \left\lfloor\frac{\varepsilon_s}{G-\varepsilon_s}\right\rfloor \le \frac{G}{G-\varepsilon_s}$, the value of $I_H^k\left(G,\varepsilon_s\right)$ is simplified to

$$I_H^k\left(G,\varepsilon_s\right)=\frac{G}{F}\left(\frac{\varepsilon_s}{G-\varepsilon_s}\right) \quad (31)$$

Using (31) in (29) we obtain

$$\mathrm{SIR_m} = \frac{G^2}{\frac{G^2(M-1)}{2F}\cdot\sum_{s=0}^{N-1}\left[\frac{p^{(s)}}{G-\varepsilon_s}\right]+\sigma_n^2} \quad (32)$$

Consider a two-class system namely *class*-0 and *class*-1, which are characterized by $\left(\varepsilon_0,\beta_0\right)$ and $\left(\varepsilon_1,\beta_1\right)$. By means of the above results and taking $\mathrm{SIR}_0 \ge \beta_0$ and $\mathrm{SIR}_1 \ge \beta_1$ and neglecting the effect of σ_n^2, we obtain

$$\left(G-p^{(1)}\right)\varepsilon_0+\left(G-p^{(0)}\right)\varepsilon_1-\varepsilon_0\varepsilon_1 \le \frac{2FG^2}{(M-1)}-G\cdot\max\left\{\beta_0,\beta_1\right\} \quad (33)$$

Equation (33) draws the overlapping region of the system, meaning the region under which we can increase ε_0 and ε_1 without violating the QoS requirements. This line is called the service curve of the system.

5. Numerical Results

For a single class system, Fig. 4 plots the SIR for an active user while varying its transmission rate or equivalently its overlapping coefficient using real codes and the one obtained in (29). In the numerical results that use real codes through (25), we use the EHC family of codes [9] and the sequences are generated using $F = 41$ available frequencies with $G = 40$. Notice that for $M = 20$ users and small value of the overlapping coefficient, the exact SIR exhibits some fluctuations, which make it deviates from the approximated SIR. A general observation is the drastic decrease in the system's SIR when $\varepsilon > G/2$.

On the other hand, and for a 2-class system, Fig. 5 shows the maximum allowable overlapping coefficients for each class, or the service curve, when varying the multimedia pdf $P^{(s)}$ while fixing $F = 80$, $\beta_0 = 210$, $\beta_1 = 90$, and $M = 20$. The important thing to notice in this figure is that when $P^{(0)} > P^{(1)}$, the system allows more relative overlap for *class*-1. As $P^{(0)} < P^{(1)}$, more relative overlap is allowed for *class*-0.

6. Conclusion

In this work, the main idea from our derivations is to find and analyze the SIR for a multi-class OFFH-CDMA system. A system model was presented and the SIR was derived based on a newly proposed bit overlap procedure. Simulation and analytical results showed that it is possible to increase the transmission rate well beyond the nominal rate of the encoder/decoder pairs.

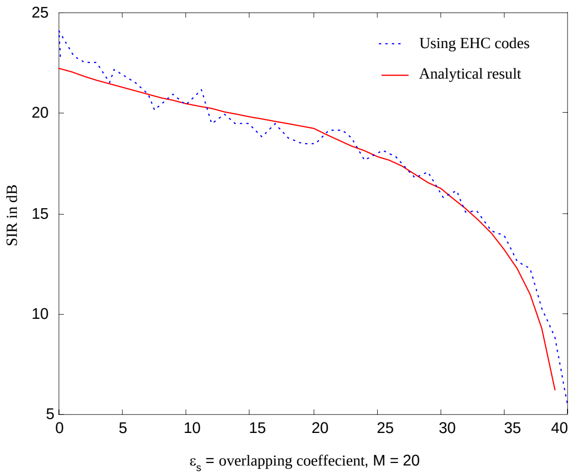

Fig. 4: System's SIR (in dB) versus the overlapping coefficient using real codes and the analytical results.

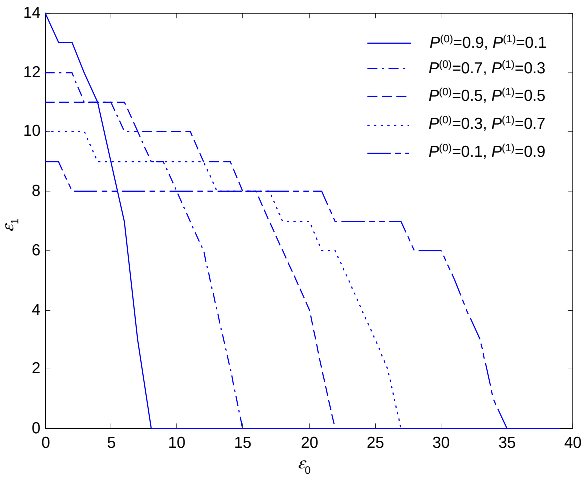

Fig. 5: ε_1 versus ε_0 when we very the multimedia pdf and for $F = 80$, $\beta_0 = 210$, $\beta_1 = 90$, and $M = 20$.

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