Service Curve Assurances versus Uplink Throughput in CDMA Networks

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ABSTRACT

The scheme proposed in this paper balances the partly conflicting objectives of meeting the diverse quality of service (QoS) needs of mobile hosts (MHs) and achieving high uplink throughput in a Direct Sequence Code Division Multiple Access (DS-CDMA) based cellular network. The QoS needs of the MHs are modeled using the notion of a service curve, which is a function characterizing the minimum number of bits a MH must transmit in any given time interval in order to meet its QoS requirement. Each MH is also assumed to have a specified bound on the acceptable bit error rate.

The technique proposed in this paper maximizes the uplink throughput subject to the service curve constraints by jointly adapting the transmitted power and the number of spreading codes used by each MH in relaying its data bits. During this joint adaptation, the technique also imposes specified bounds on the transmitted power and the number of spreading codes that a MH can handle. The proposed technique is evaluated using a discrete-event simulation. The evaluation shows that the proposed scheme can effectively balance the two above-mentioned objectives.

Keywords

Wireless networks, Multimedia systems, Quality of service differentiation.

1. INTRODUCTION

Next generation wireless and wireline network must concurrently support applications with diverse quality of service (QoS) requirements. For example, the QoS needs of data-oriented applications such as telnet, ftp, and email are considerably different from those of streaming applications such as Voice-over-IP and real audio. The need to support such diverse QoS requirements has been recognized in wireline network research for well over a decade and numerous solutions have been proposed to provide such a support. These solutions are commonly referred to as Packet Fair Queueing (PFQ) algorithms [2,5,9,16].

In wireless networks, on the other hand, research on diverse QoS support is fairly recent, especially in the context of Packet Fair Queueing algorithms. For instance, Lu, Bharghavan, and Srikanth [12] were one of the first to propose a fair scheduling policy for wireless networks that tries to approximate the Weighted Fair Queueing (WFQ) policy [5]. Following that work, Ng, Stoica, and Zhang [13], Ramanathan and Agrawal in [17] and Chang and Chen in [3] have also proposed approaches for adapting various wireline PFQ algorithm to wireless networks. As in all the wireline PFQ algorithms, the solutions in [3,5,12,13,17] assume that Time Division Multiplexing is the underlying medium access scheme. They also assume a cellular model for the wireless network. That is, the geographic area is divided into many cells and each cell has a base station (BS) through which the mobile hosts (MHs) in the cell communicate. The papers also assume that the wireless PFQ algorithm for each cell is implemented as a centralized algorithm in each BS.

In contrast to the above-cited work, we consider a Direct Sequence Code Division Multiple Access (DS-CDMA) based cellular network in this paper. In a DS-CDMA network, multiple MHs can simultaneously transmit, each using its own pre-assigned unique "spreading code". At any time instant, the BS receives attenuated signals from all the transmitting MHs. From these signals, the BS decodes the information transmitted by a particular MH using the MH's unique spreading code. In this process, the signals from other MHs manifest as interference.

QoS differentiation in a DS-CDMA network can be achieved by careful allocation of two resources: *power* and *rate*. Power allocation affects the relative received strength of signals from different MHs at the BS, which in turn determines the bit error rate in decoding a MH's information. Thus, by adjusting the power levels at which the MHs transmit, one can support QoS differentiation based on tolerable bit error rate. The rate allocation, on the other hand, determines the number of bits a MH can transmit per unit time. In a DS-CDMA network, rate allocation can be done in two ways: (i) by changing a parameter called the processing gain, and (ii) by changing the number of spreading codes assigned to the MH. In this paper, we use the latter approach for rate allocation. This latter approach is commonly referred to as the *multicode* scheme.

Prior work in DS-CDMA networks on adaptive power and rate allocation have mostly focused on throughput maximization [11,14,15]. That is, instead of QoS differentiation, they strive to maximize the total number of bits reliably sent by all the MHs to the BS. For example, in [14,15], Oh, Wasserman, and Olsen, use a game theoretic approach to dynamically allocate power and processing gain to maximize the total throughput. In [11], Jafar and Goldsmith characterize the optimal power and rate allocation to maximize the throughput in a multicode DS-CDMA network. They also describe a search-based algorithm to find the optimal solution.

In contrast, one of the primary objectives of the scheme in this paper is QoS differentiation. Throughput maximization is the other objective. We show later in this paper that these two objectives are often in conflict with each other. Our model for QoS differentiation is based on the notion of a service curve [18,19]. Specifically, a *service curve* is using a non-decreasing function of time which for each time interval, characterizes the minimum number of bits a MH must transmit in that interval in order to meet its QoS requirements. Thus, MHs with different QoS needs can be differentiated by assigning correspondingly different service curve to them. The scheme proposed in this paper dynamically adapts the transmitted power and the number of spreading codes assigned to the MHs in such a way that the service curves of all MHs are assured to the extent possible. Additional constraints considered in this paper include bounds on: (i) the maximum power level at which a MH can transmit, (ii) the number of spreading codes that can be assigned to a MH, and (iii) maximum tolerable bit error rate.

The effectiveness of our approach in balancing the two conflicting objectives is evaluated using a discrete-event simulator. The results show that if the bound on the maximum transmit power is not a severe constraint, then the service curve requirements of the MHs can be reasonably met without much loss in throughput. However, in a power inadequate system where the maximum transmit power is a limiting constraint, there is a tradeoff between achieving high throughput and reducing the discrepancy from the service curve. A service provider can tradeoff throughput for discrepancy from service curve by selecting a design parameter in the proposed scheme.

The rest of this paper is organized as follows. In Section 2, we briefly review relevant background material on service curves and DS-CDMA networks. Then, in Section 3, we formally describe the system model. The proposed solution in described in Section 4 and simulation results evaluating our approach is presented in Section 5. The paper concludes with Section 6.

2. BACKGROUND

2.1 Notion of Service and Deadline Curves

In this paper, we assume that the QoS needs of each MH can be represented using the notion of a service curve [18,19]. Formally, the service curve is a non-decreasing function of time characterizing the minimum number of bits that must be transmitted in each given time interval in order to meet the corresponding QoS requirement.

A service curve $S_i(\cdot)$ is said to have been assured to MH i at time t_2, if there exits a $t_1 \leq t_2$, where t_1 is the start of a backlog period such that

$$S_i(t_2 - t_1) \leq W_i(t_1, t_2),$$

where $W_i(t_1, t_2)$ is the number of bits transmitted by MH i in interval (t_1, t_2). Note that, t_1 need not to be the start of the backlog period containing t_2.

Algorithmically, given a service curve $S_i(\cdot)$ for MH i, the BS maintains at any given time s, a function called a deadline curve $D_i(t)$ which specifies for all time $t \geq s$ the minimum number of bits that must be transmitted in interval $[0, t)$ in order to assure the service curve $S_i(\cdot)$ at time t. More formally, if $B_i(s)$ is the set of start of backlog periods of MH i prior to time s, then

$$D_i(t) = \min_{u \in B_i(s)} (S_i(t-u) + W_i(0,u)),$$

where, as before, $W_i(0, u)$ is the number of bits transmitted by MH i in interval $(0, u)$. A simple iterative algorithm to maintain $D_i(t)$ is described in [20].

2.2 SINR Computation in Matched Filter Receiver

In a DS-CDMA network, each MH i is first pre-assigned a unique spreading code, say s_i. MH i modulates its data bits using s_i before transmitting them over the wireless channel. The modulated data bits are transmitted using a certain power level P_i. As the signal from MH i propagates to BS, it gets attenuated. Let g_i denote the amount of attenuation, called *path loss*, experienced by MH i at a given time instant. Then, the “strength” of the signal from MH i at BS at that time instant is only g_iP_i. The BS receives only the sum total of signals from all the transmitting MHs. From the total signal, BS retrieves the data bits transmitted by MH i, using a “matched filter” on the received signal. Because of the presence of signals from other MHs and random noise, the decoding of bits of MH i is not perfect.

The bit error rate in retrieving the data bits of MH i can be shown to be a function of Signal to Interference plus Noise Ratio (SINR). For a matched filter based decoding at MH i, the analytic expression for SINR is

$$SINR = \frac{(s_i, s_i)^2 g_i P_i}{\sum_{j \neq i} (s_j, s_i)^2 g_j P_j + (s_i, s_i) N_0}$$

where (s_i, s_j) denotes the inner product of spreading code s_i and s_j and N_0 is the power of the random noise.

The numerator in the above expression is the power of the signal at the BS from MH i and the two terms in the denominator are respectively called the interference and noise. The interference is the effective power in the signal from other MHs which corrupts the decoding of bits of MH i.

Note that, if the spreading codes of two MH i and j are orthogonal, then $(s_i, s_j) = 0$ and the signal from MH j will not “interfere” with the decoding of bits of MH i. In general, it is difficult to have orthogonal codes across MHs. However, if a MH transmits using more than one spreading code, then internally the codes can be mutually orthogonal. The advantage of such an orthogonal assignment is that the multiple data bits simultaneously transmitted by a MH using the multiple spreading codes will not interfere with each other at the BS.

3. PROBLEM FORMULATION

In this paper, we focus on the uplink transmissions in a single cell of a cellular network with DS-CDMA (Direct Sequence Code Division Multiple Access). Each MH is running an application that generates a stream of packets. The MHs differ in the type of applications they are running, thereby resulting in a wide diversity in the quality of service (QoS) needs of the MHs.

Based on the QoS needs of their application, the cellular network has promised a service curve to each MH. The problem is to maximize the total system throughput (i.e., total number of bits transmitted from the MHs to the BS per unit time) while meeting the service curve requirements of all MHs.

The quality of the wireless channel between a MH and the BS fluctuates over time. We assume that the fluctuations in the wireless channel can be characterized using a conventional flat Rayleigh fading model [10].

In our approach, to meet the service curve requirements of MHs, the BS periodically assigns zero, one, or more spreading codes to each MH. A MH cannot and does not transmit a packet if it has not been assigned a spreading code. The rate at which a MH transmits is directly proportional to the number of spreading codes it has been assigned. The BS also periodically assigns each MH (with at least one spreading code) a power level at which it must transmit its packet. Given the channel conditions, the assigned spreading codes and power level determine the signal to interference ratio (SINR) at the BS for decoding the bits transmitted by a MH. The SINR, in turn, determines the bit error rate experienced by the MH. The challenge for the BS is to assign the spreading codes and the transmitted power levels such that: (i) the service curve requirements of each MH is met, (ii) the total system throughput is as large as possible, and (iii) the SINR of each transmitting MH is above a specified threshold to achieve an acceptable bit error rate.

More formally, let

G ≡ processing gain,
γ^* ≡ target SINR for each MH,
g_i ≡ path loss for MH i,
n_i ≡ the number of spreading codes assigned to MH i,
$P_{i,max}$ ≡ bound on transmitted power for MH i,
P_i ≡ transmitted power for MH i,
P_{total} ≡ total received power in BS, $P_{total} = \sum_i n_i g_i P_i$
T ≡ throughput, $T = \sum_i n_i$
σ^2 ≡ power spectrum density of noise at the output of matched filter
M ≡ bound on the number of spreading codes assigned to a MH,
$D_i(t)$ ≡ deadline curve of MH i,
$W_i(t)$ ≡ number of bits transmitted by MH i in $(0, t)$.
K ≡ number of active MHs in the system

Then, ideally, the problem to be addressed is as follows.

Maximize the system throughput $T = \sum_i n_i$ subject to the constraints:

$$\forall i: \quad P_i \le P_{i,max} \tag{3.1}$$

$$\forall i: \quad n_i \le M \tag{3.2}$$

$$\forall i: \quad \gamma^* \le \frac{G g_i P_i / n_i}{P_{total} - g_i P_i + \sigma^2} \tag{3.3}$$

$$\forall i, t \ge: 0: \quad D_i(t) \le W_i(t) \tag{3.4}$$

Equations (3.1) and (3.2) characterize the physical constraints at a MH. Equation (3.1) states there is a bound on the power at which a MH can transmit while Equation (3.2) states that a MH cannot handle more than *M* spreading codes at any given time. Equation (3.3) is the bound on the SINR to ensure that the bits decoded at BS have a bit error rate below tolerable limits. Finally, Equation (3.4) is the service curve constraint.

In the problem as stated above, the service curve must be met for all MH at all time instants. Unfortunately, this is not possible unless there is a bound on how worse the channel quality can get. Since such a bound on channel quality cannot be assured in practice, exact solution of the above problem may not always be possible. In fact, we do not, as yet, have a characterization of conditions under which the above problem can be solved exactly. Instead, in this paper, we propose a solution that strives to meet Equation (3.4), but may occasionally violate it. In Section 5, we present simulation results evaluating how often and by how much Equation (3.4) is violated in our proposed solution.

4. SOLUTION APPROACH

The **M**ost **D**ata **F**irst (for the first *k* MHs) MDF(*k*) approach strives to balance the following two partly conflicting objectives. (i) meeting the service curve, and (ii) increasing the throughput. These are conflicting because the scheduling decisions one must make to maximize throughput are not always consistent with the ones must make to meet service curve. For example, to maximize throughput one must allocate as much spreading codes as possible to the MH with the best quality channel,[1] whereas, to meet the service curve the spreading codes must be given to MH that is lagging the most from its service curve. If the MH that is lagging the most has a poor channel, then it can tolerate less interference, thereby reducing the number of spreading codes that can be assigned to other MHs and reducing the throughput. However, the two objectives are only partially conflicting because a reduction in throughput also reduces the capacity to meet the service curve.

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[1] Strictly speaking, maximum throughput is reached by assigning spreading code as much as possible to the MH *with larger maximum possible received power* [11]. Here we use identical bound on transmitted power for each MH and so the above condition is equivalent to assigning as many spreading codes as possible to the MH with the better channel condition.

To balance the conflicting objectives, MDF(k) uses two phases: In phase 1, called *service curve phase*, MDF(k) selects the k MHs that are lagging the most from their respective service curves. It then assigns them, if at all possible, sufficient number of spreading codes to meet their service curves. It may not always be possible to meet the service curve of all these k MHs because of their transmit power constraints. In the second phase, called *throughput phase*, MDF(k) considers all the K MHs and assigns spreading codes and transmit powers so as to maximize the throughput subject to the spreading code assignments of the service curve phase.

By selecting a suitable value for design parameter k, a service provider can balance the above-mentioned two partly conflicting objectives. Smaller values of k emphasize the throughput objective while larger values of k emphasize the need to meet service curves. In particular, $k = 0$ means that service curve phase is null, and MDF(0) maximizes the throughput without regard to service curves. Likewise, MDF(K) maximizes the throughput only after the service curve needs of all MHs can be satisfied. Values of k between 0 and K chooses an operating point that lies somewhere in between these two extremes.

More formally, MDF(k) works as follows. Let t be the current time. MDF(k) makes an allocation decision once every Δ time units. Therefore, all its decisions are based on the needs of MHs and estimates of channel conditions in the interval $(t, t+\Delta)$.

<u>Service curve phase</u>: To meet MH i's service curve at time $t+\Delta$, $D_i(t+\Delta)$ must be less than $W_i(t+\Delta)$. If $D_i(t+\Delta) \le W_i(t)$, then $D_i(t+\Delta) \le W_i(t+\Delta)$ even if no spreading codes are assigned to MH i in $(t, t+\Delta)$. Otherwise, let m_i denote the number of spreading codes needed to ensure that $D_i(t+\Delta) \le W_i(t+\Delta)$, i.e.,

$$m_i = \begin{cases} \dfrac{D_i(t+\Delta) - W_i(t+\Delta)}{R}, & D_i(t+\Delta) > W_i(t+\Delta) \\ 0 & \textbf{\textit{otherwise}} \end{cases}$$

where R is the data rate for one spreading code. Without loss of generality, let $m_1 \ge m_2 \ge \ldots \ge m_K$. Consider the first k MHs. The pseudo code for assigning spreading codes to these k MHs in the service curve phase is shown in Figure 1. The algorithm considers the MHs one at a time ordered from 1 to k. When considering MH i, it assigns m_i spreading codes and checks whether there is a power allocation that meets the transmitted power constraints and the SINR requirements of MH 1 to MH i subject to their spreading code assignments (see appendix). If the answer is yes, then the algorithm proceeds to the next MH. Otherwise, it decrements the number of spreading codes assigned to MH i one at time until a feasible power allocation is found. The phase ends when all the k MHs have been considered. The algorithm returns the spreading code assignments to the k MHs. Note that, by the nature of the algorithm, there exists a feasible power allocation for this assignment.

<u>Throughput phase</u>: In this phase, all the MHs are considered. As stated earlier, the goal here is to maximize throughput subject to the spreading code assignments of the service curve phase. One can show that the throughput is maximized if the MHs are considered in the order of the channel gain (or equivalently, maximum received power) [11]. A pseudo code of the algorithm for this phase is shown in Figure 2. For clarity of presentation, the MHs are renumbered such that $g_1 \ge g_2 \ge \ldots \ge g_K$. Here again, the algorithm considers one MH at a time ordered from MH1 to MH K where MH1 is the MH with the best channel condition. When considering MH i, it assigns M spreading codes and checks whether there is a power allocation that meets the transmitted power constraints and the SINR requirement of all MHs. If the answer is yes, then the algorithm proceeds to the next MH. Otherwise, it decrements the number of spreading codes assigned to MH i one at time until a feasible power allocation is found. The phase ends when all the K MHs have been considered. The algorithm returns the spreading code and transmitted power assignments to the K MHs. Note that, by the nature of the algorithm, SINR requirement is met for this assignment.

```
Phase1: Service curve phase

/* Calculate deadline data*/
$\mathbf{d} = \{d_1, d_2, \ldots, d_K\}$
/*Calculate corresponding spreading code number */
$\mathbf{m} = \{m_1, m_2, \ldots, m_K\}$
Sort MHs according to $\mathbf{m}$ , (decreasing order)
/* Without loss of generality,
assume $m_1 \ge m_2 \ge \ldots \ge m_k$ */
/* Pre-assigned code is 0 for each MH */
 $np = \{np_1, np_2, \ldots np_k\} = \{0,0,\ldots 0\}$
/* maximum Transmitted power for each MH
 $\mathbf{P}_{max} = \{P_{1,\max}, P_{2,\max}, \cdots P_{k,\max}\}$*/


/* Do for the first k MHs */
for i = 1 to k
    $n_i = m_i$
    while $n_i > 0$
        /*Calculate power allocation $P_i$ for each MH*/
        $\mathbf{P} = \{P_1, P_2, \ldots P_k\}$
        /*Check Transmitted power for each MH*/
            if $P_j > P_{j,max}$ for $\forall\ 1 < j < i$
                $n_i$ --
            else
                break
            end if
    end while
end for
return n
```

Figure 1: Pseudo code of service curve phase of MDF(k)

```
Phase2: Throughput phase
Sort MHs according to path loss $g_i$
/*Without loss of generality,
  assume $g_1 \geq g_2 \geq \ldots \geq g_K$ */
/* Make the code assigned in phase 1 as pre-assigned code */
np = {$np_1$, $np_2$, …$np_k$}
/* (Note that here the subscribe number may refer to different MH from what in phase 1)*/
/* maximum Transmitted power for each MH
$\boldsymbol{P}_{max} = \{P_{1,\max}, P_{2,\max}, \cdots P_{k,\max}\}$: */
/* Do for all K MHs */
for i = 1to $K$
    $n_i = M$
    while $n_i > np_i$
        /*Calculate power allocation $P_i$ for each MH*/
        $\boldsymbol{P} = \{P_1, P_2, \ldots P_k\}$
        /*Check transmitted power for each MH*/
            if $P_j > P_{j,max}$ for $\forall\ 1 < j < i$
                $n_i$ --
            else
                break
            end if
    end while
end for
calculate P for n
return n, P
```

Figure 2: Pseudo code of throughput phase of MDF(*k*).

5. EMPIRICAL EVALUATION

5.1 Simulation Method

5.1.1 Model for Path Losses in the Wireless Channel

For all the results presented here, we use the model developed by Erceg, etc. [8]. This model was derived from experimental data collected from existing macrocells in several suburban areas of New Jersey, Seattle, Chicago, Atlanta, and Dallas. In this model, the path loss (in dB) is a random process and given by:

$$g = \left[20\log_{10}\left(\frac{4\pi\cdot d_0}{\lambda}\right) + 10\left(a - bh_b + \frac{c}{h_b}\right)\log_{10}\left(\frac{d}{d_0}\right)\right] + \left[10x\sigma_\gamma\log_{10}\left(\frac{d}{d_0}\right) + y\mu_\sigma + yz\sigma_\sigma\right] \tag{5.1}$$

where d is distance between BS and MH in meters, h_b is the base station antenna height in meters, d_0 = 100 meters and λ is the carrier's wavelength. The parameter x, y and z are independent standard Gaussian variables. Parameters x and z vary from cell to cell, while y varies from location to location within each cell. The remaining parameters are empirically specified for different terrains [8].

For the simulation results here, the frequency of the carrier is 1.9 GHz, h_b = 50 meters, a = 4.0, b = 0.0065, c = 17.1, $\sigma_\gamma = 0.75$, $\mu_\sigma = 9.6$, and $\sigma_\sigma = 3.0$.

5.1.2 Model of the Cellular Network

We simulate a single cell covering a range of 100 to 1000 meters from the BS. At the start of the simulation, each MH chooses a random location in this area and a random speed. The speed of a MH is assumed to be constant during the simulation. We update each MH's position and the path loss before each adaptive allocation. Then we use the algorithms to allocate rate and power for each MH. The adaptation is done every 0.02 seconds.

We assume that there are $K = 40$ active MHs, each transmitting an infinite stream of packets to the BS. The value of K is varied to simulate different loading conditions. We then simulate data transfers occurring over an interval of 10 seconds. After 10 seconds, we assume that some MHs will become inactive while other MHs may become active. We consider such changes as another simulation run.

For simplicity, we use linear service curve and its only parameter, slope, is specified as the data rate.

5.2 Performance Metrics

We say that a MH i is *unsatisfied* at time t if $D_i(t) > W_i(t)$, i.e., the MH has transmitted fewer bits than what is required to meet the service curve. At time t, for unsatisfied MHs, we define the amount of dissatisfaction of MH as $D_i(t) - W_i(t)$. For satisfied MHs, we define the amount of dissatisfaction as 0.

Define the following three measures at time t.

$$u(t) = \left(\frac{1}{K}\sum_{j=1}^{K} I_{\{D_j(t)>W_j(t)\}}\right) \tag{5.2}$$

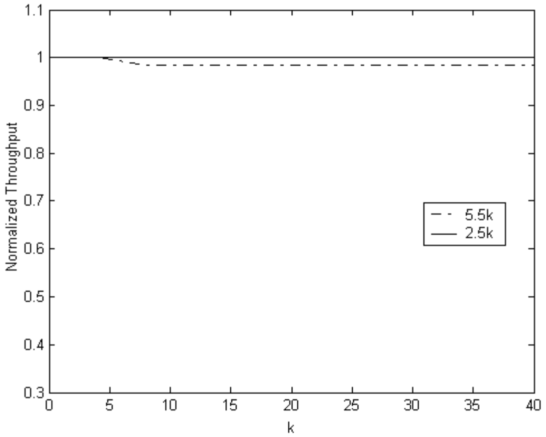
$$\bar{d}(t) = \frac{\sum_{j=1}^{K} I_{\{D_j(t)>W_j(t)\}}\cdot(D_j(t)-W_j(t))}{\sum_{j=1}^{K} D_j(t) I_{\{D_j(t)>W_j(t)\}}} \tag{5.3}$$

$$\bar{T}(t) = \sum_{j=1}^{K}\frac{W_j(t)}{t} \tag{5.4}$$

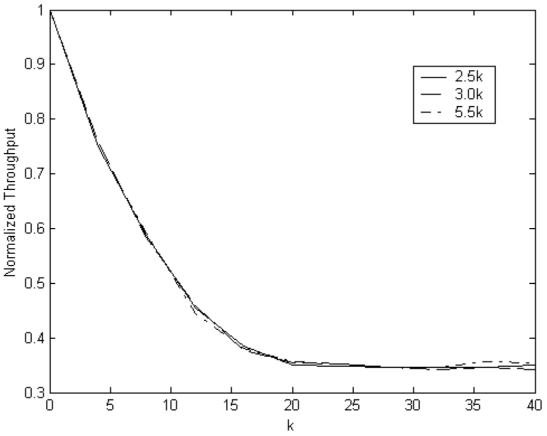
The first measure is the percentage of unsatisfied MHs at time t. The second measure is the average percentage dissatisfaction at time t. The third measure is the average MH throughput computed over the interval [0, t].

*5.2.1 Effect of Maximum Transmitted Power on Throughput of MDF(*k*)*

We first study the effect of maximum transmitted power constraint on the throughput achieved by MDF(k) as a function of k. Figure 3 shows the normalized throughput for several cases. In all cases, the normalization is with respect to the corresponding throughput achieved by MDF(0).



(a) Power adequate system



(b) Power inadequate system

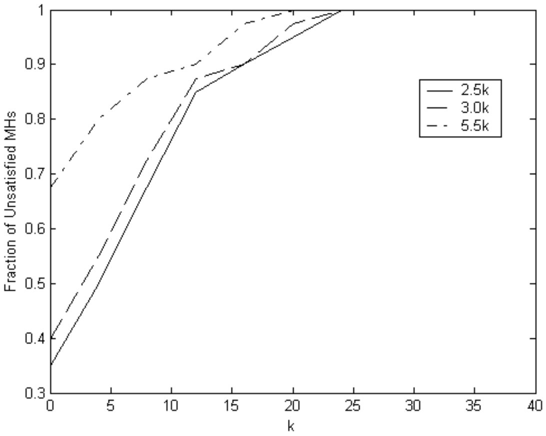
Figure 3: Throughput vs. *k*.

Figure 3(a) corresponds to a power adequate system in which the maximum transmitted power is large enough not to be a severe constraint. The figure contains results for two different service curves (2.5 Kbps and 5.5 Kbps). Note that, in this case, the throughput is insensitive to the value of *k*. This is because when the maximum transmitted power is large, a MH can easily deal with the interference caused by other MHs. Therefore, in each time step, it is possible for a large number of MHs to transmit simultaneously, each at their respective rate boundary (the assigned number of spreading codes to a MH is at the maximum allowable level). When a large number of a MHs can transmit, the effect of prioritizing *k* MHs based on service curves is not significant.

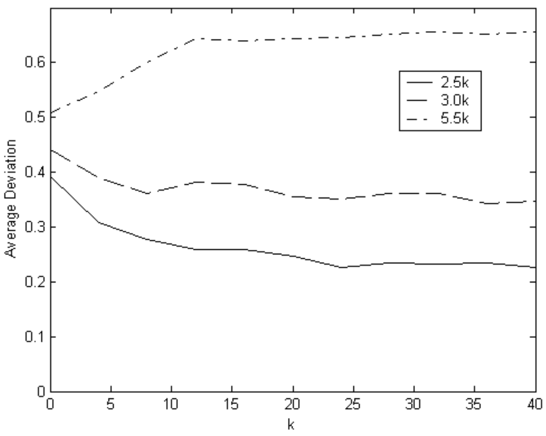
In contrast, Figure 3(b) corresponds to a power inadequate system in which the maximum transmitted power is a limiting constraint. In this case, fewer MHs can transmit concurrently as compared to the power adequate case. As a result, the order in which the MHs are assigned spreading codes plays a significant role in determining the throughput. When *k* is large, MHs are picked more based on their service curve needs than on the quality of channel. Consequently, MHs with poor quality channel are often considered earlier for code assignment. Since MH with a poor quality channel needs more transmit power than a one with a good quality channel to achieve the same SINR for a given number of spreading codes, there is a significant reduction in the total number of spreading codes that can be assigned in each step. Hence, the throughput achieved for large values of *k* is substantially less than for small values of *k*.

In the rest of this section, results are presented only for the power inadequate case since we believe it is a more realistic scenario.

5.2.2 Service Curve Assurances in MDF(k): Power Inadequate Systems



(a) Average fraction of unsatisfied MHs

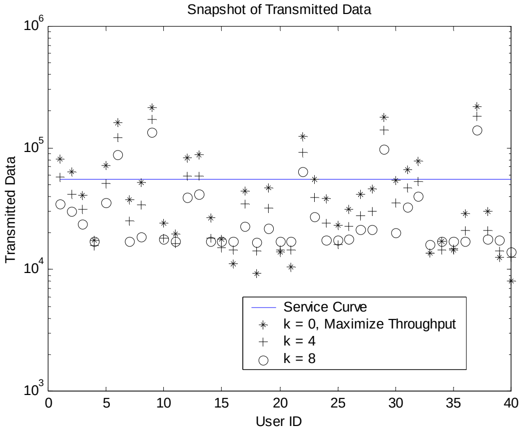


(b) Average fraction of dissatisfaction

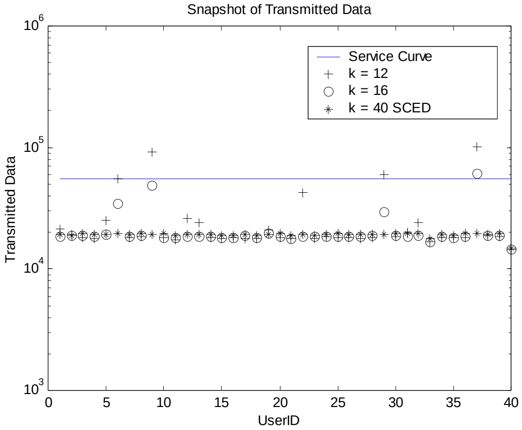
Figure 4: Comparison of different service curve data rate.

Figure 4(a) and 4(b) respectively show the average fraction of unsatisfied MHs and average fraction of dissatisfactions as a function of *k* for several different service curves. The following observation can be made from these figures. As *k* increases, the fraction of unsatisfied MHs tends to increase while the average fraction of dissatisfaction tends to decrease. This is because, as *k* increases, the need to meet service curve is emphasized and therefore the system tends to allocate resources to MHs that are lagging at expense of MHs are leading. As a result, leading MHs move towards lagging and lagging MHs move towards leading. Consequently, a larger fraction of MHs tend to lag albeit by much smaller margin.

This effect is further illustrated in Figure 5 that shows the total amount of data transmitted by the MHs at the end of 10 seconds. The x-axis is identity of the MHs and the y-axis is the amount of data transmitted by the corresponding MH. The figure shows this snapshot for several different values of *k*. Note that, when *k*=0 there is considerable variability in the amount of data transmitted by different MHs. Some MHs transmit as much as 2×10^5 bits while some others transmit as little as 10^4. In contrast, when *k*=40, the data transmitted by almost all the MHs are comparable (in the order of 2×10^4). The decrease in variance in amount of data transmitted is consistent as *k* increases.



(a) MDF(*k*), *k* = 0, 4, 8



(b) MDF(*k*), *k* = 12, 16, 40

Figure 5: Snapshot of transmitted data for different *k* with identical service curve data rate 5.5Kbps.

Few additional expected behaviors can be observed in these figures. When service curve requirement is larger, the average fraction of unsatisfied MHs and average fraction of dissatisfactions are also larger.

6. CONCLUSION

In this paper, we developed an adaptive scheme for power and rate allocation in a DS-CDMA network. The objectives of the proposed scheme are to maximize the uplink throughput and concurrently meet the QoS needs of each MH represented in the form of a service curve. As expected, due to the fluctuations in the wireless channel quality, the scheme does not always guarantee the service curve of all MHs. However, it distributes the available throughput among MHs based on their service curve requirements. The paper evaluates the effectiveness of the proposed scheme in trading off throughput for meeting the service curves. The results show that this tradeoff can be done by selecting a value for a design parameter in the proposed scheme.

The proposed scheme was based on few idealistic assumptions such as perfect knowledge of the channel conditions and centralized instantaneous scheduling at the base station. Research on relaxing these assumptions is ongoing. We are also investigating ways of characterizing the capacity of a DS-CDMA based network for use in admission control when the MHs have diverse service curve requirements.

7. APPENDIX

Power and Rate Computation in Matched Filter Receiver

For the above system model, let P_i denote the *received* power for user *i*, and m_i denote the number of spreading code assigned to MH *i*. For matched filter receiver, the received SINR (γ_i) of user *i* is

$$\gamma_i = \frac{GP_i / m_i}{\sum_{j\neq i} P_j + \sigma^2}$$

where G is spreading gain, σ^2 is noise power. P_i here is received power of MH *i*, $P_i = g_i P_{i,\ trans}$. The above equation can also be shown as

$$m_i\gamma_i \sum_{j\neq i} P_j - GP_i = -m_i\gamma_i\sigma^2$$

For the system with K active users, the received power ***P*** can be shown in matrix as follow.

$$\begin{bmatrix} -G & m_1\gamma_1 & m_1\gamma_1 & \dots & m_1\gamma_1 \\ m_2\gamma_2 & -G & m_2\gamma_2 & \dots & m_2\gamma_2 \\ m_3\gamma_3 & m_3\gamma_3 & -G & \dots & m_3\gamma_3 \\ \vdots & \vdots & \vdots & \dots & \vdots \\ m_K\gamma_K & m_K\gamma_K & m_K\gamma_K & \dots & -G \end{bmatrix} \cdot \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ \vdots \\ P_K \end{bmatrix} = \begin{bmatrix} -m_1\gamma_1\sigma^2 \\ -m_2\gamma_2\sigma^2 \\ -m_3\gamma_3\sigma^2 \\ \vdots \\ -m_K\gamma_K\sigma^2 \end{bmatrix}$$

Then P_i can be solved as

$$P_i = \frac{m_i\gamma_i\sigma^2}{(m_i\gamma_i + G)\cdot(1 - \sum_{j=1}^{K} \frac{m_j\gamma_j}{m_j\gamma_j + G})}$$

8. ACKNOWLEDGEMENT

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