Traffic Aided Uplink Opportunistic Scheduling with QoS Support in Multiservice CDMA Networks

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ABSTRACT— In this letter, we address the problem of resource allocation with efficiency and quality of service (QoS) support in uplink for a wireless CDMA network supporting real-time (RT) and non-realtime (NRT) communication services. For RT and NRT users, there are different QoS requirements. We introduce and describe a new scheme, namely, traffic aided uplink opportunistic scheduling (TAUOS). While guaranteeing the different QoS requirements, TAUOS exploits the channel condition to improve system throughput. In TAUOS, the cross-layer information, file size information, is used to improve fairness for NRT users. Extensive simulation results show that our scheme can achieve high system throughput in uplink wireless CDMA systems, while guaranteeing QoS requirements.

Keywords— Opportunistic scheduling, uplink, QoS support, multiservice, CDMA, cross-layer.

I. Introduction

Uplink scheduling in CDMA systems is gaining importance due to new uplink intensive data services (ftp, image uploads, and so on). There has been previous research on the subject of uplink scheduling [1], [2]. In [1], the authors proposed and studied algorithms for efficient uplink packet-data scheduling in a CDMA cell. The algorithms attempt to maximize system throughput under transmit power limitations on mobiles assuming instantaneous knowledge of user queues and channels. The authors of [2] adopted the use of a dynamically assigned data rate matching the channel capacity in order to improve system throughput.

Although [1] and [2] exploit the channel variations, neither study considers the mixture of real time (RT) and non-realtime (NRT) users. In this letter, we propose traffic aided uplink opportunistic scheduling (TAUOS) in multiservice CDMA networks, while considering the QoS requirements of RT and NRT users. First, we introduce a system resources maximization scheduling (SRMS) scheme. Then, we introduce the ideal fair scheduling (IFS) scheme. Finally, we describe TAUOS. In TAUOS, we give constant power resources to RT users to satisfy the constant rate requirement and allocate power resources to NRT users exploiting the channel condition to improve the system throughput. In TAUOS, we propose a traffic aided user weight update policy to improve fairness performance. The policy is similar to the compensation model in [3]. Unlike [3], cross-layer file size information is used in our proposed policy to improve fairness performance. File size information is also used in [4]; however, [4] does not consider the uplink characteristics, and information is used to reduce the total completion time rather than fairness performance.

II. Proposed Scheduling Scheme

Consider the uplink of a single CDMA cell serving N users. Let G_i be the spreading gain of user i and let γ_i be its minimal SIR required. We assume that the chip rate W for all users is fixed, and hence the spreading gain is determined by the bit rate r_i of user i, that is, $G_i = W/r_i$. In this letter, we assume that the maximum transmission power is p_{max} for all users. Given a transmission rate vector $r = [r_1, r_2,\cdots, r_N]$, there exists a power assignment $p = [p_1, p_2,\cdots, p_N]$ that meets the required SIR vector $\gamma = [\gamma_1, \gamma_2,\cdots, \gamma_N]$, if the following condition is satisfied [2]:

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$$\sum_{i=1}^{N} g_i \le 1-\frac{\eta_0 W}{\min\limits_{1\le i\le N}\left\{P_{\max} h_i\left(\dfrac{G_i}{\gamma_i}+1\right)\right\}}=1-\frac{\eta_0 W}{\min\limits_{1\le i\le N}\left\{\dfrac{P_{\max} h_i}{g_i}\right\}}, \quad (1)$$

where h_i is the channel gain, η_0 is the one-side power spectral density of additive white Gaussian noise, and $g_i=\gamma_i/(\gamma_i+G_i)$ represents the power index of user *i*. In our study, the power index is the main power resource that is allocated to users. Let $\Psi=\sum_{i=1}^{N} g_i$ be the total power index and $U_i=1-\dfrac{\eta_0 W g_i}{P_{\max} h_i}$. Then, (1) becomes $\Psi \le \min\limits_{1\le i\le N} U_i$.

For RT user *i*, data is discharged at the constant rate D_i, so the power index of RT user *i* is constant. We first allocate the constant power index to RT users and then we decide the power index for NRT user *i* at each time slot under the fairness requirement and decide the transmission rate by calculating

$$R_i=\frac{W g_i}{\gamma_i-\gamma_i g_i}. \quad (2)$$

1. SRMS Scheme

For a fixed total power index Ψ, there is a maximum allowable power index for a user which does not violate (1). We call the maximum allowable power index the power index capacity (PIC). From (1), the PIC of user *i* is

$$c_i(\Psi)=\min\left\{\frac{(1-\Psi)P_{\max} h_i}{\eta_0 W},\Psi\right\}. \quad (3)$$

Assume that set *A* contains the RT users, and set *B* contains the NRT users. Let $\Psi^{RT}=\sum_{i\in A} g_i^{RT}=\sum_{i\in A}\dfrac{\gamma_i}{(\gamma_i+W/D_i)}$, where g_i^{RT} is the constant power index of RT users and the constant value Ψ^{RT} is the total power index of RT users.

Table 1. Main notation definition.

Ψ	Total power index of all users
Ψ^*	Ψ of SRMS scheme (maximal Ψ)
Ψ_{IFS}	Ψ of IFS scheme
Ψ^{RT}	Total power index of RT users
$\hat{\Psi}$	Upper bound of Ψ considering NRT users
U_{RT}	Upper bound of Ψ considering RT users
$\overline{\Psi}$	System average Ψ
Ψ^0	Goal Ψ used in TAUOS

Proposition. $\Psi^*=\min(\hat{\Psi},U_{RT})$ is the maximal total system power index, where $U_{RT}=\min\limits_{i\in A} U_i$ and

$$\hat{\Psi}=\Psi^{RT}+\sum_{i\in B} c_i(\hat{\Psi})=\frac{\Psi^{RT}+\sum_{i\in B} P_{\max} h_i/(\eta_0 W)}{1+\sum_{i\in B} P_{\max} h_i/(\eta_0 W)}.$$

The power index of user *i* is

$$g_i=\begin{cases} g_i^{RT}, & i\in A\\ c_i(\Psi^*), & i\in B. \end{cases} \quad (4)$$

In SRMS, we allocate the power resources according to (4), and decide the transmission rate according to (2).

2. IFS Scheme

Let W_i be the weight of user *i*. In IFS, we distribute the power resources to guarantee the fairness of NRT users, that is, $R_i/R_j = W_i/W_j$, where R_i is the transmission rate of user *i*. The IFS scheme only considers fairness for NRT users. Unlike SRMS, it does not consider system throughput improvement.

We use $\overline{R}$ to estimate the total NRT user throughput, where $\overline{R}$ is the average total NRT user throughput. We update $\overline{R}$ to $(1-1/t_r)\overline{R}+1/t_r\sum_{i\in B} R_i$ at the end of scheduling slot, where t_r is the smoothing factor in a moving average calculation.

Let $\phi_i=W_i/\sum_{j\in B} W_j$. To guarantee $R_i/R_j = W_i/W_j$, $\dfrac{\hat{W}_i}{\hat{W}_j}=\dfrac{g_i}{g_j}=\dfrac{\gamma_i/(\gamma_i+W/(\phi_i\overline{R}))}{\gamma_j/(\gamma_j+W/(\phi_j\overline{R}))}$, where $\hat{W}_i$ is the power index weight of user *i*. Let $\hat{\phi}_i=\hat{W}_i/\sum_{j\in B}\hat{W}_j$. In IFS, we distribute power resources fairly to NRT users according to $\hat{W}_i$.

Considering NRT users, from (1), the upper bound of Ψ is

$$\Psi^1=1-\frac{\eta_0 W}{\min\limits_{i\in B}\left\{\dfrac{P_{\max} h_i}{\hat{\phi}_i(\Psi^1-\Psi^{RT})}\right\}} \quad \Psi^1=\min_{i\in B}\frac{1+\dfrac{\eta_0 W\hat{\phi}_i}{P_{\max} h_i}\Psi^{RT}}{1+\dfrac{\eta_0 W\hat{\phi}_i}{P_{\max} h_i}}.$$

Considering RT users, the upper bound of Ψ is

$$\Psi^2=1-\frac{\eta_0 W}{\min\limits_{i\in A}\{P_{\max} h_i/g_i\}}.$$

For IFS, the total power index is $\min(\Psi^1,\Psi^2)$.

The power index of user *i* in IFS is

$$g_i=\begin{cases} g_i^{RT}, & i\in A\\ \hat{\phi}_i\Psi, & i\in B. \end{cases} \quad (5)$$

In IFS, we allocate the power resources according (5), and decide the transmission rate according to (2).

3. TAUOS Scheme

The TAUOS scheme is decoupled as two separate entities–the traffic aided weight update block for fairness guarantees and the adaptive throughput optimization block targeting increase of system throughput.

A. Adaptive Throughput Optimization Block

In [2], the goal total power index is fixed; however, the channel condition is variable, so the fixed goal total power index is not suitable for all time slots. Unlike [2], we adaptively give a different appropriate goal total power index for each time slot rather than a fixed value for all time slots. In the estimation, we use the total power index achieved by SRMS and IFS as the baseline value. Let b be the fixed proportion. If the Ψ_{IFS} achieved by IFS is greater than $b\overline{\Psi}$, we consider that IFS has achieved high system throughput, so we let $\Psi^0 = \Psi_{IFS}$ and allocate the power index according to the IFS scheme. If the Ψ^* achieved by the SRMS scheme is less than $b\overline{\Psi}$, let $\Psi^0 = \Psi^*$ and allocate the power index according to the SRMS scheme. If $\Psi_{IFS} < b\overline{\Psi} < \Psi^*$, we believe that higher system throughput than IFS can be achieved and the SRMS can lead to unfairness. Therefore, we let $\Psi^0 = b\overline{\Psi}$ and allocate the resources according to the channel aware allocation policy (CAAP). The detailed steps in estimating Ψ^0 are the following:

1) If $\Psi_{IFS} \geq b\overline{\Psi}$, $\Psi^0 = \Psi_{IFS}$.
2) If $\Psi^* < b\overline{\Psi}$, $\Psi^0 = \Psi^*$.
3) If $\Psi_{IFS} < b\overline{\Psi} < \Psi^*$, $\Psi^0 = b\overline{\Psi}$.

After setting the goal Ψ^0, we allocate the power index as follows to optimize the system throughput:

1) If $\Psi^0 = \Psi^*$, the goal is the same as in SRMS, so we allocate the power index as (4).
2) If $\Psi^0 = \Psi_{IFS}$, the goal is the same as in IFS, so we allocate the power index as (5).
3) If $\Psi^0 = b\overline{\Psi}$, we serve the RT users at power index g_i^{RT} and distribute $\Psi^0 - \Psi^{RT}$ to the NRT users appropriately, according to the CAAP.

The CAAP is like the policy in [2]. In the CAAP, more resources are allocated to NRT users with a good channel condition and fewer resources are allocated to NRT users with a worse channel condition for the PIC constraints of the users. We allocate resources fairly to users until the PICs of users are achieved. The detailed steps of the CAAP are the following:

1) Let the remaining power index Ψ_R be $\Psi^0 - \Psi^{RT}$.
2) The power index assigned to user i in the k-th round is $g_i^k = \min(g_i^{k-1} + \Delta g_i^k, c_i(\Psi^0))$, where Δg_i^k represents the power index increment in the k-th round of power index allocation for user i and g_i^{k-1} denotes the power index assigned to user i after the (k-1)th round and $g_i^0 = 0$. The remaining power index after the k-th round is $\Psi_R^k = \Psi^0 - \Psi^{RT} - \sum_{i=1}^{N} g_i^k$.
3) In each round, we allocate the remaining power index to users according to the weights $\hat{W}_i$. The power index increment is $\Delta g_i^k = \Psi_R^{k-1} \hat{W}_i / \sum_{j \in B_k} \hat{W}_j$, where B_k is the set of NRT users that $g_i^{k-1} < c_i(\Psi^0)$, and $\hat{W}_i$ is updated by the traffic aided weight update block to guarantee fairness.
4) Stop if $\Psi_R^k = 0$ or $g_i^k = c_i(\Psi^0)$ for all i, then $g_i = g_i^k$.

B. Traffic Aided Weight Update Block

In the traffic aided weight update block, the NRT user weight W_i is updated. After updating W_i, the power index weight $\hat{W}_i$, used in CAAP, can be calculated using the definition in the third paragraph of section II.2.

Because we allocate more power resources to the users with a better channel condition, fairness is not maintained. Let $\Delta R_i = W_i^0 \overline{R} - \overline{R_i}$, where $\overline{R_i}$ is the average data rate of NRT user i and W_i^0 is the original user weight assigned by the CAC module. If $\Delta R_i < 0$, user i receives more services than expected, the weights of users for which $\Delta R_i < 0$, should be increased to give these users more resources and less to others.

In order to avoid the users with $\Delta R_i < 0$, leaving the system before they return the extreme resources that they have been given, we set smaller user weights for users who have smaller remaining file size, bigger $-\Delta R_i$, and bigger W_i^0.

Assume that set B_1 contains the NRT users for which $\Delta R_i < 0$, and set B_2 contains the NRT users for which $\Delta R_i < 0$. Let $TW = \sum_{i \in B_1} W_i^0 \times a$ be the total weight of the users who get more resources than expected which is return to the users who get fewer resources than expected, where a is the constant proportion of weights given up. The weights of NRT users are updated as

$$\begin{aligned} W_i &= W_i^0 - \frac{\alpha_i}{\sum_{k \in B_1} \alpha_k} TW, \quad i \in B_1, \quad \alpha_i = \frac{-\Delta R_i \times W_i^0}{RF_i} \\ W_i &= W_i^0 + \frac{\beta_i}{\sum_{k \in B_2} \beta_k} TW, \quad i \in B_2, \quad \beta_i = \frac{\Delta R_i \times W_i^0}{RF_i}, \end{aligned} \tag{6}$$

where RF_i is the remaining file size of NRT user i.

III. Simulation Results

The system parameters used in the simulation are as follows.

We assume that $W = 3.84$ MHz, $P_{\max} = 2$ W, and $\gamma_i = 5$ dB for all users; $D_i = 10$ kbps for RT users; and $W_i^0 = 1/N_{NRT}$ for NRT users, where N_{NRT} is the number of NRT users in the system. Assume that η_0 is 10^{-6}, scheduling interval T is 10 ms, and t_r is 1000. Assume that the file sizes follow a heavy-tailed (Pareto) distribution with the minimal file size $c = 3$ MB and shape parameter $\alpha = 1.2$. We assume that the channel gains follow Rayleigh distribution, with the average channel gain of 0.3.

In our simulation, we assumed that the number of RT users was 5, and the number of NRT users changed from 5 to 10.

Figure 1 illustrates the throughput of the system. It demonstrates that TAUOS has higher system throughput than IFS for exploiting the channel condition. It also has higher system throughput than fair channel adaptive rate scheduling (FCARS) [2] for variable total power index estimating rather than constant total power index. The SRMS scheme has higher system throughput than TAUOS without considering fairness for NRT users. From Fig.1, we can see that the system throughput of TAUOS increases when factor b changes from 0.5 to 0.75. This is because the bigger factor b is, the more likely it is that CAAP policy will run. From Fig. 2, we can see that the normalized standard deviation of TAUOS increases slightly when factor b is higher. The system throughput of TAUOS decreases slightly when factor a is changed from 0.3 to 0.5. This is because factor a is used for fairness. Higher a leads to the allocation of more resources to users with bad channel conditions to guarantee fairness.

Figure 2 shows the normalized standard deviations of NRT users' throughput for different schemes. From Fig. 2, we can see that the normalized standard deviations of NRT users' throughput for IFS, TAUOS, and FCARS are all close to 0, that is, every NRT user's throughput is close to the average throughput per NRT user. Thus, we can see that fairness for NRT users is guaranteed with the TAUOS scheme. Moreover, the normalized standard deviations of NRT users' throughput for TAUOS decrease when factor a is changed from 0.3 to 0.5.This shows that the higher factor a is, the better the fairness of the system is. It is also clear that TAUOS has better fairness performance than FCARS in using traffic information.

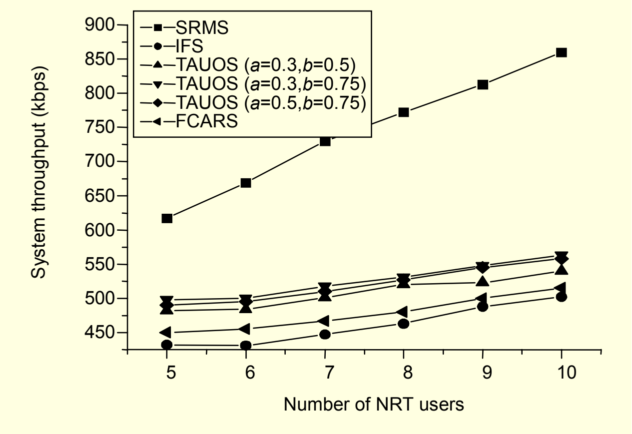

Fig. 1. System throughput.

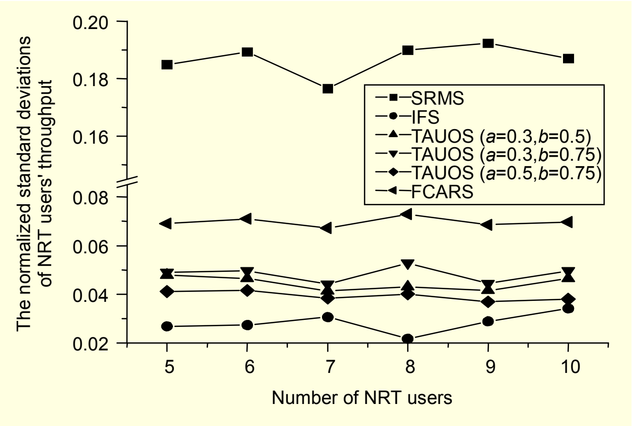

Fig. 2. The normalized standard deviations of NRT users' throughput.

IV. Conclusion

In this letter, we proposed the new TAUOS scheme, in uplink for a wireless CDMA network supporting RT and NRT communication services. We first introduced a SRMS scheme. Then we introduced the IFS scheme and describe TAUOS in detail. The simulation results show that the TAUOS scheme achieves high system throughput and has good fairness performance.

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