Schedulers for 1xEV-DO: Third Generation Wireless High-Speed Data Systems

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Abstract—Scheduling algorithms have been developed and proposed to improve system performance by taking the benefit of channel variance among users. When the optimization of the system throughput is the main objective for scheduler algorithm designs, the associated algorithms might cause unfairness in user transmission rates. To explore the fairness problem, in this paper, we will focus on the fairness performance by considering different scheduling algorithms in various fading channels. The Dynamic Target with Max/Min (DTM) Rate Controlled Scheduler Algorithm is proposed to resolve the potential fairness problems and to maintain the minimum transmission rate for all uses in which we believe that most applications require the minimum rate to maintain the application quality. The DTM algorithm includes also the maximum rate control to prevent the resource hogging from users at the good RF conditions.

Keywords—Scheduler, Fairness, Wireless, Data, 1xEV-DO, Third generation, DRC, Asymmetry Traffic

I. INTRODUCTION

As today, most road-warrior data applications, like HTTP, FTP, and etc, require more data transmission on the forward link than the reverse link. This asymmetric traffic demands will cause an inefficient use of the spectrum if the access technology is designed to provide a symmetric data traffic pattern instead. The current existing 2G [1] or even most initial 3G systems, known as cdma2000 [2] and UMTS [3], are designed to support a symmetric traffic pattern where the voice is still considered as the major service in the near future wireless communication systems. As a result, the systems are not designed efficiently for road-warrior data transmission. To optimize the spectrum efficiency for data transmissions, it is critical to have a bias treatment on the forward link to make sure that the forward link can transmit higher throughput than the reverse link. 1xEV-DO system, as specified in IS-856 [4], is an evolution of the cdma2000 system and is designed to support data-only applications. The key features for achieving higher 1xEV-DO network throughput (or aggregate sector throughput) on the forward link are discussed in [5]. There are (but not limited to) (1) channel estimation through quick DRC (data rate control) reports to have an accurate forward-link channel information, (2) channel scheduling algorithms to take the benefit of the channel variance among users, and (3) low idle-mode/overhead power transmission to reduce overall interference. In this paper, we will focus on (2), the impacts of different scheduler algorithms. The Proportional Fair (PF) Share Scheduling Algorithm [6] is proposed to achieve high network (sector) throughput by using the concept of equal-time transmission of all users at different rates. In [7,8], based on the Proportional Fair Share Scheduling Algorithm, the 1xEV-DO forward link provides 4 to 6 times throughput than the reverse link. To optimize the use of RF condition, based on [4], the rate differences can be as large as 64 times (2.4Mbps vs 38.4kbps). In other words, users at different RF conditions might result in a big difference in the transmission rates. To minimize the differences between the high data rate and low data rate users, multi-slot transmission and an incremental redundant scheme are deployed. But even with those approaches, we will show that for a case of 20 active users per sector, the average user-transmission rates can vary from 10 kbps to 140 kbps if the PF algorithm is used. This unfairness among user-transmission rates might cause the increase of unsatisfied users who fail to meet the minimum thresholds required by different data applications. To further improve the fairness and to provide acceptable user-perceived throughput, the scheduling algorithms need to be flexible to support different design criteria. The Dynamic Target with Max/Min (DTM) Rate Controlled Scheduler Algorithm is proposed not only to achieve different fairness criteria but also to control/achieve the maximum and minimum throughput constraints. The DTM can be easily extended to support different QoS by having different dynamic target groups and thresholds.

The paper is organized as follows: Section II will discuss the system model used for this study. Scheduling algorithms include both the Proportional Fair Share Scheduler Algorithms and the Dynamic Target with Max/Min Rate Controlled Scheduler Algorithm will be discussed in section III. Section IV, the impacts from the DTM algorithm will be analyzed. Conclusions are included in Section IV.
II. SIMULATION MODEL

The system model is based on Figure 1, where each user’s initial RF condition is based on the geometry distribution generated by a fully loaded cluster. On the top of each user’s geometry point, the system further introduces different fading channels. These aggregate effects are fed into the mobile predictors in order to calculate the request rates. Bases on the calculations, the predictor of each access terminal will periodically report the data rate control (DRC) index (the request rate) over its reverse DRC channel. Upon receiving DRC reports from all of the serving access terminals, the base station (BS) will then calculate the highest priority user for the next transmission. With different scheduling algorithms, the system throughput and user-transmission rates are expected to be different. In this study, a full-buffer (infinite data for each user) traffic model is used. Even the full-buffer traffic model tends to give a bias on providing better sector throughput [9], it can still be used as the baseline performance by limiting the impacts from different traffic models. In this study, seven fading channels, AWGN, 1-path, 2-path Rayleigh each at 3kmph, 30kmph, and 100 kmph, are considered. Among all, 2-path Rayleigh at 3kmph fading channel is used mostly to evaluate the PF algorithm and the DTM algorithm on fairness and throughput performance. The results from this paper will still valid (in terms of the trend) even with different fading channels.

A. Proportional Fair Share Algorithm

Several scheduler algorithms have been proposed [6, 10-13]. One of an early proposed algorithms for 1xEv-DO is the proportional fair (PF) scheduler algorithm. The principal of the PF algorithm is to schedule users for transmission with a maximum data rate channel (DRC) requested-to-average transmission rate ratio, calculated based on an IIR filter. The channel is assigned, $S(n)$, based on Expression (1) below:

$$S(n) = \arg \max_i \frac{DRC_i(n)}{R_i(n)} ,$$

where

$$R_i(n) = \left(1 - \frac{1}{T}\right)R_i(n-1) + \frac{1}{T}\ DRC_i \text{ assigned}(n)$$

$T$ is the average duration.

In general, a schedule algorithm decides the order of the channel assignment. By taking the benefit of channel variance among users, the PF algorithm intends to select the user with the highest ratio of RF condition and the average transmission rate. The algorithm is intended for achieving high system throughput with a consideration of the fairness in user transmission rates. The system throughput has been improved 3 to 4 times as compared to cdma2000 [7,8]. But the fairness, shown in Figure 2 and 3, is not controlled with the design concept of equal time transmission. By considering simulation cases of 20 active users on AWGN and 2-path Rayleigh 3 kmph fading channel conditions, the average user transmission rates could vary from 5 kbps to 120 kbps for AWGN and from 10 kbps to about 140 kbps for 2-path Rayleigh 3 kmph fading. Based on the equal-time transmission design, the number of transmitted slots is about the same in AWGN and there is a minor difference in transmitted slots for 2-path Rayleigh fading. In the full-buffer case, users with high transmission rates will transmit more data than users requested for lower transmission rates. This bias will make the sector throughput higher than it should. In Figure 4, if we consider only the 2-path Rayleigh 3 kmph fading case, as shown, the PF algorithm is not designed to resolve the fairness problems where there are 10% each of the transmission rates fall below 5 kbps and exceed 90 kbps respectively.

Another disadvantage of the PF algorithm is that the algorithm also fails to control of the minimum user transmission rate to meet the transmission rate criteria of any data applications. For example, if an application needs the minimum rate of 10 kbps, in PF algorithm, there are about 20% of the cases fails to meet the minimum transmission rate criterion for 2-path Rayleigh 3 kmph fading case. The minimum rate control is even worse in the AWGN case. There are 30% of case the transmission rates are less than 10 kbps. To have a better management of the fairness among active users and to guarantee the minimum transmission rate, we proposed the Dynamic Target Maximum/Minimum (DTM) Rate Controlled Scheduling Algorithm. In DTM, the algorithm includes also the maximum rate control to avoid the resource hogging from high data rate users. In a real situation, the maximum rate will be controlled automatically when the
number of active users increases.

Figure 2. Average Transmission Rate and Transmission Slots @ AWGN

Figure 3. Average Transmission Rate and Transmission Slots @ 2-Path Rayleigh, 3kmph

Figure 4. CDF of Average Transmission Rate @ 2-Path Rayleigh, 3kmph

B. Dynamic Target with Minimum (DTM) Rate Controlled Scheduling Algorithm

The DTM is designed to achieve the fairness among active users. Different from a fixed target transmission, the DTM is to dynamically control the user-perceived throughput of all active users close to the dynamic target throughput calculated based on the mean user-perceived throughput of all active users. The idea is to maintain the fairness among active users only. The algorithm also provides the control on the minimum and maximum user-perceived throughput.

By adding a weighted factor \( F_i(n) \) on Expression (1), the DTM algorithm is in Expression (2).

\[
S(n) = \arg \max_i \frac{DRC_i(n)}{R_i(n)} + F_i(n)
\]

(2)

where

\[
F_i(n) = F_i(n-1) + \frac{F_i^d(n)}{M}
\]

and

\[
F_i^d(n) = \begin{cases} 
-\frac{1}{M} (R_i(n)-R_{\text{target}}), & R_{\text{target}} < R_i(n) \\
-\frac{1}{M} (R_i(n)-R_{\text{max}}), & R_{\text{max}} < R_i(n) < R_{\text{max}} \\
-\frac{1}{M} (R_i(n)-R_{\text{min}}), & R_{\text{min}} < R_i(n) < R_{\text{max}} \\
e^{(R_{\text{max}}-R_i(n))}, & R_i(n) < R_{\text{min}}
\end{cases}
\]

and where \( R_{\text{avg},i}(n) = \frac{\sum R_i(n)}{N} \).

In Expression (2), \( DRC_i(n) \) and \( R_i(n) \) are the same as defined in Expression (1). \( F_i(n) \) is a weighted factor of the computation of a user \( i \), and is updated with an update function \( F_i^d(n) \). \( R_{\text{max}} \) and \( R_{\text{min}} \) represent the maximum and minimum user throughputs. \( M \) is a variable used to represent the level of the control from the DTM; and \( N \) is the number of active users at a given time instant in the system. From Expression (2), as \( M \) approaches to infinite (or to a large number), the DTM will approach to the PF. The behavior of the update function \( F_i^d(n) \) is illustrated with respect to Figure 5 where for a user whose user perceived throughput lies between \( R_{\text{min}} \) and \( R_{\text{max}} \), the update function is proportional to the difference between the user’s actual perceived throughput and the average user perceived throughput for all active users \( (R_{\text{target}}) \). For active users whose user perceived throughput falls outside the operating range, the update function is an exponential function of the difference between user perceived throughput and either \( R_{\text{min}} \) or \( R_{\text{max}} \).
In this section, the impacts of DTM algorithms are evaluated.

In Figure 6, by considering different control levels, $M$, the STD (standard deviation) of user transmission rate is reduced with the decrease of the value $M$ ($1/M$ is the control level). The STD can be controlled within 5 kbps for all different fading channel cases if $M$ is set to 3 and less. In Figure 7, by considering a 2-path Rayleigh 3kmph fading case, the average user transmission rates are varied from 20 kbps to 30 kbps for the DTM and 10 kbps to 140 kbps for the PF. The CDF (cumulative distribution function) of user-transmission rates is plotted in Figure 8 to demonstrate that the DTM can not only manage effectively the fairness among users but also maintain the minimum rate condition.

In Figure 8, we consider the user-transmission rate with $M = 1, 10, 100, 1000$, and the PF. As expected, $M = 1$ provides the best control in terms of the fairness of user-transmission rates. For $M = 1$, 80% cases the user throughput falls within 15 kbps to 30 kbps. Only less than 4% cases that the user-transmission rates are less than 10 kbps. As the increase of the value $M$, the control of the fairness will get worse and will be bounded by the PF algorithm. Since the DTM is proposed based on the top of the PF algorithm, the tightness of the fairness control is in fact at the cost of the sector throughput.

In Figure 9, the sector throughput can be reduced by 40% to 50% at $M = 1$ (as compared to the PF algorithm). Even the actual reduction will depend on the data applications. Relatively, the throughput reduction will occur when the fairness control is implemented and the reduction will be proportional to the level of the fairness control. In short, with different choices of the value $M$, the DTM algorithm can support the fairness and the minimum transmission rate criteria at a cost of the sector throughput.

V. CONCLUSIONS

Scheduler has been designed mostly to optimize the system throughput. In this paper, we raise another important design issue on the fairness among user-transmission rates. Instead of having a fixed target transmission, the concept of the dynamic target rate control is proposed to manage the fairness among active users. Given there exists a tradeoff among the fairness, minimum rate requirements and sector throughput, the DTM algorithm has the capability of meeting different design criteria. Furthermore, the DTM algorithm can also be extended to support different user priority and QoS by setting different control levels, target rates and minimum/maximum rates among users and/or applications.
REFERENCES


[3] 3GPP TS 25.302, Services Provided by the Physical Layer


