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Title: Per-User Reverse Rate Control for Shared Packet Data Channel in 1xEV-DV

Abstract: A per-user forward rate-control channel (F-RCCH) is proposed to allow a base station to control the reverse link data rate of each active Mobile Station (MS) sharing a packet data channel. By assigning data rates to active MS's based on their forward link data rate controls (DRC's), overall reverse link sector throughput can be improved, potentially very significantly. Basic simulation results are provided to illustrate these potential gains.

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Recommendation: Discuss and Adopt in WG-5

1 INTRODUCTION

1xEV-DV requirements [1] have set very challenging goals for reverse link packet data performance:

- *Peak data rate of at least 1.25 Mbit/s in an outdoor, vehicular environment;*
- *Peak data rate of 2 Mbit/s in a stationary, indoor environment;*
- *System-wide average data rates in a fully loaded system of at least 600 kbit/s in an outdoor, vehicular environment.*

However much of the focus of 1xEV-DV framework proposals to date have been in increasing forward link throughput by adopting many of the concepts previously developed for 1xEV-DO. Specifically, these proposals take advantage of the fact that in packet data applications it is not necessary to provide any rate guarantees to individual users. By instead serving these users at variable rates based on their channel characteristics (described by a parameter fSIR, defined later), forward link sector throughput (sum of rates) can be increased significantly.

Even though reverse link is operationally quite different from the forward link, it is possible to similarly increase reverse link sector throughput by supporting variable rate packet data transmission and adjusting user's data rates based on their channel characteristics (now described by a parameter rSIR, also defined later). Such an approach also better aligns the forward and reverse link rates of a packet data user.

To effectively support such variable-rate reverse link operation, a per-user rate control mechanism needs to be included in 1xEV-DV. In this contribution, we describe how the reverse link sector throughput can be improved using variable-rate transmission with per-user rate control and discuss alternative ways of adding a per-user rate control channel to the forward link without introducing significant overhead.

2 INCREASING REVERSE LINK SECTOR THROUGHPUT

Consider a set of N active Mobile Stations (MS's) who are sharing a packet data channel within in a sector. Let the reverse link transmission rate of the i'th user be R_i, i = 1, 2,…N, where R_i is chosen from a finite set. As an example, in 1xEV-DO R_i's are chosen from the set {9.6, 19.2, 38.4, 76.8, 153.6 kbit/s}. We For simplicity in the analysis that follows, we assume that active MS's always have data to transmit.

A. INCREASING THROUGHPUT IN THE SINGLE-SECTOR CASE

First, consider the case of a single-sector operation~~,~~ where system performance is examined in only one sector, ~~paying no attention to~~essentially ignoring interference from/to other sectors. The Base Station (BS) is power controlling the MS's in such a way that their signals arrive at the receiver with just enough power S_i to achieve a certain E_b/I_0. Generalizing the results given in [2] to the case of variable-rate operation considered~~ed~~ here, it can shown that the data rate R_i of the i'th user is approximately proportional to

$$R_i \propto S_i / (S_{intra}(i) + \text{Noise}),$$

where $S_{intra}(i) = \Sigma_{j \neq i} S_j$ is the total signal power received from all other MS's in the sector, and "Noise" represents the total receiver noise power including the effects of receiver noise figure. Next, we write the signal power S_i received from the i'th MS as

$$S_i = P_i A_i,$$

where P_i is the transmit power of the i'th MS and A_i is the squared reverse link channel gain between the i'th MS and the serving sector.

Suppose that initially all MS's are transmitting at the same data rate $R_i = R_0$ producing the same received power $S_i = S_0$ at the BS receiver. Now, suppose we modify the rate allocation such that the data rate R_i of the i'th user is set to be proportional to its channel gain A_i. At the same time, we modify the transmit powers P_i to achieve the desired E_b/I_0, while ~~we increase the transmit power P_i of the MS with the highest value of $G_0(i)$ and at the same time reduce the transmit power of the MS with the smallest value of $G_0(i)$ by the same amount,~~ keeping the total transmit power [i.e., $\Sigma_i P_i$] fixed. It can be shown that as long as the channel gains A_i are not all identical and the system is fully loaded (such that the "Noise" term can be ignored), this new power and rate allocation will always increase the sector throughput. ~~if the "Noise" term can be ignored, which would be the case when the sector becomes fully loaded.~~

This example illustrates that by allocating data rates based on the individual reverse link channel characteristics (represented by A_i), reverse link sector throughput can be increased. Even higher sector throughputs can be ~~achieved~~ realized if we were to allow only 1 MS with the best channel condition to transmit, ~~essentially~~ thus operating with no interference from other MS's in the same sector. In fact it is known [3] that the optimum throughput-maximizing strategy on a multi-user fading channel is to use a TDMA ~~system~~ approach where only the user with the best channel condition gets to transmit. Of course, such an approach can be unfair to certain users who remain in poor channel conditions for a long time. Therefore, in ~~normal~~ real operation, one would seek to maximize the sector throughput while satisfying a certain fairness criterion.[1]

1 This is similar to fairness issues found on the forward link.

B. ***REDUCING INTERFERENCE TO OTHER SECTORS***

In the previous subsection, we saw ~~how~~ that if we ignore inter-sector interference we can increase the sector throughput by letting MS's with good channel characteristics (large A_i) transmit at a higher data rate relative to MS's with worse channel characteristics. ~~In multi-sector operation, however, we are also concerned~~In this subsection, we'll consider inter-sector ~~about~~ interference ~~created to other sectors. Next, we~~ and illustrate how rate allocation on the reverse link can also reduce such interference.

First, we write the total interference from the i'th MS to all other sectors as P_iB_i, where B_i is the sum of the squared reverse link channel gains between the i'th MS and all other neighboring sectors. Here, P_i is again the transmit power of the i'th MS.

As in the previous section, suppose that initially all MS's are transmitting at the same ~~bit~~ data rate $R_i = R_0$ producing the same received power $S_i = S_0$. Now, suppose we increase the transmit power P_i of an MS with a *small* value of B_i and at the same time reduce by the same amount the transmit power of ~~the~~ an MS with a *larger* value of B_i ~~by the same amount~~, keeping the total transmit power [i.e., $\Sigma_i P_i$] fixed. It is straightforward to see that this simple modification will always reduce the total interference created to other sectors.

This example illustrates that by allocating data rates to MS's based on their individual interference characteristics (represented by B_i~~(i)),~~), total interference to other sectors can be significantly reduced. As in the previous example, interference can be reduced, possibly dramatically, if we allow only 1 MS with the best interference condition to transmit. Again, in normal operation one would seek to minimize interference while satisfying a certain fairness criterion.

C. INCREASING THROUGHPUT IN MULTI-SECTOR OPERATION

In multi-sector operation we try to increase sector throughput while taking into account both ~~intra~~intra-sector and inter-sector interference. In this case, the data rate R_i of an MS is approximately proportional to

$$R_i \propto S_i /(S_{intra}(i)+ S_{inter} + \text{Noise}),$$

where S_{inter} ~~is~~ represents the interference from adjacent sectors.

~~Combining the earlier results~~Based on the results of the previous two subsections, ~~one can show that the reverse link sector throughput can be increased~~we now introduce the following ~~if we allocate the data rates based on the following~~ reverse link SIR parameter:

$$rSIR(i) = A_i/B_i.$$

This captures the two components of the channel which we used for rate allocationallocation discussed earlier: A_i and B_i. By assigning higher data rates to users based on the channel parameter rSIR, one can increase the sector throughputwe would take into account the effect of A_i in increasing single-sector throughput gain as well as the effect of B_i in reducing inter-sector interference by controlling both intra-sector and inter-sector interference.

Of course, the values of rSIR(i) are generally unknown at the serving sector, particularly the component B_i, which would have to be measured at other BS's and then somehow communicated to the serving sector. Luckily, various strategies can be employed to estimate approximate rSIR(i) from a knowledge of fSIR(i) which is the forward link SIR seen by the i'th MS. Specifically, we define fSIR(i) according to

$$fSIR(i) = C_i/D_i\ (i),$$

where C_i is the squared forward link channel gain between the i'th MS and the serving sector and $D_i(i)$ is the sum of the squared forward link channel gains between the i'th MS and all other neighboring sectors.

It should be noted that most 1xEV-DV framework proposals include a data rate request capability, similar to the Data Rate Control (DRC) feature found in 1xEV-DO, where the MS reports to the sector its achievable data rate based on its measurement of fSIR(i), or an approximation to it. As a result, the BS already has knowledge of fSIR(i). Now, if the channel gains in the forward and reverse directions were identical (i.e., $A_i = C_i$, $B_i\ (i) = D_i\ (i)$), we would have rSIR(i) = fSIR(i), and the serving sector would also know the values of rSIR(i).

In reality, both rSIR(i) and fSIR(i) are random quantities that typically depend on path loss, shadow fading and Raleigh fading. Path loss and shadow fading tend to be highly correlated in the two directions of transmission, but Raleigh fading is almost completely uncorrelated. As a result, rSIR(i) and fSIR(i) are rarely the same. However, if we average rSIR(i) and fSIR(i) over a sufficiently long period, they will become strongly correlated. Therefore, we believe using an appropriatelyan averaged version of the DRC values received from the MS, the serving sector can allocate reverse link rates essentially in proportion to the forward link throughput allocated given to each MS. Simulation results provided in Section 4 show that very significant gains can be achieved using this approach.

3 POSSIBLE WAYS OF ADDING A PER-USER RATE CONTROL CHANNEL

1xEV-DO uses RateLimit messages and RAB (Reverse Activity Bit) to control the reverse link rate. However, RAB is a probabilistic global control mechanism that cannot be used for per-user rate control. Alternatively, the BS can use RateLimit messages to control the maximum allowed reverse link rate of each MS. However, these messages carry significant

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