SOUTH-WEST UNIVERSITY "NEOFIT RILSKY"
BLAGOEVGRAD, BULGARIA

VOLUME 5
2007

SCIENTIFIC Research

ISSN 1312-7535

ELECTRONIC ISSUE

IMPROVING FAIRNESS IN CDMA-HDR NETWORKS

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Abstract. *Improving throughput and fairness in Cellular Data Networks is a problem of present interest. Non high throughput and unfairness of data streams and sharing the network resources greatly limit putting into practice and the commercial market wining of such networks and technologies.*

In article are considered main realized in practice way of raising throughput and fairness in wireless networks. Using simulation results obtained with an available online simulator, I present some advantages of using more accurate estimation of the SINR combined with H-ARQ in Cellular Data Networks.

1. INTRODUCTION

Cellular Data Networks are becoming more and more popular nowadays. In these networks, time is divided into many time slots and each wireless terminal-WT is transmitting packets (to a base station). WTs use one or more time slots to transmit their payload, but each time slot can only accommodate one WT. Multiple WTs are accommodated using the time division multiple access-TDMA technique. As a result, each WT can use the maximum power of the entire base station-BS. In the wireless mobile environment, the RF condition changes significantly with time. When the RF condition is good, little coding protection is needed and modulation with high constellation can be used, making it possible to transmit at a high data rate in a given timeslot. The data from each timeslot are scrambled and spreaded using a computer generated pseudo-random -sequence (chip) unique to the sector of cell (Code-Division Multiple Access- CDMA). Cellular Data Networks-CDNs combine the advantages of both techniques- TDMA and CDMA. This combination is well suited to the bursty nature of packet data, as well as has the advantage of being able to have frequency reuse in every sector.

CDNs as CDMA system are known to be interference limited, which means that their capacity can be increased by reducing the minimum required (for stable reception of data at the receiver) energy of signal with a given Signal to Interference and Noise Ratio-SINR. The SINR is a function of several factors such as path loss, shadowing, fading, noise, and intercell interference.

Such CDNs, as CDMA-HDR (High Data Rate), 1xEVDV (1x Evolution for High-Speed Integrated Data and Voice) , and other systems realize procedures for power control [2]: The WT measures the SINR of the received signal through the pilot channel and sends feedback to the BS; Based on the feedback from the WT, the BS adjusts its transmitted power level.

The structure of the reverse link traffic channel [5] is shown in Figure 1. The pilot channel aids coherent demodulation and tracking. The reverse rate indicator channel is used to inform the base station about the data rate being transmitted on the reverse link. If the base station decides to transmit a packet for a given WT, it is required to transmit it at the data rate specified by the DRC request from that WT. The acknowledgement channel is used to support early completion of forward link packets.

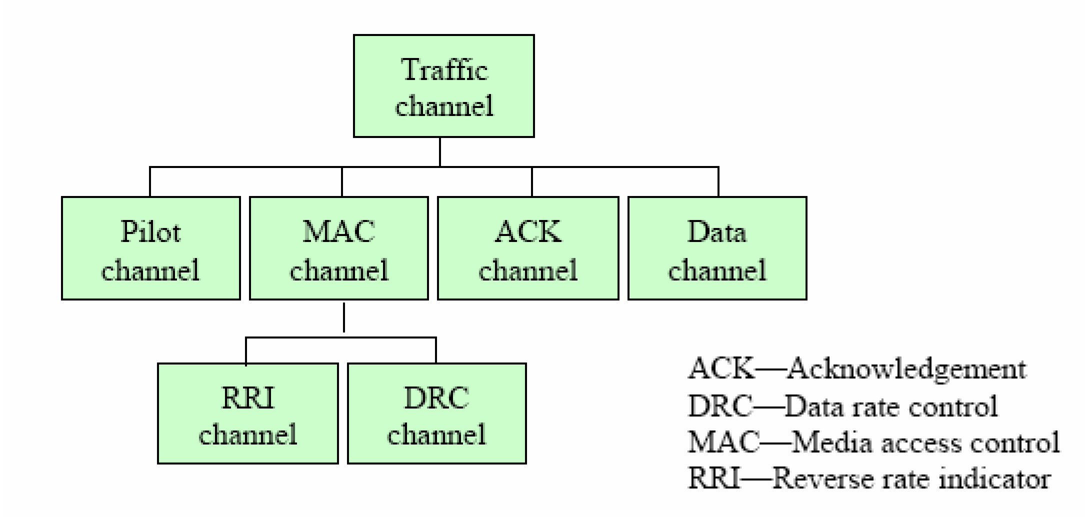

Fig.1

While the data rate adaptation discussed above significantly improves spectral efficiency, further gain can be obtained by dividing the total packet energy in each packet into several portions and incrementally transmitting the packet with a port of the energy using multiple subpackets in separate timeslots, and terminating the transmission as soon as the packet is decoded correctly at the other end. This gain exists because the estimation of the RF environment at the WT is not perfect, e.g. the data rate requested by WT via DRC channel for the base station to transmit is usually conservative. This is realized by Hybrid Automatic Repeat Request- H-ARQ and Early Packet Termination.

The Hybrid Automatic Repeat Request- H-ARQ (or more sophisticated Hybrid ARQ/FEC) is usually used to improve data throughput [2] and to allow for early packet termination. The general procedure of the H-ARQ is as follows: The packet is coded, interleaved, added CRC and formed into subpackets that are transmitted. The receiver decodes the packet and checks the CRC. If the CRC check passes/ does not pass, an acknowledgment /negative acknowledgment is sent back to the transmitter. Early packet termination refers to a successful reception of a packet before the nominal packet duration when the channel condition is good. In H-ARQ, the information bits are conveyed using several subpackets. If the packet can be decoded correctly before all the subpackets are transmitted, the packet transmission is terminated early and there is no need for additional transmissions. The repetition of the packet bits in the subpacket is accomplished by means of channel coding to obtain further coding gain. To allow time for the WT to process each subpacket and feed back the information to the base station, each subpacket is transmitted disjointly in time. In terms of energy, H-ARQ can be thought of as a scheme where additional energy for each subpacket is transmitted until the required SINR for the entire packet is reached [1]. The effect of H-ARQ is quite similar to that of the fast power control technique since it minimizes the total interference to other WTs by controlling the power used to transmit packets. The H-ARQ is used to improve network performance in presence of inter-cell interference [5].

In [1], *Kwon et al.* consider the problem of controlling the transmitted power. H-ARQ combined with fast power control achieves a larger reduction in the interference on the CDMA reverse link compared to the system only with fast power control, however this kind of gain is obtained at the expense of larger packet delay.

Other works such as [5] have studied the effect of inter-cell interference over the forward link, and the benefits of H- ARQ in countering the interference, or rather a mismatch between the data rate that should be transmitted and the data rate that is requested by the WT is effectively mitigated by H-ARQ and early packet termination.

In [3], Mhatre et al. study the impact of network load in the neighboring sectors on the inter-cell interference in a cellular data network. The observation that signal received by a WT over the forward link contains interference from the neighboring base stations is used by the terminal to predict its SINR more accurately.

The signal received by a WT over the forward link in a cellular data network contains interference from the neighboring base stations. In Fig. 2 is shown a WT in sector 0 of cell C receives inter-cell interference from sector 1 of cell C' and sector 2 of cell C''.

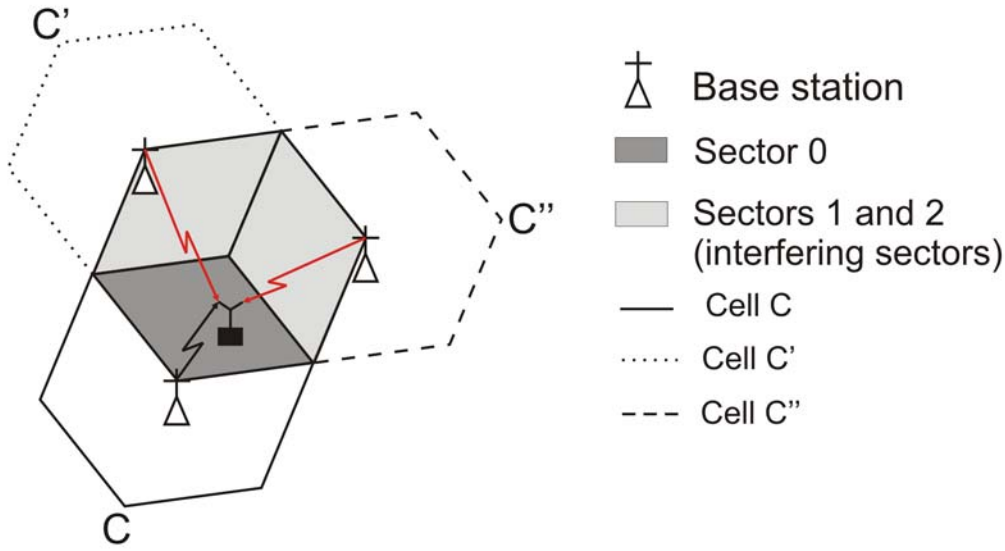

Fig. 2

In [3] is show that the SINR is:

(1) $$SINR = \frac{G_0^2 A^2 T_C}{\frac{1}{3} A^2 T_C (G_1^2 \rho_1 + G_2^2 \rho_2) + 2N_0}$$

where A is the signal amplitude, Tc is width of pulse (chip) , Gi is the channel gain from the base station of the interfering sector to the terminal, and ρ_i is the traffic load on the forward link of i-th sector (ρ_i is the probability that a time slot on the forward link of i-th sector is busy).

The SINR given by (1), is a function of Gi, and given by:

(2) $$G_i^2 = cd_i^{-n} .10^{\xi_i/10} .W_i^2$$

In (2), the first term in the product is deterministic (for a fixed WT location), and corresponds to path loss, while the second term is a random variable corresponding to lognormal shadowing loss. Here, ξ_i is a Gaussian random variable with mean 0, and variance σ_G. Shadowing is correlated over each time slot depending on the speed of the WT as per Gudmundson model [6]. Last term- Rayleigh fading is accounted through Wi.

However, in the actual implementation of CDMA-HDR [3], the BSs are GPS-synchronized and all the BSs transmit their pilot signal at the same time. Hence, the SINR measured by the terminals contains the worst case inter-cell interference, since the interfering signals are transmited constantly during the measurement phase. Referring to (1), this amounts to measuring the SINR with $\rho_1 = \rho_2 = 1$, i.e:

(3) $$SINR' = \frac{G_0^2 A^2 T_C}{\frac{1}{3} A^2 T_C (G_1^2 + G_2^2) + 2N_0}$$

If the terminal has the information about the network loads in all the sectors that are in its active set, it can calculate the actual SINR'' using (1):

$$(4) \qquad SINR'' = \frac{G_0^2 A^2 T_C}{\frac{1}{3} A^2 T_C (G_1^2 \rho_1 + G_2^2 \rho_2) + 2N_0}$$

Thus, using more accurate estimation of the SINR, WT will be able to improve data throughput.

Moreover, H-ARQ also improves throughput, even in spite of initial conservative SINR estimates [5], because as mentioned above, H-ARQ adjusts to network loading in the adjacent sectors.

The classical index of fairness [7] displays level of satisfaction of each user/WT, respectively fair sharing of the network resources, and is given by:

$$(5) \qquad Fairness = \left(\sum X_i\right)^2 / n \sum X_i^2$$

So, Fairness =1 speaks of quite fairness sharing of the network resources between users, then and *Fairness* =0 corresponds to absolutely opposite situations. The performance metric is based on data throughput (X_i).

I expect that more accurate initial estimation of the SINR and H-ARQ can improve throughput and fairness. In next section I will verify through simulations whether these improve the fairness.

2. SIMULATION RESULTS

I present simulation results of fairness when three WTs are served over the forward link,as run two sets of simulations with two subsets. In the first set, all WTs use (3) in order to estimate SINR, and H -ARQ for early packet termination (Primary Scheme), while in the second set, all WTs use (4) to estimate SINR, and also use H-ARQ (Secondary. scheme). In the first subset, all the three WTs are pedestrian, while in the second- all WTs are vehicular terminals.

Simulation parameters are listed in Table I, and have been taken from [6]. Each simulation is run for 20,000 time slots, and 600 independent simulations are run to gather WT throughputs within 90% confidence interval. I select WT locations so that the terminal is equidistant from the two interfering base stations. The locations from the serving base station of WTs are selected to be $0.4R_0$, $0.7R_0$ and R_0. The cell radius R is 1 Km. I use ITU path loss models for vehicular (120 kmph) and pedestrian (3 kmph) WTs. Shadow correlation distance is the same for both vehicular and pedestrian models- 20m, and depends only on the environment (urban or suburban).

Table 1

Carrier frequency, fo	2000 MHz
Log-normal Shadowing variance, $\square_G$	10 dB
Shadow correlation distance	20.0 m
Noise spectral density, *No*	-174 dBm/Hz
A, amplitude of transmit waveform (base station transmit power of 15W)	5.48
Chip duration, T_c (1.25 Mcps)	0.8 *us*
Radius of the sector, *R*	1 Km
Ro for 90% cell coverage	0.95R = 0.95 Km
Miscellaneous gains: antenna gains, body loss, cable loss	15.2 dB
Building penetration loss, (only for pedestrian WTs)	12 dB
Pedestrian path loss in dB, $10\log_{10}(cd^n)$ (f_0 in MHz, d in Km)	$30\log_{10}(f_0) + 49 + 40\log_{10}(d)$
Vehicular path loss in dB, $10\log_{10}(cd^n)$ (f_0 in MHz, d in Km)	$21\log_{10}(f_0) + 58.83 + 37.6 \log_{10}(d)$
Fraction of multi-path power captured by the receiver (vehicular WT)	0.784

In all our simulations, although the time-varying shadowing and fading, I assume that the WT location remains unchanged during the course of the simulation. In all the simulations, I assume for simplicity that the network loads in both the interfering sectors are the same, i.e., $\rho_1 = \rho_2 = \rho$, and I vary ρ to study the fairness of Primary and Secondary Schemes for different network loads in the interfering sectors.

Table 2

□	X1	X2	X3	Fairness
1.0	991	423	149	0.688231
0.9	999	428	151	0.6894
0.8	1007	432	153	0.690167
0.7	1012	436	155	0.691723
0.6	1018	439	158	0.693303
0.5	1023	442	160	0.694448
0.4	1027	445	162	0.695846
0.3	1034	450	165	0.697832

Table 3

□	X1	X2	X3	Fairness
1.0	992	423	148	0.687252
0.9	992	432	156	0.696332
0.8	990	443	163	0.705844
0.7	987	453	172	0.716467
0.6	985	468	182	0.728971
0.5	980	480	193	0.741667
0.4	973	496	208	0.758444
0.3	963	517	228	0.780033

In tables 2and 3, I present the throughput (kbps)received by each WT as a function of the interfering network load under the both schemes for pedestrian model. Table 2 gives the indexes of throughput and fairness for standard CDMA-HDR networks (Primary Scheme). In columns titled as X1, X2, and X3 are presented end to end throughput for WTs 1, 2, and 3. In the last column is calculated the indexes of fairness using (5). Simulation results for Secondary Scheme are given in table 3. I note that as the interfering network load decreases, both the schemes result in higher throughput for WTs 2 and 3. Unlike Primary Scheme, where the throughput of WT 1 increases with decreasing network load, in Secondary Scheme, the throughput of WT 1 decreases with decreasing network load. This is because both the schemes are designed to improve the throughput of a WT when the inter-cell interference is lower. However this benefit is especially more pronounced for WTs located near the cell boundary (WTs 2 and 3).

Table 4

□	X1	X2	X3	Fairness
1.0	980	295	75	0.576896
0.9	987	300	77	0.579541
0.8	989	305	80	0.584005
0.7	995	310	85	0.589046
0.6	998	315	87	0.592432
0.5	1006	320	92	0.596884
0.4	1009	325	97	0.602399
0.3	1016	330	102	0.606917

Table 5

□	X1	X2	X3	Fairness
1.0	980	290	75	0.574225
0.9	969	310	84	0.594229
0.8	961	320	92	0.607488
0.7	957	330	102	0.621268
0.6	957	360	112	0.643369
0.5	961	390	124	0.664721
0.4	968	430	142	0.692183
0.3	978	490	170	0.729792

I observe similar results for the vehicular model in (tables.4 and 5). Near the cell boundary the throughput degrades more rapidly, due to a lower path loss exponent (more in vehicular than pedestrian model), i.e. more serious. intercell interference.

In Fig. 7, I plot the fairness as a function of the interfering network load under Primary and Secondary Schemes for pedestrian model (See respectively table 2, and table 3).

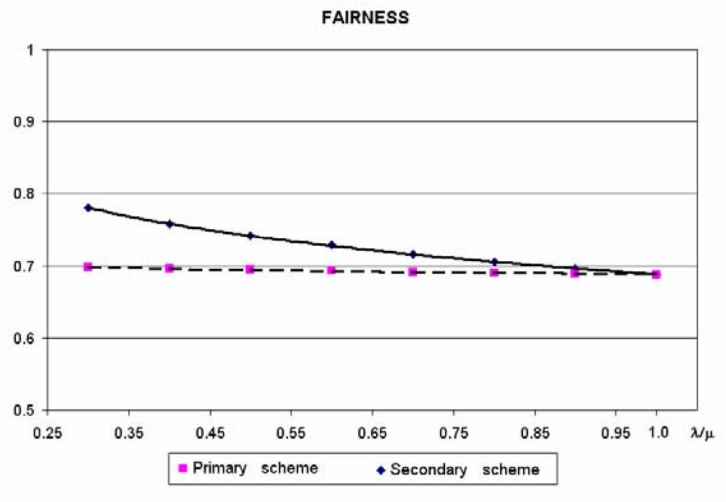

Fig. 7.

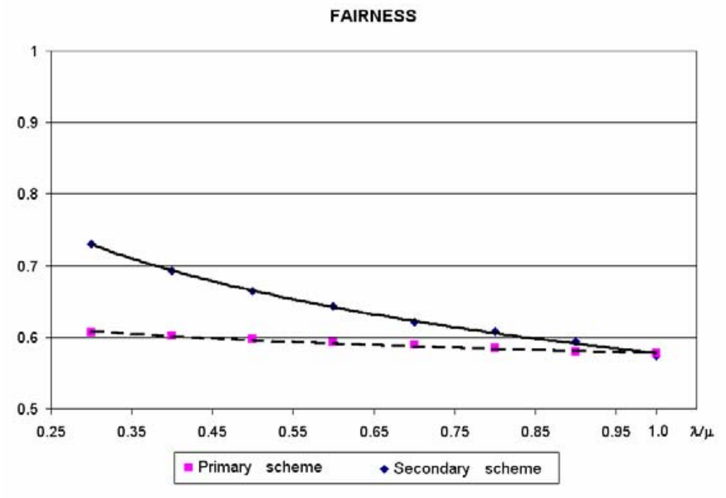

Fig. 8.

In fig. 8 is compared the fairness of primary scheme (squares), and secondary scheme (dots) for the vehicular model.

As expected, I observe similar results in Fig. 8, but the fairness improvement of WTs 2 and 3 is even higher in the vehicular case than the pedestrian case. It can explain with fact, that the Secondary Scheme benefits the WTs located far from the serving base station, as well as penalizes near located WTs As it has been shown above proposed mechanism (Secondary Scheme) is better than standard CDMA-HDR, taking on account throughput as well as according fairness.

3. CONCLUSIONS

This article shows the advantages of using more accurate estimation of the SINR combined with H-ARQ in Cellular Data Networks, as well as presents some simulation results obtained with an available online simulator [4].

Using the proposed in the present work method the fairness can raise and thus, avoid beatdown effect.

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