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ON THE USE OF CELLULAR TECHNOLOGY FOR DIGITAL TV BI-DIRECTIONAL RETURN CHANNEL SERVICES

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ABSTRACT

In this work the behavior of particular cellular technology for use in a wireless implementation of a bi-directional Digital TV return channel is considered. The analysis is done using a simulation tool, based on the Tangram-II platform, that incorporates a detailed propagation model and the relevant features of the CDMA2000 EV-DO system. Internet access through web browsers was judged to be the key application to be provided. This paper presents both throughput and latency results with varying number of terminals in the system. It also identifies variations in the user quality of service due to their geographic position. The results show that even if some parameters of the scheduling algorithm are varied, it is difficult to improve the fairness performance of the technology. A very simple solution is proposed to enhance these fairness characteristics.

I. INTRODUCTION

This work was motivated by the desire of the Brazilian government to include a bi-directional return channel to the Digital TV system soon to be deployed in the country. The reference architecture, as defined by ITU, for a digital TV system can be found in [1]. The availability of the return (or interactive) channel is considered key to allow a significant part of the country's population to cross the digital gap by having access to modern life information services (e-mail, banking, e-government, medical related services, etc.) through the Internet. The access terminals, will be mostly set-top boxes with limited processing and memory capabilities placing some constraints on which services can be offered and how they can be accessed. The target is to offer bit rates to the users at least comparable to those obtained today through dial up services, leading to a requirement of a minimum average rate of 50 Kbps. There is also a willingness that higher peak bit rates be available for part of the time and that these be higher than 100Kbps.

Because of the limitations on the cost and complexity of the set-top boxes it is envisioned that most services will be web based which also simplifies the human interface. This assumption influenced the choice of traffic model used to obtain the performance results reported in this paper. Another assumption that was made is that a vast majority of the users will be stationary, at least for the first years of system deployment. Mobile users will be a minority and most will be moving at pedestrian speeds, i.e., at about 3Km/h. This second assumption did influence the choice of parameter values and features to be considered in the analysis of the technology addressed in this study which is the CDMA20001x EV-DO Rev.0 (IS-856). Other technologies were considered for use in the interactive channel and will be the topic of other contributions.

The EV-DO [2, 3] is a third generation cellular technology conceived to serve an increasing demand for wireless packet data communications. In the uplink this technology operates as the CDMA20001x with all normal features of this technology such as soft handoff. In the forward link the EV-DO is a time division multiplexing system designed to provide a high total sector throughput allowing a maximum bit rate of 2.4 Mbps in its revision 0 (3.1 Mbps in Rev.A).

An important consideration in designing a return channel system that will be used as a main Internet access tool for a large population is that the system should provide comparable (or at least good quality) services to all its subscribers. It is not desirable that a user due to its geographical location be in a permanent disadvantage with respect to other users which are paying the same price for the subscription. Note that in a highly mobile environment this is very hard to occur because users are changing their location constantly. However, in a scenario where most terminals are stationary, this unwanted situation can happen. In particular, the EV-DO has one intrinsic difficulty regarding fairness due to the downlink scheduling algorithm which is most commonly used. In this work we propose a possible solution to circumvent this shortcoming of the EV-DO which not only can enhance the fairness characteristics of the service but will also increase the total throughput in the cell site.

There have been several papers published addressing the performance of EV-DO systems [3, 4, 5, 6, 7, 8]. In one of them [9] there is a focus on a population of static users. However, in none of them, the average bit rate achieved by users in different regions of the cell is addressed in detail. Here a simple solution is proposed and discussed to reduce unfairness. Furthermore, our contribution uses a traffic model which differs from those used in other papers in the literature.

In the next section a brief review of the main features of the EV-DO technology is presented. In Section III the simulation and traffic models employed in this work are introduced. A simulation tool is used to implemente the EV-DO characteristics and to evaluate the benefits brought by a particular solution to enhance the fairness behavior of that technology. The results are discussed in Section IV. Concluding remarks and suggestions for future work are offered in Section V.

II. CDMA2000 1XEVDO OVERVIEW

The cellular technology EV-DO, also known as TIA IS-856 standard [2], is optimized for packet data transmission and is part of a family of CDMA20001x third generation technologies. The EV-DO forward link operates on a Time Division Multiplexing (TDM) mode where at each 1.67 ms slot the data transmission is directed to a single user. This transmission is always made at peak access point (or cell site) power and the peak rate is 2.4 Mbps. As most modern wireless communication techniques, the EV-DO employs adaptive modulation/coding schemes in both forward and reverse links, although they are implemented in different ways depending on the direction considered. In the downlink, the choice of bit rate depends on the carrier-to-interference ratio (C/I) perceived by the access terminal (AT). The AT passes the instantaneous channel quality information to the access point (AP) through the bit field DRC (Data Rate Control) in the reverse link. Table 1 shows the available forward link modulation and coding schemes for the EV-DO (Rev.0) including respective bit rates, packet lengths and minimum SINR (signal-to-interference+noise ratio).

Congestion control in the reverse link is achieved by a reverse activity (RA) bit sent in the downlink by the AP. This bit is code multiplexed with the power control (RPC) logical channel to form the medium access control (MAC) signal. The MAC information is then time multiplexed with the pilot signal and the actual information bits.

The time multiplexed forward link signal spreading chip rate (1.2288Mc/s) and carrier spacing (1.25MHz) are compatible with other CDMA systems such as CDMA20001xRTT and IS-95.

From Table 1 it can be seen that the higher the downlink bit rate the lower the robustness to channel impairments hence the higher bit rate options will only be available when the propagation conditions are favorable and/or the system loading is low. Another interesting observation is that when the AP uses a low bit rate to transmit to a given user it will occupy larger number of slots to send a packet then when the bit rate employed is high. Hence, serving users in worst geographic/propagation condition will necessarily reduce the total bit rate achieved by the system. This characteristic will be addressed again when discussing system performance in Section IV. The EV-DO forward link behavior differs from those of typical TDMA systems. In traditional TDMA each active user gets exclusive use of one (or several) slot in each frame. In EV-DO each slot can be assigned for transmission to any terminal among those active. The choice of the terminal whose traffic will be sent in a given slot is made by a scheduling algorithm. This scheduling algorithm is not defined in the IS-856 standard. However, a scheme often suggested for use in the EV-DO AP is the *Proportional Fair Scheduling* (PFS) which is described in [10]. Following the PFS principle, the user with the best instantaneous condition in terms of propagation and interference, as determined by the set of DRCs received by the access point, is chosen to receive information in that slot. This policy would maximize the overall bit rate in the sector/cell but in practice it is necessary to include some fairness consideration to avoid completely starving some terminals. Indeed the PFS does include this concern in its design. The fairness level is controlled by a parameter $\alpha \in (0\,,\,1)$ that determines for how long a terminal will be allowed to go without having a slot assigned to it. Hence α controls, to a certain extent, the degree of fairness in the system. A typical value for α is 0.001.

Bit Rate (Kb/s)	Packet length (slots)	FEC Rate	Modulation Scheme	Minimum SINR (dB)
38.4	16	1/4	QPSK	-11.5
76.8	8	1/4	QPSK	-9.2
102.6	6	1/4	QPSK	-6.5
153.6	4	1/4	QPSK	-3.5
204.8	3	1/4	QPSK	-3.5
307.2	2	1/4	QPSK	-0.6
614.4	1	1/4	QPSK	-0.5
921.6	1	3/8	QPSK	2.2
1228.8	1	1/2	QPSK	3.9
1843.2	1	1/2	8-PSK	8
2457.6	1	1/2	16-QAM	10.3

Table 1: Available transmission modes for EV-DO forward Link (Rev.0)

The EV-DO reverse link is based on the CDMA access method but with the flexibility of allowing different transmission bit rates. The actual bit rate achieved by a terminal depends on its propagation conditions and distance to the access point as well as on the cell/sector loading as determined by the AP. The congestion control mechanism implemented by the AP manages to keep the loading conditions within the cell below a given threshold. The bit rate adjustment due to changing loading conditions is done probabilistically [11], i.e., when the AT receives the appropriate RA bit command from the cell site it will change (or not) its rate in the requested direction with a given probability which can be a function of the rate the terminal is using at that moment.

There are 5 bit rates available in Revision 0 uplink, namely, 9.6, 19.2, 38.4, 76.8 and 153.6 Kbps. The modulation scheme is the same (BPSK) for all rates as well as the packet duration (53.3ms). The transmit power for each of the bit rates is different with higher rates obviously requiring a higher received power for the same level of packet error rate (PER). Consequently users located at the edge of the cell/sector will experience an average bit rate lower than those at close range. The specific rate achieved by a terminal, as stated before, will depend on the instantaneous system loading.

The reverse link allows for the adoption of an Early Termination mechanism [3, 7] where there is a gradual transmission of redundancy bits. However the significant benefits afforded by this mechanism are derived when the terminals are very mobile, which is not the case in the application considered in this paper. Therefore Early Termination was not implemented to obtain the results described in the sequel.

III. Simulation Model

The proposed simulation model was developed to evaluate the users´ delay and throughput as a function of the user population and of their distance to the AP. The model is composed of a web user population accessing the Internet through the EV-DO system. The simulation results were obtained using the Tangram-II [12] modeling environment. The adopted EV-DO model takes into account the most relevant physical and link layer characteristics of the CDMA2000-1xEVDO standard, such as the propagation model, the power control, the packet scheduling algorithm, and the inter-cell and intra-cell interferences. The implementation of these features is part of this work and produced an open-source network-level model. The simulation model is based on the following assumptions: (i) The users are stationary and hence no handoffs are requested or performed; (ii) each user will act according to its traffic model; (iii) there is only one AP with a single omnidirectional antenna (i.e. no sectorization), therefore there is no virtual soft-handoff; (iv) *Proportional Fair Schedule* is used at the AP for downlink access control; v) downlink interference is computed through straightforward geometrical calculations; vi) to obtain the results presented in Section IV the uplink total inter-cell interference is made equal to 40 % of the value of the intra-cell interference; (v) *Early Termination* mechanism was not included in the model because all users are supposed stationary. In the following subsections the main features of the proposed model are described.

A. Physical Layer Model

Three mechanisms are represented in this layer: the propagation loss, the reverse link power control and the congestion control.

$L_{total}[dB]$, which is the total loss between the user and the access point, is given by:

$$L_{total}[dB] = L_{prop}[dB] + L_{pen}[dB] + D[dB], \quad (1)$$

where L_{prop} is the propagation loss, L_{pen} is the building penetration loss, and D is the flat fading.

The propagation loss model is based on [13, 14]. In this work we consider only the dense urban scenario. The values for the model parameters are the following: the carrier frequency is equal to $450MHz$, the terminal height is $1.5m$, the height of the AP antenna is $40m$, and the penetration loss is equal to $10dB$. The flat fading is modeled using a log-normal random variable with mean $0dB$ and standard deviation equal to $8dB$.

Similarly to other CDMA technologies, the reverse link power control is implemented in three steps. The first step is the inner-loop power control. The AT computes the propagation loss from the received power of the pilot channel and the AP transmitted power, in order to estimate the initial transmission power. The closed-loop power control is the second step. It consists of a fine tuning of the transmission power as the channel conditions change. The terminal estimates the minimal transmission power needed to have a given signal quality and maintain the PER bellow a desired threshold. Furthermore, this control minimizes the system interference. The model used for the closed-loop power control is based on [15], which recommends a 1% PER. We do not model the third step, i.e. the outer-loop power control, because we consider static users and only one cell.

We call P_{pilot} the value obtained from the reverse link power control described above. If the condition $P_{pilot} > P_{MAX} - DataGain[CurrentRate]$ is satisfied, the terminal decides that it has sufficient power to transmit the next message. (P_{MAX} is the maximum available power, and $DataGain[CurrentRate]$ is the data gain given the transmission rate.) Note that the terminal will try to satisfy this condition with the highest possible rate (which is the $CurrentRate$).

Finally, the third mechanism we model is the congestion control described in Section II which is based on [2, 15].

B. Link Layer Model

The main feature of the link layer is the forward link packet scheduling algorithm known as *Proportional Fair Scheduling* (PFS). The main objective of PFS is to give some priority to users in favorable conditions while keeping other users being served as a regular basis. To achieve this, cross-layer concepts are used, that is, from the link layer, PFS reads values (i.e. SINR) which in 1G, 2G and 2.5G standards are available only to the physical layer.

PFS is divided into two steps. In the first the user with the highest $\frac{DRC_i(t)}{R_i(t)}$ is selected, where $DRC_i(t)$ is the rate requested by user i and $R_i(t)$ is the mean rate this user has been receiving data:

$$j = \underset{i}{arg\,max} \left[\frac{DRC_i(t)}{R_i(t)}\right] \quad (2)$$

On the second step, each user mean data rate is updated as follows:

$$R_i(t+1) = (1-\alpha) * R_i(t) + \alpha * CRT_i(t) \quad (3)$$

$$\begin{cases} CRT_i(t) = DRC_i(t) & \text{if } i = j \\ CRT_i(t) = 0 & \text{if } i \neq j \end{cases} \quad (4)$$

where CRT_i is the current data rate of user i at time t. Parameter α regulates the throughput-fairness trade-off.

Each terminal obtains the maximum allowed bit rate to transmit (which is the value used for the $DRC_i(t)$) according to the signal to interference noise ratio (SINR), and send the $DRC_i(t)$ to the AP. Table 1 shows in the fifth column the minimum required SINR for a given bit rate (first column).

C. User Model

As already mentioned in the Introduction, we assume that all services are web based. The behavior of a web application can be described as follows. When a user clicks in a HTTP link, several web requests are generated. The first corresponds to the main object request. When the main object arrives at the terminal, it is parsed and a new web request is generated for each in-line object reference found. After the user has received all objects of an web page, he/she spends some time (reading time) before clicking in another HTTP link. This behavior is modeled by an ON-OFF source. We assume that web requests generated within an interval of 60 seconds belong to the same ON period [16]. Then, each interval larger than 60 seconds with no web requests is considered an OFF period. Moreover, we use the probability distributions obtained in [16], that is, a Weibull for the ON periods and for the interval between two consecutive requests, and a Pareto for the OFF period.

Another important characteristic of the HTTP model is the distributions of the main and in-line object sizes. Note that these distributions tend to be quite different, since the main object is typically a HTML file, and the in-line objects may be components of a multimedia content, such as an audio or video file. The main and in-line object sizes are modeled by a Log-normal distribution with different parameters for the 2 classes of objects as suggested in [17].

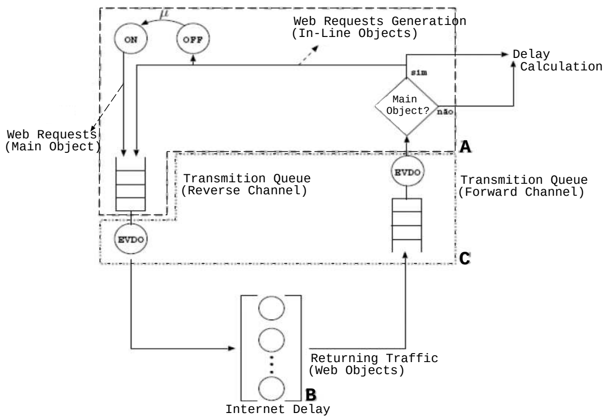

Figure 1: Model Overview

Figure 1 shows a high level graphical description of the simulation model. The figure is divided into different sections. Section *A* is the web user model, section *B* represents the Internet delay, and section *C* models the EV-DO protocol. When the user is in the ON state, he/she generates a web request. This web request waits in the transmission queue of the terminal until it is transmitted to the Internet object (this object emulates the Internet Round Trip Time (RTT) delay). After one RTT, the requested web object arrives at the AP queue to be sent to the user.

IV. Numerical Results and Discussion

The following scenario was considered in the simulations: (i) the other-cell interference perceived by the access point is equal to 40% of the intra-cell interference; (ii) the population varies from 10 to 80 users; (iii) the cell radius is equal to 1Km; (iv) the users are randomly positioned in the cell; (v) the congestion control parameters p and q are based on [2]; (vi) the AT and AP maximum power transmission are 23dBm and 55.8dBm, respectively; (vii) the thermal noise is -165dBm; (viii) the cable loss is 3dB; (ix) the AP gain is 17dB; (x) the sensibility for each user is -119dBm; (xi) the parameter α of the PFS is equal to 0.001.

In the first set of experiments, the study focus on the user fairness with respect to the throughput and delay. Note that, in experiments, the cell radius is divided into ten equally spaced sub-sectors which we call zones, being zone 1 the closest to the AP and zone 10 the farthest. The population is then divided into 10 subsets each associated with one of the zones.

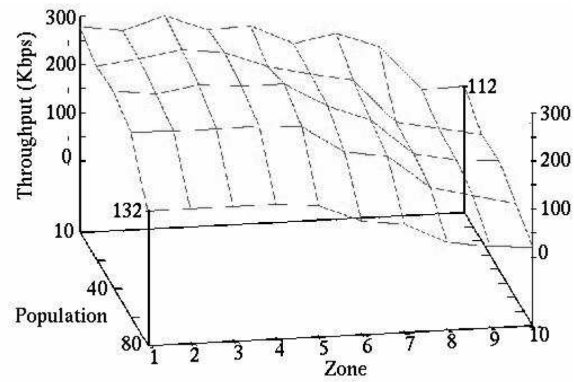

Figure 2: User throughput vs. population and zone

Figures 2 and 3 show the throughput and delay variation as a function of the user position in the cell. We can observe that the user's throughput in zone 10 is 20% of that for an user in zone 1, when the total population is equal to 80. The user delay has the same behavior. It increases from 3s (zone 1) to 50s (zone 10) indicating a significant fairness decrease as the distance from the AP increases.

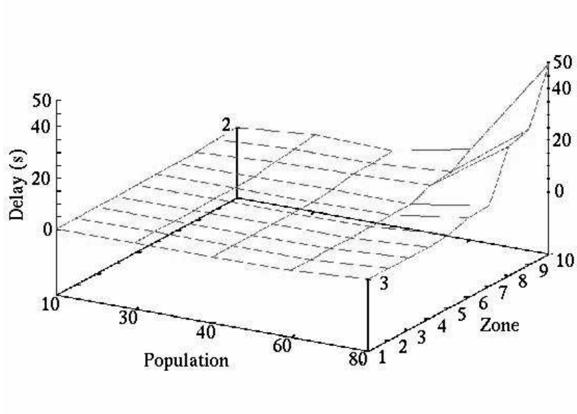

Figure 3: User delay vs. population and zone

As mentioned in Section II, the parameter α in Equation 3 controls the degree of fairness in the system and a typical value is $\alpha = 0.001$. This parameter was varied to analyze its influence on the user fairness. Figure 4 shows the user throughput for a population of 30 users and α equal to 0.001 and 1. From this figure, it can be seen that the throughput of the low rate users remains low while the high bit rate have their throughput substantially decreased. Therefore the results of increasing α is not encouraging, since the fraction of time slots used by terminals in poor conditions also increases and these terminals can only receive data at low rates. This is the reason why the base station total bit rate will greatly decrease.

In this work it is proposed to reduce the intrinsic unfairness of the scheduling algorithm by allowing users that are located towards the cell border to use directive antennas. These antennas can be inexpensive, as for example a Yagi. As will be

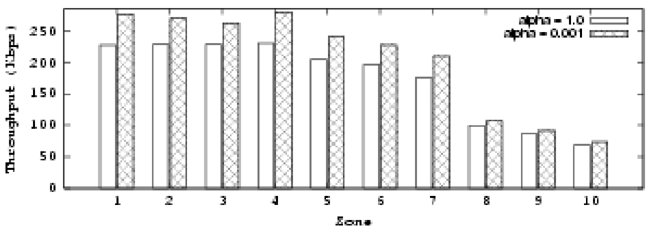

Figure 4: User throughput vs. alpha

shown shortly, it is sufficient that the gain provided by the antenna be as modest as 8 dB (including the interference reduction effect).

In order to demonstrate the effectiveness of this solution in improving fairness, throughput and delay results are presented in Figures 5 - 7 for the four different situations: (i) *no-user* : directional antennas are not employed; (ii) *1-user* - a unique user in zone 10 uses a directional antenna; (iii) *1-zone* - all users in zone 10 use directional antennae; and (iv) *2-zones* - all AT in zones 9 and 10 use directional antenna.

We can notice that, in the *1-user* and *1-zone* cases , the throughput increases for all zones when compared to the *no-user* case. This happens because the SINR of the users in zone 10 is significantly improved when the directional antenna is used. Therefore, these users will be able to transmit a packet using a FEC scheme with less redundancy (see Table 1), increasing the number of free slots in the system.

The results for the *2-zones* case shows that the throughput of the users in zone 9 is significantly improved. The value of the user's throughput in the zones 9 and 10 (with a directional antenna) is 75% of that for an user in the zone 1 (this value was 20% for the case *no-user*).

In Figure 6 we plot the delay for the four cases. We note that the difference among the delays in each zone significantly decreases. For example, the delay of a user in zone 10 decreases from 10s (case *no-user*) to 1s. This is due to the directional antenna that is used for the last two zones.

Finally, we perform an experiment for the *2-zones* case considering a population of 80 users. The main goal of this experiment is to analyze the proposed solution when the load of the system increases. Figure 7 shows the achieved throughput for a population of 60 and 80 users. Similar fairness improvement is observed.

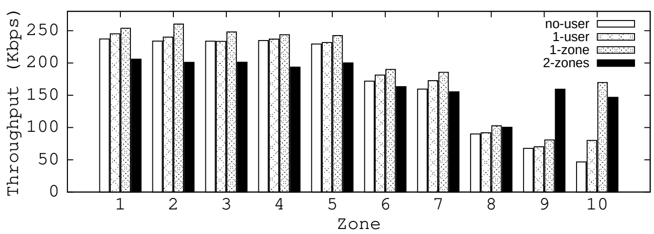

Figure 5: User throughput in each zone when directional antennas are employed.

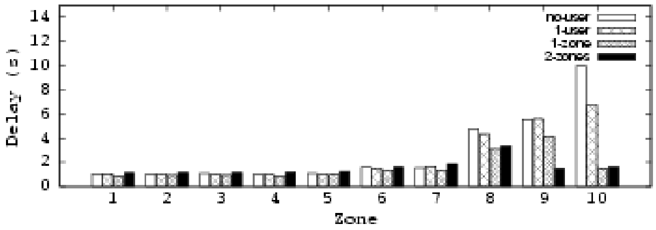

Figure 6: User delay in each zone when directional antennas are employed.

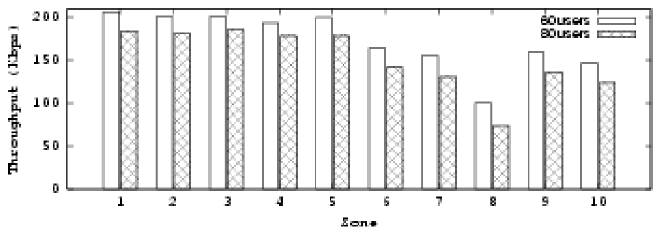

Figure 7: User throughput in each zone with directional antennas for two populations.

V. Conclusions

The use of the return channel of a Digital TV system to allow access to modern life Internet services in developing nations appears to be promising. Several technologies can be considered to implement this interactive channel. Here a wireless access technology was considered, the CDMA20001x EV-DO standard. Although the throughput and delay provided by the EV-DO for web based services was generally adequate, its fairness profile is not ideal for the application being considered. This shortcoming is due to intrinsic characteristics of the system. It is difficult to overcome this deficiency just by adjusting the scheduling algorithm without unduly reducing the overall cell site throughput, which is also undesirable. However, it was shown that the fairness behavior can be efficiently improved if a small fraction of the subscribers employ inexpensive directive antennas.

Acknowledgement

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