Abstract—The cdma2000, a candidate submission to ITU-R for IMT-2000 radio interface, has many MAC states such as Control Hold State (CHS), Active State (AS), Suspended State (SS), and Dormant State (DS) for packet data services. A mobile station consumes the power differently as these MAC states and many timer objects called normal hold timer, slot-hold timer, virtual traffic timer, and slotted suspended timer, determine the MAC transition time of a packet data. In this paper, we show the relationship between the achieved power saving gain and the mean packet delay degradation.

I. INTRODUCTION

The limited energy stored in the battery operated mobile equipment leads to the development of algorithms that save energy as much as possible. Existing multiple access control (MAC) layer protocols for wireless communications, such as cellular digital packet data (CDPD), global system of mobile communications (GSM), and the cdma2000 system, allow the mobile terminals to operate in different power saving mode [1],[2].

In particular, the cdma2000 that uses code division multiple access (CDMA) technology to meet the needs for the next generation of wireless communication systems, provides various power saving modes using enhanced MAC protocol. Due to limited air-interface capacity, limited number of base station (BS) equipment, and constraint on mobile station (MS) power consumption, dedicated channels for packet service users are allocated on demand and released shortly after the end of the activity period. However, releasing the dedicated channels and re-establishing them introduce latency and signaling overhead due to the re-negotiation process that has to be taken place between the BS and the MS prior to user's data exchange. The cdma2000 MAC avoids this latency and overhead by permitting the MS and the BS to save a set of state of information after the initialization phase is completed [3]. The cdma2000 MAC utilizes timer entities that provide trigger for certain MAC state transitions (e.g., the normal hold timer $T_{normal\_hold}$ that triggers the transition from the Normal Substate to the Slotted Substate of the CHS). As these timer values give a tradeoff between the power saving gain and the mean packet delay degradation, it is important to set the proper timer values.

In this paper, we show the relationship between the achieved power saving gain and the mean packet delay degradation, and provide the guidelines to determine the timer object values in the cdma2000 system. We conduct simulation experiments to study the cdma2000 sleep mode performance. Moreover, we investigate the system with reservation channels for voice terminals (VT’s) and derive the system performance such as channel utilization and packet loss probability.

This paper is organized as follows: In Section II, we provide overview of the MAC state and the sleep mode operation in the cdma2000 system. In Section III, some modeling details and assumptions used in our simulation are presented. In Section IV, we evaluate the performance of sleep mode operation according to various timer values in view of the expected waiting time and the power consumption. We also consider the performances of two systems, namely, the system with reservation channels for VTs and the system without reservation channels. Finally, we express our conclusions in Section V.

II. THE CDMA2000 MAC STATE TRANSITION AND THE SLEEP MODE OPERATION

For the physical layer independent convergence function (PLICF) data service, the cdma2000 has many MAC states such as CHS (Normal Substate and Slotted Substate), AS, SS (Virtual Traffic Substate and Slotted Substate), and Null State as shown in Fig. 1 [4].
the CHS. In this state, dedicated traffic channel resources are released, however, the dmcch.control channel remains in operation to provide a very fast reassignment of traffic channel resources when needed. Therefore, the cdma2000 MAC provides the ability to quickly return to the AS while also providing the low power consumption of a slotted mode of operation. In the Normal Substate of the CHS, the MS is continuously processing the forward link dedicated MAC channel and therefore the latency re-enabling the reverse dedicated MAC channel is minimal.

The transition to the Slotted Substate of the CHS occurs after a period of inactivity in the Normal Substate of the CHS. In the Slotted Substate, the pilot and power control channels are periodically enabled and disabled to provide a limited degree of power control. This power saving option is only available to packet voice service options that are delay sensitive.

For packet data service options that are delay insensitive, the packet data service enters into not the Slotted Substate of the CHS but the SS after the Normal Substate of the CHS [5]. The Slotted Substate of the CHS does not provide the most efficient use of radio resources and the highest level of reduction of MS power consumption. In this SS, the dedicated channels are released but the mobile can acquire a dedicated traffic/control channel relatively quickly since the state information is maintained by both the BS and the MS.

While in the SS, the MS monitors the forward common MAC channel (f-cmch.control). When in the Virtual Traffic Substate of the SS, the MS sends location update messages to the BS in order to maintain a Virtual Active Set and to make the BS aware of its current location.

In the SS, there is a cost associated with maintaining the Virtual Active Set due to the exchange of location update messages, and in most cases this cost prohibits the mobile station from operating in this state for a long period of time. For this reason, the packet service should transit to the Slotted Substate of the SS after a period of inactivity. In the Slotted Substate of the SS, the Virtual Active Set is no longer maintained and the f-cmch.control is monitored in the slotted mode to reduce power consumption. When there is no user data to exchange for a relatively long period of time, the data service option is disconnected, and the packet or circuit data instance is terminated. The termination of the data Service Option causes the dedicated/common router (DCR) PLICF entity to transit to the DS, however, this state is not reflected in the data service PLICF which is applicable only when a Service Option is connected.

III. SYSTEM MODELING

A. Source Models

We conduct simulation experiments to study the effect of timer objects for sleep mode operation in the cdma2000 system. In this simulation, we consider only the reverse link and each MS is capable of generating two different types of traffic: voice and data. The number of new MSs incoming into system is generated with rate of $\alpha$ and each MS requests voice service with probability $p_v$ or data service with probability $(1 - p_v)$. The following paragraphs describe the simulation models for data and voice, respectively.

1) Data Model: Recently, the number of web users is exponentially increasing and we expect that most of data traffic will be web traffic. We, therefore, use web traffic model as data model. As shown in Fig. 2, one session in web traffic model is composed of packet calls and one call consists of packets. The packet calls per session are geometrically distributed with mean 5 sec and inter-arrival time between packet calls is exponentially distributed with mean 120 sec. The number of packets per packet call is Pareto distributed with parameters $\beta = 1.1$ and $k = 2.27$ (mean number = 25) [5]. Here, Pareto distribution with parameters $\beta$ and $k$ is given as

$$F(z) = \begin{cases} 1 - \left(\frac{z}{k}\right)^\beta, & \text{if } z > k > 0 \\ 0, & \text{if } z \leq k. \end{cases}$$

Inter-arrival time between packet arrivals is exponentially distributed with mean 0.01 sec and the packet size is fixed to 90 bytes. Moreover, a data packet transmitted after 800 ms is assumed to be dropped.

2) Voice Model: Generally, a packet voice is modeled as a two-state Markov process representing a source with a slow speed activity detector (SAD). The length of talk spurs and silence has exponential distribution with mean 1.00 sec and 1.35 sec, respectively [6]. In addition, a voice packet is assumed to be dropped if it is impossible to be transmitted within 36 ms [7]. A basic data rate per a channel is assumed to be 9.6 kbps. An MS transmits either voice packets with 9.6 kbps rate or data packets with one rate among 9.6 kbps, 19.2 kbps, 38.4 kbps, 76.8 kbps, and 153.6 kbps.

B. Sleep Mode Modeling and Scheduling Algorithm

Each MS has buffers for packets to transmit and the BS has a message queue to store the request packets from MSSs. The message queue operates as a FIFO. If an MS generates the packets, the MS enters into the AS through the CHS. If the BS is able to accept the MS's request, the MS can transmit its packets without delay after MAC state transition to the AS. However, if the air interface capacity to grant the requested transmission rate is insufficient, the packet transmission is delayed until the BS accepts the MS's request. The cases that the BS allows the MS's transmission without delay are as follows: 1) First case is that the air interface capacity is sufficient to grant the requested transmission rate and there are no request packets in the message queue of the BS. 2) Although there are reserved packets in the message queue, an MS transmits its packets promptly when
code channel resources are free enough to satisfy the MS's request and the MS's packet transmission doesn't affect the transmission of the reserved packets. For upper two cases, the MS transmits its burst packets after MAC state transition to the AS from its current state. For example, if we let the transition time of voice packet and data packet, respectively, the signaling of voice packet and data packet, respectively, are summarized in Table I. As 5 ms and 20 ms frame are used for signaling of voice packet and data packet, respectively, MAC state transition time of voice packet is faster than that of data packet.

After the packet transmission, the transition to the CHS occurs. The transition to the Slotted Substate of the CHS takes place after a period of inactivity $T^v_{normal,hold}$ in the Normal Substate of the CHS when the type of the MS's traffic is voice. For web traffic, however, the packet service enters into not the Slotted Substate of the CHS but the SS after a period of inactivity $T^v_{virtual}$. If the MS using web doesn't generate any packets for $T^v_{virtual}$ interval, transition to the Slotted Substate of the SS from the Virtual Traffic Substate of the SS takes place. When there is no user data to exchange for a relatively long period of time $T^v_{slotted-suspend}$, the data service option is disconnected and the packet service returns to the NULL State.

Moreover, we investigate the system with channels reserved for VTs. As the system reserves the channels for VTs, the system prohibits the data terminals (DT's) from occupying all channels and is able to quickly allocate the traffic channels to VTs.

## IV. Simulation Results

The performances of the system with reservation channels and the system without reservation channels are compared. Also, the relationship between the achieved power saving gain and the expected waiting time is considered with various timer object values. The system parameters used in this simulation are summarized in Table II. From the simulation experiments, we study how the rate of new MSs incoming into system α, the number of reservation channels for VTs $C_R$, and the timer object such as $T^v_{normal,hold}$ affect the output measures such as the channel utilization $U$, the expected packet waiting time $E_w$ and the packet loss probability $P_l$.

### TABLE I

<table>
<thead>
<tr>
<th>Traffic Type</th>
<th>MAC State Transition</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice, Data</td>
<td>NULL State $\rightarrow$ AS</td>
<td>$TR_{null}$</td>
<td>0.60 sec</td>
</tr>
<tr>
<td>Voice</td>
<td>Normal Substate of CHS $\rightarrow$ AS</td>
<td>$TR_{normal}$</td>
<td>0.01 sec</td>
</tr>
<tr>
<td></td>
<td>Slotted Substate of CHS $\rightarrow$ AS</td>
<td>$TR_{slotted-keep}$</td>
<td>0.02 sec</td>
</tr>
<tr>
<td>Data</td>
<td>Normal Substate of CHS $\rightarrow$ AS</td>
<td>$TR^d_{normal}$</td>
<td>0.04 sec</td>
</tr>
<tr>
<td></td>
<td>Virtual Traffic Substate of SS $\rightarrow$ AS</td>
<td>$TR^d_{virtual}$</td>
<td>0.12 sec</td>
</tr>
<tr>
<td></td>
<td>Slotted Substate of SS $\rightarrow$ AS</td>
<td>$TR^d_{slotted-suspend}$</td>
<td>0.20 sec</td>
</tr>
<tr>
<td></td>
<td>DS $\rightarrow$ AS</td>
<td>$TR^d_{normal}$</td>
<td>0.30 sec</td>
</tr>
</tbody>
</table>

### TABLE II

<table>
<thead>
<tr>
<th>Items</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of channel</td>
<td>$C_{tot}$</td>
<td>30</td>
</tr>
<tr>
<td>Max. tolerable setup delay</td>
<td>$D_{setup}$</td>
<td>1.5 s</td>
</tr>
<tr>
<td>Max. tolerable delay of voice packet</td>
<td>$D^v_{max}$</td>
<td>0.636 s</td>
</tr>
<tr>
<td>Max. tolerable delay of data packet</td>
<td>$D^d_{max}$</td>
<td>0.8 s</td>
</tr>
<tr>
<td>Probability belongs to VT</td>
<td>$P_v$</td>
<td>0.3</td>
</tr>
</tbody>
</table>

### A. Effects of the rate of new MSs incoming into system $\alpha$ and the number of reservation channels for voice terminals $C_R$

Fig. 3 shows the sleep mode performance in the cdma2000 system with various number of reservation channels for VTs. Here, for voice packet, the normal hold timer $T^v_{normal,hold}$ is assumed to be 1 sec and for data packet, the normal hold timer $T^d_{normal,hold}$, the virtual traffic timer $T^d_{virtual}$, and the suspended slotted timer $T^d_{slotted-suspend}$, is assumed to be 1 sec, 30 sec, and 50 sec, respectively. Fig. 3(a) indicates that the channel utilization increases as α increases. Here, the channel utilization $U$ is defined as follows:

$$U = \frac{\sum_{i=1}^{M} T^i_{p} \cdot C^i_{p}}{T_e \cdot C_{tot}}$$ (2)

where $T^i_{p}$ is the i-th packet transmission time during the simulation time $T_e$ when the i-th packet needs the $C^i_{p}$ channels, M is the total number of packets successfully transmitted during $T_e$, and the total number of channel is $C_{tot}$.

Fig. 3(b) shows the relationship between the voice packet loss probability and $C_R$. For heavy traffic (large value of α), it is more likely that an MS waits for the BS's permission to transmit packets. Therefore, the voice packet loss probability exponentially increases as $C_R$ increases. For $C_R < 2.5$, the voice packet loss probability shows zero regardless of $C_R$. When $C_R$ is larger, the request of VT is easily accepted by BS. Thus, the expected waiting time of voice packet is shorter and the voice packet loss probability decreases as $C_R$ increases.

Fig. 3(c) indicates that the data packet loss probability exponentially increases as $C_R$ increases. Increasing of $C_R$ significantly reduces the number of channels for data packet. As $C_R$ increases, the MS with data packet waits more longer to receive
B. Effect

The BS's permission and thus the data packet loss probability increases. There is a tradeoff between the voice packet loss probability and the data packet loss probability as shown in Fig. 3(b) and (c). As the number of reservation channels increases, the voice packet loss probability decreases while the data packet loss probability increases. For $\alpha < 4$, if we choose $C_R$ as 5, the degradation of data packet loss probability can be neglected. Therefore, the proper number of channels for VT should be chosen in the consideration of traffic load and priority service for VTS.

B. Effect of the Timer Object

Fig. 4 and Fig. 5 show the expected waiting time of voice packet and data packet in the case of using various timer values, respectively in the system with $C_R = 5$. To calculate these expected waiting times numerically, we define $P_{T(1)}$ as the state probability that the MAC state of packet data service is in $\{1\}$ state. For example, $F_{\text{normal\_hold}}$ stands for the probability that the voice packet is in the Normal Substate of the CHS. As the silent time of voice is exponentially distributed with mean 1.35 sec, $F_{\text{normal\_hold}}$ is given by

$$F_{\text{normal\_hold}} = F_X(T_{\text{normal\_hold}})$$

where $F_X(x)$ is the exponential distribution with mean 1.35 sec, i.e., $1 - e^{(1/1.35)x}$ and $T_{\text{normal\_hold}}$ is the normal hold timer of voice packet.

For data packet, the probability that a data packet is in the Normal Substate of the CHS $P_{\text{normal\_hold}}$ or in the Virtual Traffic Substate of the SS $P_{\text{virtual}}$ or in the Slotted Substate of the SS $P_{\text{slotted\_suspend}}$ or in the DS $P_{\text{dormant}}$ is calculated as follows:

$$P_{\text{normal\_hold}} = F_Y(T_{\text{normal\_hold}})$$
$$P_{\text{virtual}} = F_Y(T_{\text{normal\_hold}} + T_{\text{virtual}}) - P_{\text{normal\_hold}}$$
$$P_{\text{slotted\_suspend}} = F_Y(T_{\text{normal\_hold}} + T_{\text{virtual}} + T_{\text{slotted\_suspend}})$$
$$- (P_{\text{normal\_hold}} + P_{\text{virtual}})$$
$$P_{\text{dormant}} = 1 - (P_{\text{normal\_hold}} + P_{\text{virtual}} + P_{\text{slotted\_suspend}} + P_{\text{dormant}})$$

where $F_Y(y)$ is the exponential distribution with mean 120 sec which is the inter-arrival time between packet calls, i.e., $1 - e^{(1/120)y}$ and $T_{\{1\}}$ is the timer object of MAC state $\{1\}$.

Therefore, for $C_{\text{tot}} \rightarrow \infty$, the expected waiting time of voice packet $E_{\text{w}}$ and the expected waiting time of data packet $E_{\text{d}}$ are obtained by

$$E_{\text{w}} = P_{\text{normal\_hold}} \cdot T_{\text{normal\_hold}} + (1 - P_{\text{normal\_hold}}) \cdot T_{\text{slotted\_hold}}$$
$$E_{\text{d}} = P_{\text{normal\_hold}} \cdot T_{\text{normal\_hold}} + P_{\text{virtual}} \cdot T_{\text{virtual}}$$
$$+ P_{\text{slotted\_suspend}} \cdot T_{\text{slotted\_suspend}}$$
$$+ P_{\text{dormant}} \cdot T_{\text{dormant}}$$

where $T_{\{1\}}$ is the MAC state transition time to the AS from $\{\}$ state and the state probabilities $P_{\{1\}}$ and $P_{\{\}}$ are calculated using (3) through (7).

For example, when $T_{\text{normal\_hold}}$, $T_{\text{normal\_hold}}$, $T_{\text{virtual}}$, and $T_{\text{slotted\_suspend}}$ are [1 sec, 1 sec, 30 sec, 50 sec], respectively, the voice packet and the data packet is expected to wait for 0.01691 sec and 0.23204 sec, respectively by (8) and (9). In Fig. 4 and Fig. 5, we observe that $E_{\text{w}}$ and $E_{\text{d}}$ are approximated to 0.01689 sec and 0.23223 sec, respectively when $\alpha \rightarrow 0$.

Fig. 4 shows that the expected waiting time of voice packet is more shorter as the normal hold timer of voice packet $T_{\text{normal\_hold}}$ increases. For small $T_{\text{normal\_hold}}$, the voice packet is likely to stay not in the Normal Substate of the CHS but in the Slotted Substate of the CHS, that is, the voice packet frequently enters into sleep mode. Therefore, $E_{\text{w}}$ becomes longer while the power saving gain is more achieved. Fig. 5 shows the expected waiting time of data packet with various virtual timer values and slotted suspended timer values. As $T_{\text{slotted\_suspend}}$ increases, the number of DT's visiting the DS is small. Thus, $E_{\text{d}}$ decreases while the power saving gain is less obtained. Due to the same reasons mentioned above, an MS increases the power consumption and it takes much shorter time to transmit data packet as $T_{\text{virtual}}$ increases.
Fig. 4. The expected waiting time of voice packet vs. incoming rate according to various $T_{\text{normal-hold}}$ values.

Fig. 5. The expected waiting time of data packet vs. incoming rate according to various timer object values.

V. CONCLUSIONS

In this paper, we show the relationship between the achieved power saving gain and the expected packet waiting time. As the timer values such as normal hold timer, slotted hold timer, virtual timer and slotted suspended timer increase, the MS has the more battery power consumption while the expected packet waiting time is shorter. Moreover, to provide efficiently delay sensitive service in the system with voice and data traffic, we present the system with reservation channel for VTs and analyze the performance in view of channel utilization and packet loss probability. The results show that the proposed system is more efficient in view of the voice packet loss probability while the data packets are a little more lost. This paper provides guidelines to determine the timer values used in sleep mode operation and the number of reservation channels for VTs in the cdma2000 system.

REFERENCES


