Trading CDPD Availability and Voice Blocking Probability in Cellular Networks

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Abstract

Cellular digital packet data offers mobile users access to a low-cost, ubiquitous, wireless data network. CDPD can be overlaid on existing AMPS analog cellular systems and share their infrastructure equipment on a noninterfering basis. Since CDPD utilizes the idle radio resources of AMPS, it is important to ensure that the normal AMPS activities are not affected by CDPD. Several timers and system parameters are defined in CDPD for this purpose. This article investigates how these timers and parameters affect the performance of AMPS/CDPD systems. Our study provides guidelines for the selection of input parameters to aid CDPD network planning. Specifically, we study the trade-off between CDPD availability and voice blocking probability. In this article, CDPD availability is defined as the proportion of time that the RF channels can be used to transmit CDPD data. We observe that selecting too large values for CDPD dwell time and the maximum number of CDPD channel streams will degrade the voice blocking probability without improving CDPD availability. On the other hand, selecting a too large value for the CDPD layoff time will degrade CDPD availability without improving voice blocking probability.

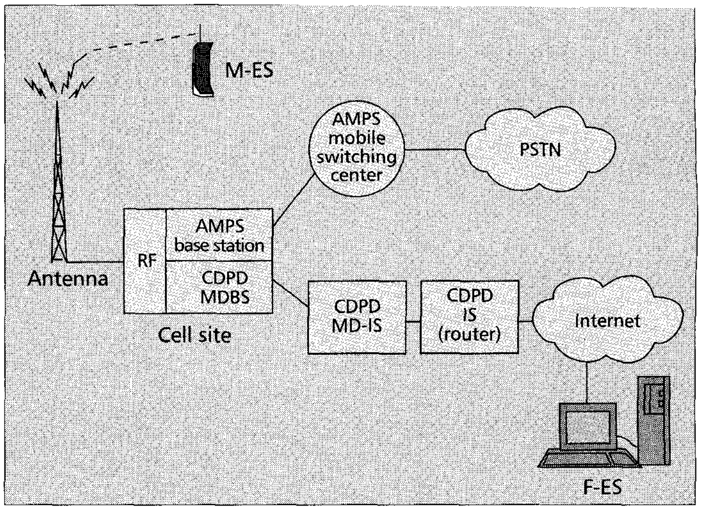
Cellular digital packet data (CDPD) [1–3] networks provide wireless data communications services to mobile users by sharing the radio equipment and unused RF channels with Advanced Mobile Phone System (AMPS) networks [6]. Basically, CDPD transmits packet data over idle AMPS channels, and autonomously switches to another channel when the current channel is about to be assigned for voice usage. CDPD may serve as the wireless extension to other data networks (e.g., Internet) or public switched telephone networks. It supports *connectionless network services* where every packet is routed individually based on the destination address of the packet and knowledge of the current network topology.

Figure 1 illustrates the CDPD network architecture. A CDPD user communicates with the CDPD network using the mobile end system (M-ES). The physical location of M-ESs may change from time to time, but continuous network access is maintained. The mobile data base station (MDBS) is responsible for detailed control of the radio interface, such as radio channel allocation, interoperation with cellular voice channel usage, and radio media access control. In order to share radio resources with the cellular system, MDBSs are expected to be collocated with voice equipment (i.e., AMPS base stations, BSs) that provide cellular telephone service. Furthermore, MDBSs may share cellular equipment (such as antennas for transmitters and receivers) to communicate with the M-ESs. The mobile data intermediate system (MD-IS) connects to several MDBSs via wired links (e.g., multiple DS0 trunks) or microwaves. The MD-ISs support user mobility by exchanging user location information (using the mobile network location protocol) with each other and routing the incoming data frames to destinations based on the user location information. Two distinct routing functions are performed by the MD-IS: the mobile home function and mobile serving function, which are similar to the functionalities of the home and visitor location registers [5] in the cellular network. The intermediate system (IS) enables the CDPD network to communicate with other data networks (e.g., Internet). ISs support the network-layer functionality, and route Connectionless Network Protocol datagrams between MD-ISs and Internet Protocol datagrams between MD-ISs and fixed end systems (F-ESs).

An M-ES communicates with an MDBS through a 19.2 kb/s raw duplex wireless link (referred to as a *CDPD channel stream*). A CDPD channel stream can be shared by several M-ESs. The link from the MDBS to the M-ESs is called the *forward link*, and the link from the M-ESs to the MDBS is called the *reverse link*. When a frame arrives at an MD-IS, the frame is queued in a buffer and sent to the destination MDBS. The MDBS then broadcasts this frame on the forward link. All M-ESs in the MDBS radio coverage area listen to the broadcast frame. Only the M-ESs with valid identifiers can decode the data. It is clear that the transmission on the forward link is broadcast contentionless delivery.

On the other hand, since many M-ESs may share a CDPD channel stream simultaneously, the access to the CDPD reverse link follows the *slotted, nonpersistent, digital sense multiple access with collision detection* (DSMA/CD) protocol. This protocol is similar to the CSMA/CD used in IEEE 802.3 LANs, except that the M-ESs sense the reverse channel idle/busy control flags on the forward link at every microslot. A microslot is equivalent to the duration of transmitting 60 bits, which is 3.125 ms.

Since CDPD utilizes the idle radio resources of AMPS (to be elaborated on in the next section), it is important to ensure that normal AMPS activities are not affected by CDPD. Many studies [6–11] have analyzed the interference between AMPS and CDPD systems. Specifically, these studies investigated how CDPD affects the voice call blocking probability and carrier-to-interference (C/I) ratio of a cell's coverage area to the cellular voice system. These studies did not consider timers and system parameters defined in the CDPD specifications [1], which limit the RF channel occupation by each CDPD channel stream. This article investigates how these timers and parameters affect the performance of AMPS/CDPD systems. Specifically, we study the trade-off between CDPD availability and voice blocking probability. In this article, CDPD availability [7] is defined as the proportion of time that the RF channels can be used to transmit CDPD data. (Note that this definition is different from how one usually thinks of availability, as a measure of whether or not the system is broken.) Our study provides guidelines for the selection of input parameters to aid CDPD network planning.



■ **Figure 1**. *The CDPD network architecture.*

CDPD Channel Assignment and Hopping

An MDBS is allocated a frequency pool that contains a subset of frequencies of the associated AMPS BS at the cell site (Fig. 1). The MDBS utilizes the radio resource management entity (RRME) to select and assign an RF channel for each channel stream configured for the MDBS. To determine the frequencies in the CDPD frequency pool, a channel status protocol (CSP) is implemented [2]. Through the CSP message exchange, the CDPD system communicates with the AMPS system to update the shared channel status, which prevents both systems from choosing the same frequency at the same time. Alternatively, the MDBS may employ a sniffer that periodically scans the shared channels to identify the availability status of these RF channels. In this approach, CDPD determines the channels in the CDPD frequency pool without the involvement of AMPS (in other words, the AMPS system does not notice the existence of the CDPD system who shares the AMPS resources).

When a voice call arrives at an AMPS BS, the AMPS system will select an idle RF channel to serve this incoming voice request. If this RF channel is occupied by a CDPD channel stream, the MDBS must relinquish this RF channel within 40 ms. This action is called *forced* or *emergency hop*. The MDBS then tries to re-establish the forced-hopped channel stream on another idle RF channel. If no such channel is available, the forced-hopped channel stream enters a *blackout* period [7] until an idle RF channel is re-assigned to this channel stream. In the CSP implementation, the hop procedure is exercised at the CDPD system when the AMPS system sends a channel busy message to the CDPD system to indicate that the specific RF channel is about to serve voice traffic [2].

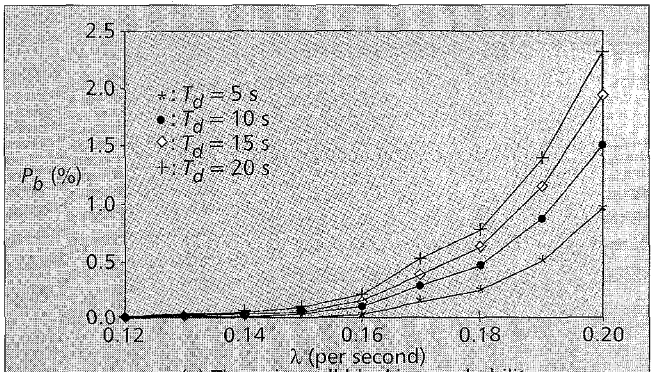
The MDBS also periodically performs channel switching (referred to as *timed* or *planned hop*) to avoid *channel sealing* or *channel stealing*. When the AMPS system notices interference on a channel (due to the CDPD activities on this channel), the channel is sealed and becomes unavailable to a voice user. In this case, CDPD steals the channel from the AMPS system. To avoid sealing of an RF channel, the MDBS uses timed hops to switch a CDPD channel stream periodically. In the timed hop mechanism, a *dwell timer* is defined for each shared RF channel to specify the period for which the channel stream can use the RF channel before a timed hop is performed. On the expiration of this timer, the MDBS RRME invokes the planned hop procedure to switch the CDPD channel stream to another RF channel. Specifically, the MDBS sends a switch channel message to the M-ESs of the CDPD channel stream through the old RF channel. Then it ceases transmission on the channel stream and tunes to the new frequency within 40 ms. The shared RF channels are also configured with a *layoff timer*. After a planned hop, the released RF channel cannot be used for CDPD before its layoff timer expires. This timer prevents a blackout CDPD channel stream from selecting an RF channel just released from CDPD (i.e., whose dwell timer just expires).

Consider a CDPD MDBS that shares RF channels with an AMPS BS. Suppose that there are N RF channels in an AMPS BS, and the maximum number of RF channels which can be simultaneously used by the CDPD channel streams is N_{CDPD}. When the dwell timer of a CDPD channel stream expires, the utilized RF channel is released. (This RF channel will not be used by CDPD until its layoff timer expires.) The CDPD channel stream then hops to another idle RF channel. If no such channel exists, the CDPD channel stream is blacked out. (In some implementations, the CDPD channel stream may keep the old RF channel if no other RF channel is available. This approach is not considered in our study.) When a voice conversation is complete, there are two possibilities: if the number of CDPD channel streams is less than N_{CDPD} and the layoff timer of the RF channel has already expired, the released RF channel is assigned to a blackout CDPD channel stream. Otherwise, the RF channel is returned to the idle channel pool. When the layoff timer of the RF channel expires, the system checks if the number of CDPD channel streams is less than N_{CDPD}. If so, this idle RF channel is assigned to a blackout CDPD channel stream.

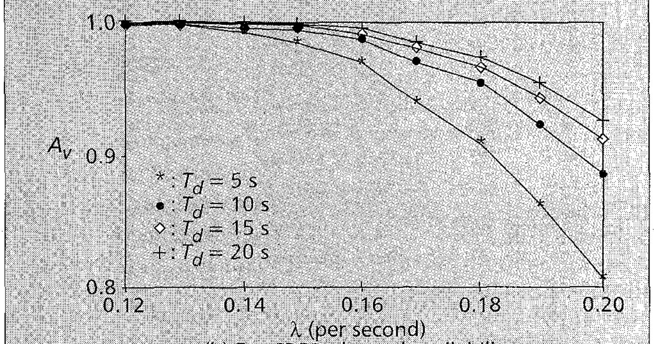
Performance Evaluation

Assumptions and Output Measures

This section describes the assumptions and output measures for the CDPD/AMPS performance study under the timed hop



(a) The voice call blocking probability



(b) Per CDPD channel availability

■ Figure 2. *The effect of* T_d ($N_{CDPD} = 10$, $T_l = 3$ s, $\alpha = 0.8$).

and emergency hop mechanisms. The following assumptions are made in the simulation model:

- The voice calls to an AMPS BS are a Poisson process with arrival rate λ.
- The voice call holding times are exponentially distributed with mean T_h s. In our experiments, $T_h = 3$ min.
- The maximum number of RF channels that can be simultaneously used by the CDPD channel streams is N_{CDPD}.
- The CDPD dwell time is a fixed period of T_d s.
- The CDPD layoff time is a fixed period of T_l s.
- The number of RF channels in an AMPS BS is N. In our experiments, $N = 50$.
- A forced hop is successfully performed with probability α. That is, for an RF channel occupied by a CDPD channel stream, if AMPS needs the channel, then with probability α, the CDPD system successfully performs a forced hop to release the channel. The parameter α determines the effectiveness of the sniffer. A perfect sniffer can always detect the need of AMPS and $\alpha = 1$. In practice, the sniffer may not be perfect and $\alpha < 1$.

Suppose that we observe the CDPD system during the period $[0, T]$; then several outputs can be measured:

- N_T: the total number of voice call arrivals in $[0, T]$
- N_b: the total number of blocked voice calls in $[0, T]$
- $T_{CDPD}(i)$: the amount of RF channel i's time occupied by CDPD during $[0, T]$
- $T_{CDPD} = \sum_{i=1}^{N} T_{CDPD}(i)$: the total amount of time RF channels are used by CDPD during $[0, T]$
- P_b:the voice blocking probability, which is defined as

$$P_b = \frac{N_b}{N_T} \tag{1}$$

- A_v: the per CDPD channel availability, which is defined as

$$A_v = \frac{T_{CDPD}}{T \cdot N_{NCDPD}} \tag{2}$$

- A_v^*: the overall CDPD system availability, which is defined as

$$A_v^* = N_{CDPD} \cdot A_v = \frac{T_{CDPD}}{T} \tag{3}$$

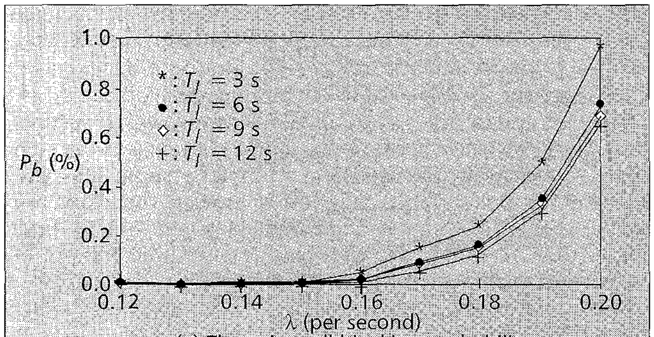
It is clear that the smaller the P_b value, the better the performance of the AMPS system. On the other hand, the larger the A_v^* value, the better the performance of the CDPD system. The details of the simulation model are given in the appendix.

Simulation Results

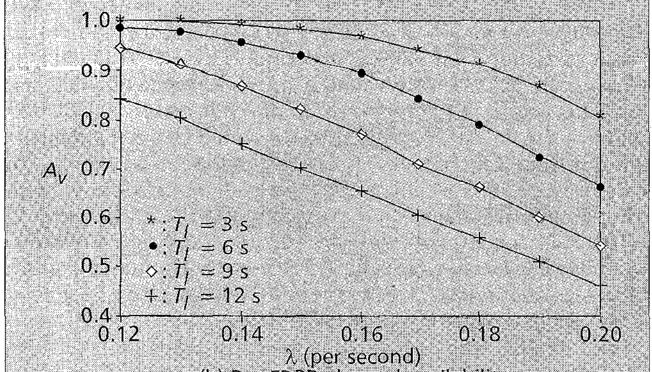
Based on the simulation model, we conduct simulation runs under various ranges of input parameters. Selected data are presented here. Simulations using a wide range of parameter values indicate similar results to those described below.

The Effect of Dwell Time T_d — Figure 2a plots the voice call blocking probability P_b as a function of λ with various dwell time periods T_d, where $N_{CDPD} = 10$, $T_l = 3$ s, and $\alpha = 0.8$. It is clear that P_b is an increasing function of λ and T_d. Figure 2b plots the per CDPD channel availability A_v as a function of λ.

- When $T_l = 3$ s, for $\lambda \leq 0.12$/s and for all T_d values considered in our study, $A_v \cong 100$ percent. This phenomenon is explained below. If λ is small, most AMPS channels are idle. Thus, when a timed hop is executed, the CDPD channel stream can always find an idle RF channel, which results in $A_v \cong 100$ percent.
- As λ increases, A_v decreases. When λ is large, most RF channels are occupied by voice conversations. In other words, it becomes difficult for CDPD channel streams to find idle channels during timed hops, which results in decreasing A_v.
- On the other hand, A_v is an increasing function of T_d. The number of timed hops increases as T_d decreases, which results in higher probability of hopping failure, and a smaller A_v.
- A nontrivial result is that P_b is more sensitive to T_d than Av is. For example, when $\lambda = 0.2$/s, if T_d is increased from 5 s



(a) The voice call blocking probability



(b) Per CDPD channel availability

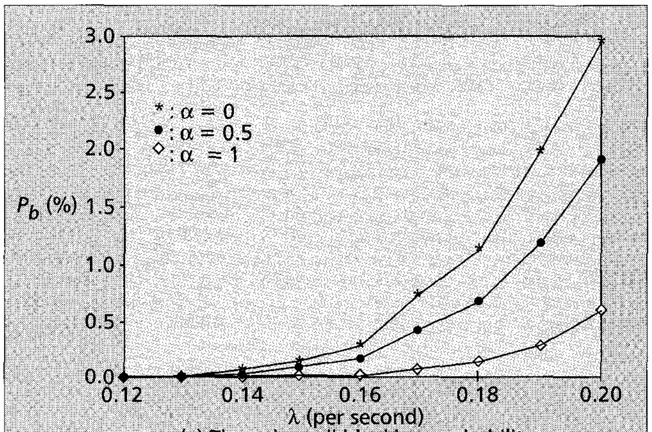
■ Figure 3. *The effect of* T_l ($N_{CDPD} = 10$, $T_d = 5$ s, $\alpha = 0.8$).

to 10 s, P_b is increased by 54.92 percent and A_v is increased by 9.88 percent. If T_d is increased from 10 s to 15 s, P_b is increased by 29.14 percent and A_v is increased by 3.05 percent.

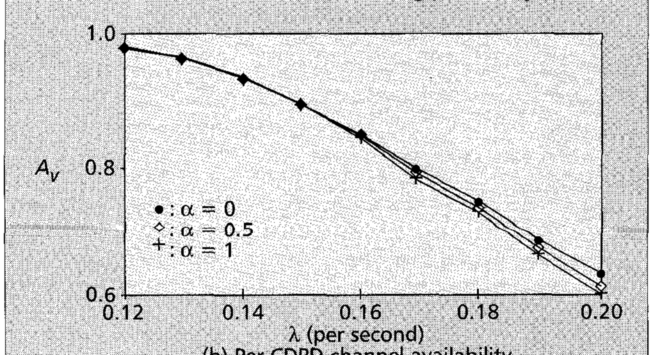
The Effect of Layoff Time T_l — Figure 3a plots P_b as a function of λ with various layoff time values T_l, where $N_{CDPD} = 10$, $T_d = 5$ s, and $\alpha = 0.8$.

- P_b is a decreasing function of T_l. A larger T_l causes CDPD channel streams to wait longer before reusing the layoff channels. Thus, a voice call has a better opportunity to find an idle channel, which results in a smaller P_b.
- The curve for $T_l = 9$ s is almost identical to the curve for $T_l = 12$ s. In other words, increasing T_l does not significantly improve P_b after $T_l > 6$ s.
- Figure 3b indicates that the per CDPD channel availability A_v decreases as λ increases.
- A nontrivial result is that for $\lambda \leq 0.15$/s, increasing T_l degrades A_v significantly without any P_b improvement. This phenomenon is explained below. When T_l increases, the RF channels are more likely to be in the layoff state, and the channel cannot be used by CDPD channel streams. However, these channels are not fully utilized by the AMPS system because the voice call arrival rate is small (and the blocking probability is already small without these extra channels). Thus, A_v decreases significantly without improving P_b.
- For $T_l > 9$ s, A_v is much more sensitive to T_l than P_b is. For example, when $\lambda = 0.2$/s, if T_l is increased from 6 s to 9 s, A_v is decreased by 18.06 percent and P_b by 8.00 percent. However, if T_l is increased from 9 s to 12 s, A_v is degraded by 15.45 percent but P_b is only improved by 3.80 percent.

We conclude that the selection of a large T_l will degrade A_v without improving P_b.

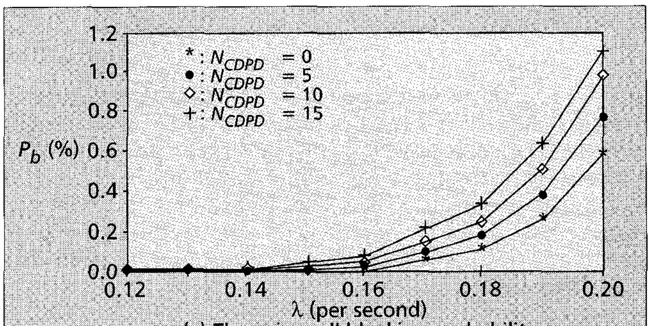


(a) The voice call blocking probability

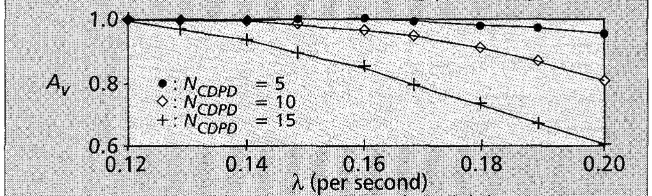


(b) Per CDPD channel availability

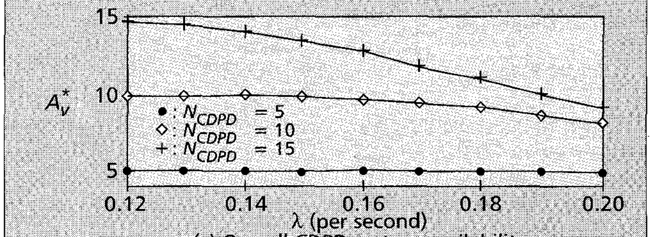
■ **Figure 5.** *The effect of* α (T_d = 5 s, T_l = 3 s, N_{CDPD} = 15).



(a) The voice call blocking probability



(b) Per CDPD channel availability



(c) Overall CDPD system availability

■ **Figure 4.** *The effect of* N_{CDPD} (T_d = 5 s, T_l = 3 s, α = 0.8).

The Effect of the Maximum Number of CDPD Channels N_{CDPD} — Figure 4a illustrates the impacts of N_{CDPD} on the voice call blocking probability, where $T_d = 5$ s, $T_l = 3$ s, and $\alpha = 0.8$. It is clear that P_b is an increasing function of N_{CDPD}.

Figure 4b plots A_v against N_{CDPD}.

- The figure indicates that by increasing N_{CDPD}, A_v decreases. The effect becomes more significant for a large N_{CDPD}. This phenomenon is due to the fact that the number of timed hops increases as N_{CDPD} increases, which results in higher probability of hopping failure, and thus smaller A_v.
- A nontrivial result is that A_v is more sensitive to N_{CDPD} than P_b is. For example, when $\lambda = 0.2$/s, if N_{CDPD} is increased from 5 to 10, P_b is increased by 28.29 percent and Av is decreased by 15.49 percent. If N_{CDPD} is increased from 10 to 15, P_b is increased by 13.96 percent and A_v is decreased by 24.92 percent.

Figure 4c exhibits the overall CDPD system availability A_v^* as a function of λ with various N_{CDPD} values.

- A_v^* is a decreasing function of λ and an increasing function of N_{CDPD}. Specifically, when N_{CDPD} is large, A_v^* drops significantly as λ increases. For example, when λ increases from 0.12/s to 0.2/s, A_v^* decreases by only 4.60 percent for $N_{CDPD} = 5$, but decreases by 38.26 percent for $N_{CDPD} = 15$.
- P_b is more sensitive to N_{CDPD} than A_v^* is. For example, when $\lambda = 0.2$/s, if N_{CDPD} is increased from 5 to 10, A_v^* is increased by 69.01 percent and P_b is increased by 28.29 percent. If N_{CDPD} is increased from 10 to 15, A_v^* is increased by 12.62 percent and P_b increased by 13.96 percent.

Based on the above discussion, we conclude that if N_{CDPD} is sufficiently large, increasing N_{CDPD} degrades P_b without improving A_v^*.

The Effect of the Forced-Hop Probability α — Figure 5a plots P_b as a function of λ with various α values, where $N_{CDPD} = 15$, $T_l = 3$ s and $T_d = 5$ s. It is apparent that P_b decreases as α

increases. Figure 5b indicates that A_v slightly decreases as α increases. A nontrivial result is that if the sniffer mechanism is effective (i.e., α is large), P_b can be significantly improved without degrading A_v. For example, when $\lambda = 0.2$/s, if α increases from 0 to 1, A_v decreases from 0.6332 to 0.5971 and P_b decreases from 2.91 percent to 0.56 percent. This phenomenon is explained as follows. We make the following approximations:

$$T \cong \frac{N_T}{\lambda} \tag{4}$$

and

$$T_{CDPD,\alpha=1} \cong T_{CDPD,\alpha=1} - (P_{b,\alpha=0} - P_{b,\alpha=1}) \cdot N_T \cdot T_h) \tag{5}$$

From Eqs. 2 and 5,

$$A_{v,\alpha=1} \cong \frac{T_{CDPD,\alpha=0} - (P_{b,\alpha=0} - P_{b,\alpha=1}) \cdot N_T \cdot T_h}{N_{CDPD} \cdot T} \tag{6}$$

From Eq. 4, Eq. 6 is rewritten as

$$A_{v,\alpha=1} \cong A_{v,\alpha=0} - \frac{(P_{b,\alpha=0} - P_{b,\alpha=1}) \cdot \lambda \cdot T_h}{N_{CDPD}} \tag{7}$$

For $\lambda = 0.2$/s, we have $P_{b,\alpha=0} = 2.91$ percent, $P_{b,\alpha=1} = 0.56$ percent, $T_h = 180$ s, $N_{CDPD} = 15$, and $A_{v,\alpha=0} = 0.6332$. Substituting these values into Eq. 7, we have $A_{v,\alpha=1} = 0.577$. This result is consistent with the data obtained from simulation. (In the simulation, we have $A_{v,\alpha=1} = 0.5971$.)

Conclusion

This article studies the effects of T_d (the dwell time), T_l (the layoff time), N_{CDPD} (the maximum number of CDPD channel streams), and α (the successful forced-hop probability) on three output measures: P_b (the voice call blocking probability), A_v (the per CDPD channel availability) and A_v^* (the overall CDPD system availability). Based on the simulation experiments, we have the following observations:

- If T_d is sufficiently large (e.g., $T_d > 15$ s in our examples), increasing T_d degrades P_b without improving A_v.
- If the call arrival rate λ is sufficiently small (e.g., $\lambda < 0.15$/s in our examples), increasing T_l significantly degrades A_v without improving P_b.
- If T_l is sufficiently large (e.g., $T_l > 6$ s in our examples), increasing T_l degrades A_v without improving P_b.
- If N_{CDPD} and λ are sufficiently large (e.g., $N_{CDPD} > 10$ in our examples), increasing N_{CDPD} degrades P_b without improving A_v.
- If the sniffer mechanism is effective (i.e., α is large), then P_b can be significantly improved without degrading A_v^*.

Our observations provide guidelines for the selection of input parameters (i.e., T_d, T_l, and N_{CDPD}) to aid CDPD network planning, and indicate that an effective sniffer mechanism (including the efficient CDPD channel stream transfer mechanism) is essential to a high performance CDPD/AMPS system.

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Appendix: Description of the Simulation Model

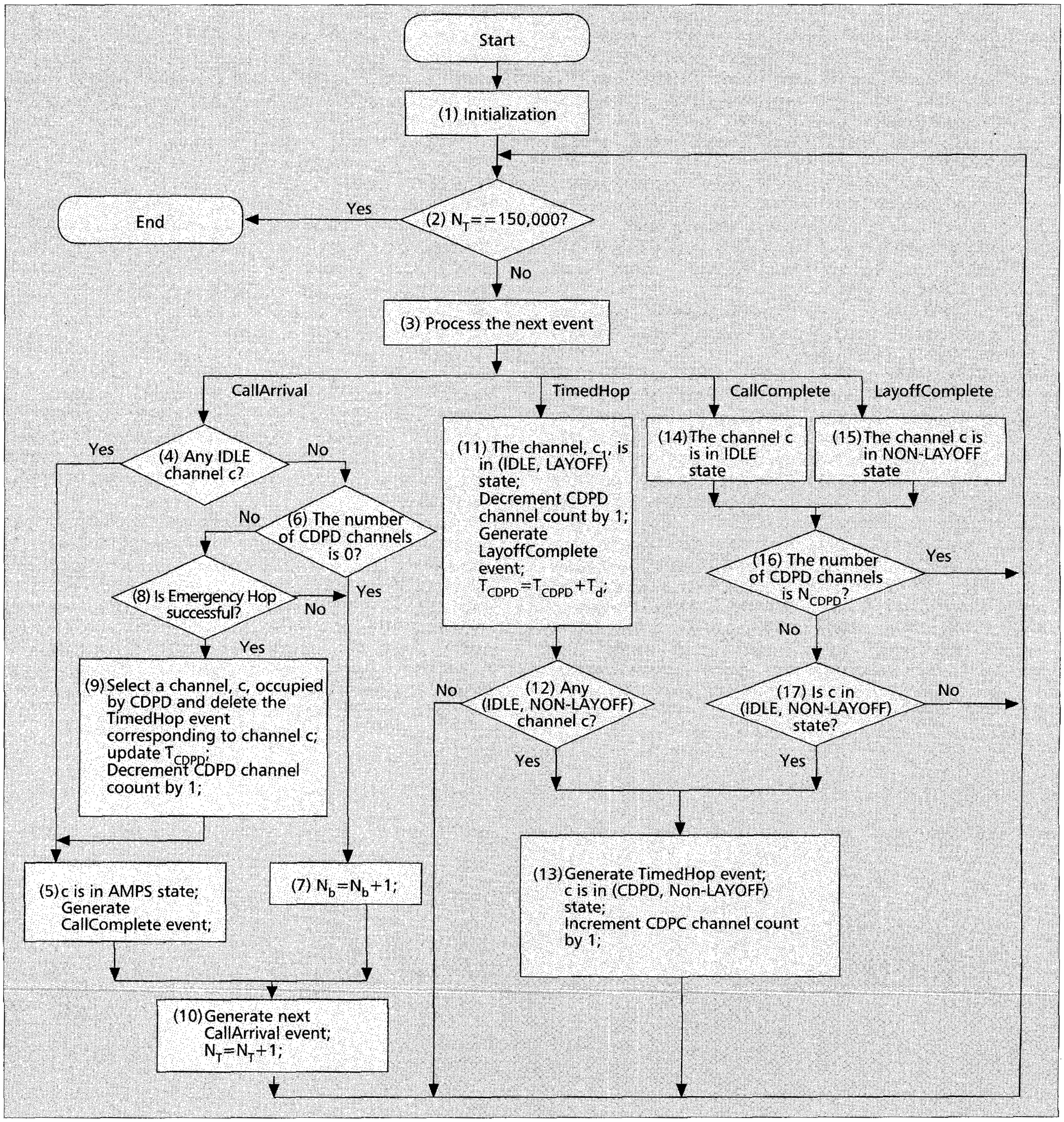
This appendix provides details of our simulation model. There are four types of events in the simulation: a `CallArrival` event represents a voice call arrival, a `CallComplete` event represents a voice call completion, a `TimedHop` event represents the expiration of the dwell timer for an RF channel that is occupied by a CDPD channel stream, and a `LayoffComplete` event represents the expiration of the layoff timer for an RF channel that is not used by a CDPD channel stream. An event contains the following attributes:

Type attribute indicates the type of event (`CallArrival`, `CallComplete`, `TimedHop`, and `LayoffComplete`).

Timestamp attribute indicates the time when the event occurs.

ChannelNo attribute is used in a `CallComplete`, a `TimedHop`, or a `LayoffComplete` event to identify the channel whose status is affected by the event.

Every RF channel is characterized by a status pair: the first part is the *layoff* status, which indicates whether the channel is in the LAYOFF or the NON-LAYOFF state. The second part



■ Figure 6. *The simulation flow chart.*

is the *usage* status, which indicates whether the channel is idle (the IDLE state), used by AMPS (the AMPS state), or used by a CDPD channel stream (the CDPD state). If the channel is in the LAYOFF state, it is either idle or used by AMPS. If the channel is in the NON-LAYOFF state, then it is either idle or busy (i.e., the channel is used by an AMPS voice user or a CDPD stream).

A simulation clock is maintained to indicate the progress of the simulation. In other words, the clock value is the timestamp of the event being processed. The output measures of the simulation are N_b and T_{CDPD}, which are used to compute P_b, A_v, and A_v^* according to Eqs. 1, 2, and 3, respectively.

In every simulation run, $N_T = 150{,}000$ incoming voice calls are simulated to ensure that the simulation results are stable. The total number of RF channels in a BS is $N = 50$. The voice call holding times are exponentially distributed with mean $T_h = 180$ seconds, and the voice call arrivals to the AMPS BS follow the Poisson process with rate λ. The flow chart of the simulation is given in Fig. 6.

Step 1 in this flow chart initializes the simulation run with the following tasks:

1. Generate a `CallArrival` event and N_{CDPD} `TimedHop` events, and then insert the events into the event list. This list is sorted in the non-decreasing timestamp order.
2. Set the states of N_{CDPD} RF channels as (CDPD, NON-LAYOFF), and the remaining $N - N_{CDPD}$ channels as (IDLE, NON-LAYOFF).
3. Set the CDPD channel count (which represents the number of RF channels currently used by the CDPD channel streams), N_T, N_b, and T_{CDPD} to 0.

Step 2 checks the number of voice call arrivals N_T. If N_T reaches 150,000, the simulation run terminates and the output measures are computed. Otherwise, step 3 is executed. This step deletes the first event from the event list and retrieves the information (Type, Timestamp, and ChannelNo) from the deleted event. Depending on the event type, the execution proceeds to one of the four paths (`CallArrival`, `TimedHop`, `CallComplete`, or `LayoffComplete`).

- If the event type is `CallArrival`, then step 4 checks if an RF channel with state IDLE is available. If such a channel c exists, then this channel is selected for the voice call. The usage status of c is set to "AMPS" and a `CallComplete` event for channel is generated at step 5. The timestamp of this `CallComplete` event is the clock value plus the voice call holding time (drawn from the exponential distribution with mean 180 s). If no idle channel is available, step 6 checks if the CDPD channel count is zero. If so, all RF channels are occupied by voice calls, and the arrival call is blocked. In this case, N_b is incremented by one at step 7. Otherwise (some RF channels are used by CDPD channel streams), the system attempts to execute an emergency hop (forced hop) at Step 8. With probability α, the AMPS system hops to a good-quality CDPD channel to serve the incoming voice request. In this case, step 9 is executed and a CDPD channel c is randomly selected for voice transmission. The `TimedHop` event corresponding to the selected channel is deleted from the event list, the CDPD channel count is decremented by one, and $T_{CDPD}(c)$ is incremented by the period for which the RF channel is used for CDPD until it is force-hopped. The simulation proceeds to generate a `CallComplete` event at step 5. At step 10, a `CallArrival` event is generated and N_T is incremented by one. The timestamp of this `CallArrival` event is the clock value plus the interarrival time (drawn from the exponential distribution with rate λ). If the forced hop fails at step 8 (with probability $1 - \alpha$), the incoming voice call is blocked, and step 7 is executed to update N_b. Similar to step 5, after step 7 is executed a `CallArrival` event is created at step 10.
- If the event type is `TimedHop`, step 11 is executed where the corresponding channel c_1 (indicated by the ChannelNo attribute of the event) is set to the (IDLE, LAYOFF) state, the CDPD channel count is decremented by one, T_{CDPD} is incremented by T_d, and a `LayoffComplete` event for this RF channel is generated. The timestamp value of this `LayoffComplete` event is the clock value plus the layoff time T_l. The CDPD channel stream (which releases RF channel c_1) attempts to find another idle RF channel. Step 12 checks if an (IDLE, NON-LAYOFF) channel c exists. If so, channel c is set to the (CDPD, NON-LAYOFF) state, the CDPD channel count is incremented by one, and a `TimedHop` event is generated for channel c (step 13). The timestamp value of this `TimedHop` event is the clock value plus the dwell time T_d.
- The actions for the `CallComplete` and `LayoffComplete` events are similar except for the first steps (i.e., steps 14 and 15). At step 14 (i.e., the event type is `CallComplete`), the usage status of channel c is set to IDLE. On the other hand, step 15 (i.e., the event type is `LayoffComplete`) sets the layoff status of channel c as NON-LAYOFF. Steps 16 and 17 check if the number of CDPD channel streams is less than N_{CDPD} and c is in the state (IDLE, NON-LAYOFF). If so, step 13 is executed to accommodate one more CDPD channel stream by utilizing RF channel c.

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