A Dynamic Reservation Protocol for Prioritized Multirate Mobile Data Services Based on DECT Air Interface

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***Abstract*—This paper presents an application of the dynamic reservation protocol on DECT systems for prioritized multirate mobile data services. This protocol allows data terminals to access uplink channels through contention-free reservations. It can adapt to traffic variations by dynamically changing the transmission cycle length. Since this protocol is built on the top of the DECT physical layer, it can be implemented on the DECT systems without interfering with the voice service, just like CDPD on top of the digital AMPS.**

***Index Terms*—Data services, DECT, multirate, priority, protocol.**

I. Introduction

THERE is an ever-growing demand for mobile data services. To satisfy the wide range of data applications such as database access, file transfer, and credit card verification, a large number of protocols have been proposed for local wireless environment [1]–[3] and mobile computing environment [4]–[8]. At the same time, integrating data services into the existing cellular networks is readily achievable and research and standardization efforts for data services on the AMPS, GSM, and E-TDMA systems have also been going on in earnest. Bianchi *et al.* [9] have evaluated the performance of a few proposals for GPRS, including the dynamic channel stealing (DCS) method. Hamalainen *et al.* [10] have proposed a variable rate reservation access (VRRA) algorithm for packet data services on time-division multiple-access (TDMA)-based cellular networks. Most of these designs are based on integrating voice and data traffic onto one physical channel.

The authors of this paper have previously proposed a dynamic reservation protocol for data services on GSM networks [11]. But since data communications require high a data rate for good performance, the DECT air interface, being able to support 1.152 Mb/s per carrier, has a significant advantage over GSM. It is particularly suitable for high-density small-cell applications such as cordless PBX and wireless data access in business and home environments [12]. The dynamic reservation protocol mentioned above is ideally suited for efficient access of data services on DECT. There are, however, important differences between GSM and DECT that requires a significant modification of the original protocol. First, GSM is a frequency-division duplex (FDD) system that has separate uplink and downlink frequency bands, while DECT is a time-division duplex (TDD) system that uses the same frequency band for both uplink and downlink transmissions. Second, DECT system has channel rate much higher than that of the GSM system.

For the rest of the paper, we will discuss in detail the contention-free access mechanism, the priority mechanism, the provisioning of multirate services, and the delay/throughput performance of the protocol.

II. The Dynamic Reservation Protocol

The dynamic reservation protocol for the DECT air interface can be used in any single cell between a base station and many mobile terminals. The physical channels in DECT networks are organized as TDMA frames. Each frame lasts for 10 ms and comprises 24 full slots, 12 for downlink and 12 for uplink. One full slot can further be used as two half slots. Each full slot can accommodate 388-b upper layer data while each half slot can accommodate 148-b upper layer data. DECT network is designed mainly for carrying voice traffic. Due to the bursty nature of data traffic, the native DECT system cannot achieve efficient channel utilization. The dynamic reservation protocol can change that by assigning a flexible bandwidth virtual circuit to each logged data terminal, and a large number of logged terminals can share one or more carriers reserved for data services. Details are as follows.

A. Virtual Circuit Connection

A data terminal requesting a virtual circuit sends a Connection_Request signal to the base station in the *random access channel* of the DECT system. In this signal, the terminal specifies the service type and its performance requirements such as priority and the latency constraint. If the addition of this new connection does not violate the service quality of the existing terminals, the setup request is accepted and a virtual circuit is assigned to the requesting terminal after a successful authentication procedure by the upper layer protocol. The assignment is announced to the terminal by a Connection_Confirm Signal. This signal consists of four parts: 1) the assigned carrier for the data terminal to use; 2) a virtual circuit identifier; 3) the priority class and its group number (see next section); and 4) the slot position for the logged terminal to make transmission reservations.

Manuscript received October 3, 1997; revised November 12, 1998. This work was supported by the Hong Kong Research Grant Council.

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Publisher Item Identifier S 0018-9545(00)02565-2.

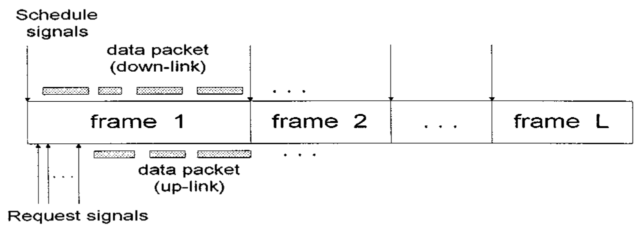

Fig. 1. Signals for the virtual circuit connection.

RS	CBRSN	UA	DA	network status	fields
5	3	192	176	12	bits

Fig. 2. Format of the schedule signal.

As the above two signal types will not appear in the DECT data channel, the detail design of the signal formats is not important and so will not be specified here.

When a virtual circuit is established, the Schedule and Request signals are used on the data channel for its maintenance. Fig. 1 shows the transmissions of these two signals as well as the data packets on the data channel. The first downlink slot of every TDMA frame is reserved for the Schedule signal. It specifies the usage of each uplink TDMA slot of the current frame and each downlink slot of the next frame. It also indicates the reservation open for a number of logged terminals, i.e., those with a virtual circuit set up. These terminals respond with a Request signal in their assigned slot positions where these positions are specified in the Connection_Confirm signals. The Request signal indicates whether the terminal wants to make a transmission reservation in the current cycle, to change its service priority, and to maintain its virtual circuit connection. A terminal that fails to respond in a few consecutive cycles will have its virtual circuit connection terminated.

B. Signal Formats

The Schedule signals are transmitted using a basic physical packet P32 with a payload of 388 b. The format of the Schedule signal is shown in Fig. 2. The RS field indicates whether the terminals are allowed to make reservation in this frame. RS set to 00 000 indicates that the uplink of this frame is for information only and no reservation is allowed. The other 31-b combinations are used to indicate which group of class-2 terminals can send their Request signals in this frame. The CBR slot number (CBRSN) field indicates the number of reserved CBR slots. The uplink assignment (UA) field carries the uplink slot assignments of the current frame when this frame is not a reservation frame, while the downlink assignment (DA) field carries the downlink slot assignments of the next frame. The UA field is divided into 12 subfields. Each subfield contains a 16-b virtual circuit identifier (VCI), corresponding to the 12 uplink slot. The DA field is divided into 11 subfields of 16 b each for the downlink virtual circuits identifier. The remaining 12 b can carry network status information such as channel condition, dynamic tariff information, etc., as well as CRC codes, if needed. Note that there are only 11 slots per frame for downlink data because one slot is always used by the Schedule signal.

VCI	SPC	NRS	LC	fields
16	8	8	116	bits

Fig. 3. Format of the request signal.

The Request signals are transmitted using low-capacity physical packet P08j so that they can be transmitted on half slots. A frame contains 24 half uplink slots, so up to 24 terminals can make reservation in one TDMA frame. Fig. 3 shows the format of the Request signal. Terminals use this signal to inform the base station the virtual circuit identifier (VCI), the service priority change (SPC), the number of requested slots (NRS's), and the link control (LC) information. SPC set to zero indicates that a CBR data service is requested by the terminal. In this case, the NRS field specifies the requested data rate but not the requested slot number. The LC field can contain information such as acknowledgment of received data units in the last cycle and the CRC for the previous three fields.

C. Reservation and Transmission

The transmission of data is done in cycles. At the beginning of a transmission cycle, logged terminals can make reservations on the assigned uplink reservation slots. The base station immediately computes a transmission schedule (or slot assignment, see Section III) based on these reservations and broadcast it to the terminals in the Schedule signal. Terminals then make transmissions in their assigned slots. Each transmission cycle begins with a set of Schedule signals sent by the base station in consecutive frames. Each Schedule signal initiates a sequence of Request signals, one from each logged terminal. A requested slot number (RSN) field is used in the Request signal to specify the number of slots requested for uplink transmission. All terminals are required to monitor the Schedule signals for the polling of reservation and the uplink and downlink transmission assignments. A terminal transmits and receives only at the slots indicated in the Schedule signal. The base station will initiate a new transmission cycle at the end of the scheduled transmission.

D. Priority Services

Multipriority data transmission can be achieved by assigning different access rights to different priority classes. One design is to let class-1 terminals have access right in every transmission cycle, class-2 terminals have access right once every n_2 cycles, class-3 terminals have access right once every $n_1 n_2$ cycles, and so on. Another meaningful design is to let the class-3 terminal have access right every $n_1 + n_2$ cycles. But for simplicity, we shall limit our study to the most important two-class priority case. Consider a two-class case where class 1 has higher priority. We can divide class-2 applications into n groups, where n is a design parameter. In each transmission cycle, all class-1 applications and one class-2 group are allowed to make reservation. With that, a class-2 application can make reservations only once every n cycles. The delay performance of the two classes can therefore be traded off by changing n. The access right for a particular data terminal is assigned during the virtual circuit connection setup according to the application requirements. For example, e-mails need not be instantly responded and so can be assigned to a class-2 group. On the other hand, web page access should be considered as a class-1 traffic.

Applications requiring a very low response time can be allowed to make reservation in each frame by allocating a particular uplink slot for that purpose. Transmission can then start immediately from the next frame. In this case, the reservation delay will be less than two frames, or 20 ms. The overhead for this fast access is one slot per frame.

E. Variable Bit Rate (VBR) and Constant Bit Rate (CBR) Services

The dynamic reservation protocol is designed for VBR services. Nevertheless, CBR data services can also be integrated in the network without difficulty. A terminal requiring CBR data services can indicate its required bit rate to the base station in its Request signal. If the request is acceptable, the base station can immediately assign some fixed number of slots, say one slot per ten frames, and announce it in the Schedule signal. A CBR_Slot_Number field is defined in the Schedule signal. It indicates the number of slots being reserved for CBR traffic. These reserved slots are placed at the beginning of the uplink direction of a frame. CBR slots can be released by the terminal through a Request signal with the RSN field set to zero.

F. Error Recovery

The dynamic reservation protocol being studied here is a media access sublayer protocol. It sits on top of the data link layer whereby all channel errors are dealt with, typically, in the following manners:

- *voice or video traffic—data interleaving followed by forward error correction*;
- *data traffic—error detection followed by ARQ techniques*.

On the other hand, errors in the transmission of Schedule and Request signals can be handled in a manner similar to that in IEEE 802.11. In other words, the CRC codes in the signals are checked. If an error is found in a Request signal, the signal is simply discarded by the base station. The affected terminal will repeat its reservation request after a timeout. If an error is found in the Schedule signal, the signal is discarded by all logged terminals. Failure to receive any expected Request signals at the base station would prompt the base station into a timeout and the restart of a new cycle. As the protocol acts only on correctly received signaling information and uses timeout for restarting, protocol deadlock will not occur.

III. Assignment Algorithm

The base station performs the assignment procedure for each transmission cycle based on the information received in the Request signals. The procedure is similar to that in [11]. We include it here for ease of reference. The assignment results are the number of assigned slots and the starting location for individual logged terminals. To satisfy the delay requirements for

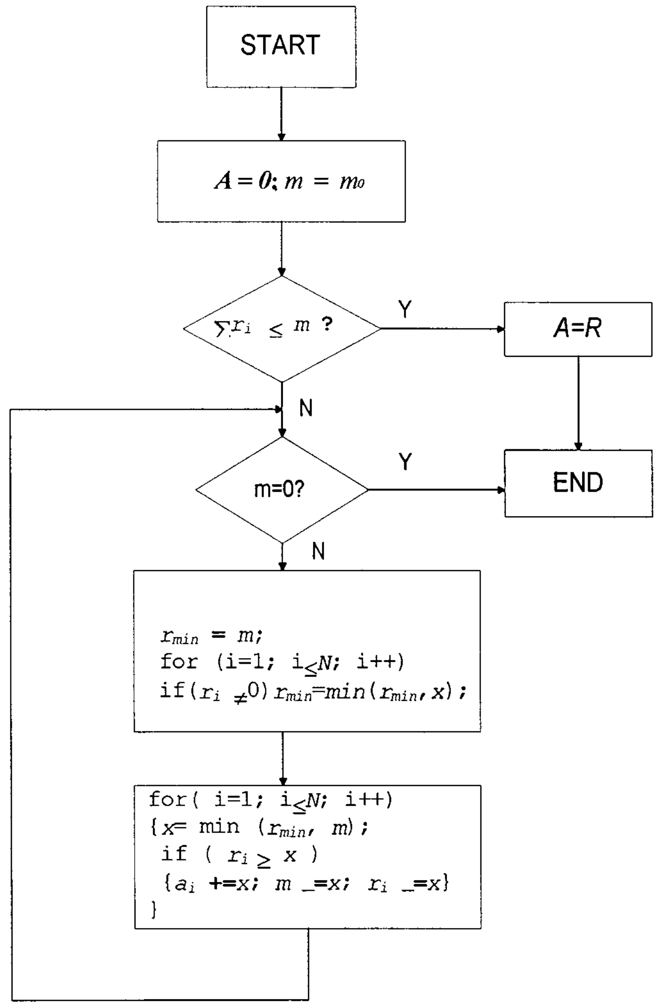

Fig. 4. Assignment procedure.

high priority services, the duration of transmission cycles is limited to L frames. For simplicity, we still consider the two-class case. Let N_1 be the number of class-1 terminals and N_2 be the number of class-2 terminals and let $N = N_1+N_2$. $N_1+(N_2/n)$ slots are used as reservation slots in each cycle and a number of slots, say, c slots, are reserved for CBR services. Therefore, a maximum number of $m_0 = 12L - N_1 - (N_2/n) - c$ slots can be allocated to logged terminals for their uplink transmission in each cycle.

Let the number of requested slots from terminal i be denoted as r_i and let $\mathbf{R} = [r_1, r_2, \ldots r_N]$. Only $1/n$ of class-2 terminals can send their reservation request each time, so there are at most as $N_1 + (N_2/n)$ elements of vector $\mathbf{R}$ have nonzero values. Let the actual number of slots assigned to terminal i be denoted as a_i. The assignment algorithm aims at finding an appropriate assignment vector $\mathbf{A} = [a_1, a_2, \ldots, a_N]$ and deciding the transmission order of the terminals. If the total number of requested slots is no larger than m_0, the requests of all logged terminals can be granted and we can set $\mathbf{A} = \mathbf{R}$. Otherwise, some of the terminals will not get all the slots they requested and an assignment protocol is needed to find an appropriate $\mathbf{A}$.

Fig. 4 illustrates the assignment procedure. At the start of the assignment procedure, $\mathbf{A}$ is initialized to $\mathbf{0}$, and the total number

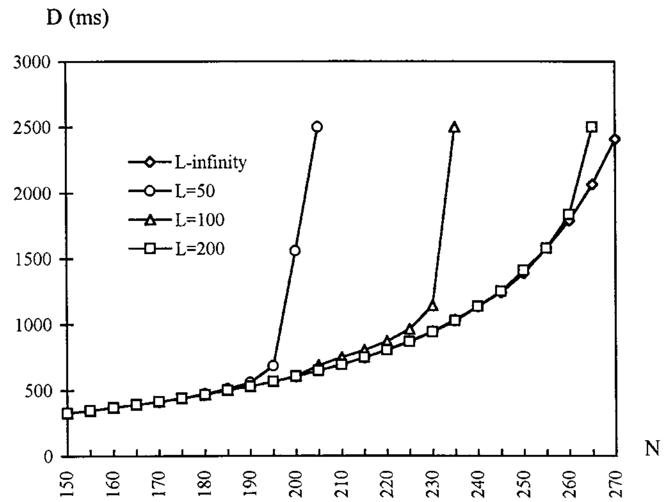

Fig. 5. Message delay versus number of terminals.

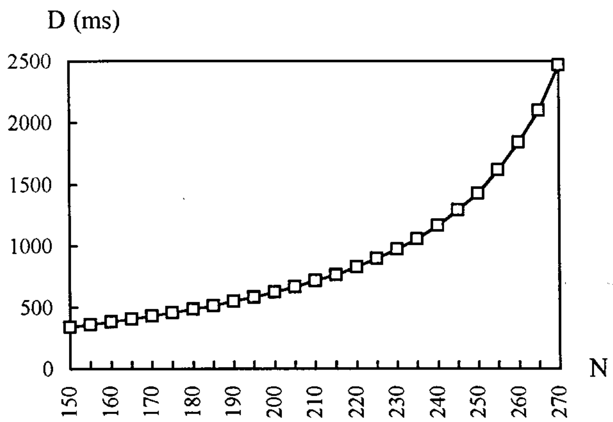

Fig. 6. Message delay versus number of terminals.

of remaining slots m is initialized to m_0. When the sum of requested slots is more than what can be assigned in one transmission cycle, the assignment is performed in a cyclic way. In each assignment cycle the smallest nonzero r_i, denoted as $r_{\min}$, is found first and a_i is updated as $a_i = a_i + \min(r_{\min}, r_i, m)$, for $0 \leq i \leq N$. At the same time r_i and m are decrement accordingly. Repeat this cyclic process until $m = 0$.

The transmission order is arranged according to the service priority. Class-1 terminals transmit first following by class-2 terminals, etc. Among those belonging to same class, terminals with a shorter message transmit first.

IV. Performance Evaluation

In this section, we describe the simulation model and evaluate the performance of the dynamic reservation protocol. As discussed in many previous works, it is difficult to characterize and model the data traffic in the fast evolving mobile computing environment. We assume here traffic generated from basic applications such as e-mail, web browsing, and file transferring. The message length may vary from several bytes (e.g., to specify a mouse movement) to several megabytes for transferring multimedia files. We assume that one DECT carrier is reserved for data services, which provides 465.6-kb/s uplink channel to

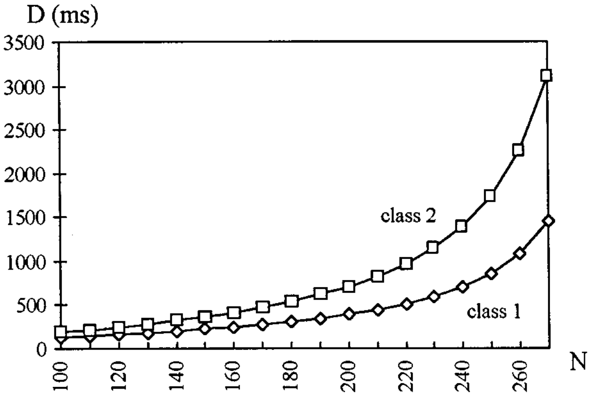

Fig. 7. Delay comparison for first and second class terminals.

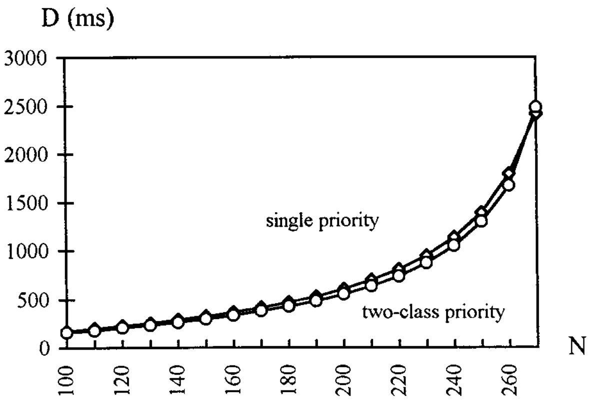

Fig. 8. Comparison of average message delay for single-class and two-class priority schemes

media access layer. During the simulation period, the number of logged terminals $N = N_1 + N_2$ remains unchanged and each terminal generates messages according to a Poisson process, with rate $\lambda = 0.5$ per s. The combined arrival of messages is also a Poisson process with rate $0.5(N_1 + N_2)$ per s. The message length is assumed to be in unit of 48 bytes, or equivalently, in unit of slots required for transmission. Similar to that in [4], we assume the message length is geometrically distributed with a mean $X = 8$ units so that the average data rate per user is 1536 b/s. Therefore, a theoretical maximum of 300 terminals can be supported on one carrier.

We define the message delay D as the total delay from the generation of the message at a terminal until it is successfully transmitted. It includes the waiting time until the end of the current transmission cycle, the time for making reservation, the waiting for the scheduled transmission, and the message transmission time. Fig. 5 shows the average message delay D versus the number of logged terminals N when all terminals have the same service priority with L, the maximum length of transmission cycles in frames, as a parameter. We find that at a mean message delay of 1000 ms, the scheme can support 235 logged terminals, which represents channel utilization $\rho = 0.78$. At $\rho = 0.9$, the mean delay is 2.4 s. This compares favorably to other data access methods [10], [11] proposed for digital cellular methods, which offer a maximum throughput of 0.6–0.7. Fig. 5 also shows that a tight limit on the length of a transmission cycle, say to no more than 50 frames, could significantly

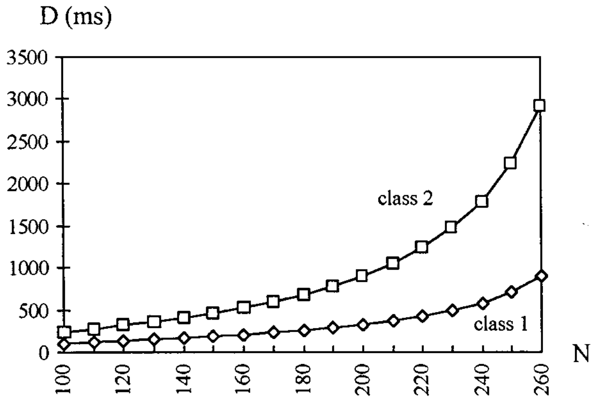

Fig. 9. Comparison of message delay between the first and second class terminals.

limit the system throughput. This is due to the larger reservation overhead. If the limit is set to 200 frames, the performance becomes virtually indistinguishable from that without limit. However, in situations where there are multiple classes of terminals, setting a limit on the transmission cycle length has the benefit of protecting the light traffic terminals from the dominance of the heavy traffic terminals.

Next, we consider the case where the terminals are only half as active ($\lambda = 0.25$ per s), but the average message length X is doubled to 16 units. In this case, the theoretical maximum number of terminals that can be supported by the dynamic reservation scheme remains unchanged. Fig. 6 shows the delay throughput results. Compared with Fig. 5, we find that this more bursty input traffic causes a slightly increase of message delay.

We now let the logged terminals be equally divided into two classes or let $N_1 = N_2 = N/2$ and the class-2 terminals be equally divided into two groups. The input traffic is the same as that in Fig. 5. Fig. 7 gives the mean message delays for the two classes. It is seen that the average message delay for class-1 terminals can be significantly reduced at the expense of the class-2 terminals. When the total number of terminals N is 260, the average delays for the two classes of terminals are 1077 ms and 2254 ms, respectively, whereas from Fig. 5 we find that the average delay is 1791 ms for the same value of N. For the same case, we compare in Fig. 8 the overall message delay for the two-class priority case to that of the single-class priority case and find that the former gives a slightly smaller delay. This is due to the reduction of reservation overhead from $N_1 + N_2$ to $N1 + (N_2/2)$ in each cycle. While the reservation traffic for class-2 terminals is reduced to a half in each cycle, the number of slots each class-2 terminal is reserving is actually the combined message volume generated in the last two cycles.

Fig. 9 gives the mean message delays for class-1 and class-2 terminals when class-2 terminals are equally divided into four groups with all other conditions the same as that in Fig. 7. In this case, the message delay for class-1 terminals can further be reduced at the expense of the class-2 terminals.

V. Conclusion

In this paper, we introduced the use of the dynamic reservation protocol for multipriority multirate data services based on the DECT air interface. This protocol has nice properties such as contention-free reservation, adaptation to traffic load variations, supporting of multipriority services, and superior delay/throughput performance demonstrated by simulation results.

Acknowledgment

The authors acknowledge the suggestions from two reviewers which rendered a significant improvement in the content of this paper.

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