

Traffic characteristics of PCS call-terminating control

SHIKATA Yoshiaki and TAKAHASHI Yoshitaka⁺

Abstract

In a personal communication system (PCS), a scheme for reforwarding call-terminating setup messages (SETUP messages) from a network is used to guard against their loss. We have developed simulation program for evaluating the traffic characteristics of a reforwarding scheme, in which messages registered in the paging-channel queue in a cell station are cyclically forwarded to the wireless area. This model corresponds to the finite-capacity BPP/D/1/N model with vacation time. We then added a method for calculating the "timeout" probability. Finally, using this program, we clarified the traffic characteristics of PCS call-terminating control.

Key word: personal communication system, call-terminating setup, reforwarding, loss probability, vacation time, BPP/D/1/N model

1. Introduction

A personal communication system (PCS) is an economical and customer-flexible telecommunication system. It contains cell stations that connect personal stations to the existing network via wireless circuits. Schemes for reforwarding call-terminating setup messages (SETUP messages) [1] are used to guard against their loss, which would make it impossible to set up calls. In this reforwarding scheme, a connection loss may occur due to loss or transmission delay of the first and reforwarded SETUP messages. Therefore, the loss probability of this scheme should be evaluated to clarify the quality of the PCS network.

In this reforwarding scheme, the network reforwards a SETUP message after a constant time span from the time that the first SETUP message has been forwarded. So, this reforwarding process of SETUP messages is regarded to be a Branching Poisson Process (BPP) which consists of one parent and one child. In order to evaluate the loss probability applicable to call-terminating control in PCS networks, BPP model with finite capacity queue is to be analyzed. But unfortunately BPP is not renewal, we can not use the standard theory of the GI/GI/1 queue where GI stands for a renewal process [2]-[6]. In order to evaluate traffic characteristics of PCS network, we have developed a simulation program [7]. It has two evaluation methods: evaluating the queue overflow rate and evaluating the waiting overtime rate in the paging-channel (PCH) queue in each cell station. These two evaluations can be applied to the call-terminating scheme in which the target personal stations are divided into several groups, and SETUP messages are forwarded periodically to each group in

⁺ Associate Professor of Commerce Associate Dean Waseda University

turn [8]. We take into account message transmission errors when evaluating the probability that the network does not receive a response message within the given time.

Using this simulation program, we evaluated the loss probability of our reforwarding scheme. A loss means that the call cannot be established due to queue overflow, waiting overtime, or an error in transmitting the SETUP message, although the personal station is ready to accept the call. We do not consider lost calls when hunting for wireless channels but consider only those calls that hunt for these channels and arrive at the PCH queue in a cell station. The former call loss probability at the channels can be evaluated independently, say, by using the classical Erlang-loss formula. We treat the latter loss probability for the call arriving at the PCH queue. We clarified traffic characteristics of PCS call-terminating control and existence of the best reforwarding timelag which minimizes the loss probability in these reforwarding schemes.

2. PCS call-terminating control

A database in a PCS network manages the personal station location information. When terminating a call to a personal station, the network refers to the location information in this database and selects a path to the target personal station. The network simultaneously forwards SETUP messages to the cell stations composing the paging area (identical to location area) (Fig. 1). Each cell station forwards the SETUP message by using the paging channel to alert the target personal station, and the cell station receiving a response from the personal station forwards it to the network.

Reforwarding of a SETUP message is generally used to guard against the loss of messages. Reforwarding the messages unconditionally ensures that message loss is rapidly compensated for by successive forwarding. When a cell station forwards a SETUP message to a personal station, a scheme is applied in which the target personal stations are divided into several groups and SETUP messages are forwarded periodically to each group. In this message-forwarding scheme, personal stations periodically watch only their forwarding time slots [1]. The cell station registers the SETUP messages received from the network in PCH queues provided for each group and forwards the messages during the assigned forwarding time slots. When a group's forwarding time slot

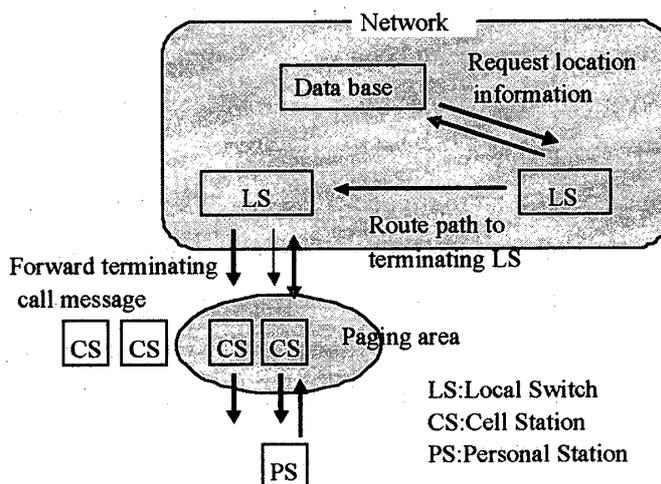


Fig.1 Method for terminating a call to a personal station

arrives, one message is sent from the PCH queue for the group (Fig. 2). As long as the queue is not empty, one message is sent at each slot. When the queue becomes empty, the state switches to the vacation state, and the messages received during this state wait until the next forwarding time slot.

3. Evaluation of timeout rate

3.1 Timeout

The features of our call-terminating control scheme are as follows:

- (1) The network forwards the SETUP message to the cell stations and sets a timer for response.
- (2) The cell stations registers the SETUP message on the PCH queue provided for that group.

(3) When the periodic forwarding time

slot for that group arrives, the cell stations pick up one SETUP message from the queue provided for that group and forward it to the wireless area.

(4) The alerted personal station forwards a response message to the network via a cell station.

(5) After a reforwarding timelag the network reforwards a SETUP message and procedure (2) to (3) are repeated, but the alerted personal station does not forward a response message in the case that it has already forwarded a response message when it has received the first SETUP message.

If the network does not receive a response message within the fixed time, a "timeout" is said to have occurred. A timeout can happen in the following cases: (A) the SETUP message overflows the PCH queue in a cell station, (B) the SETUP message or response message is lost because of a signal transmission error, (C) the network receives the response message after the timer for response has expired, or (D) the target personal station is not in the paging area or its power is turned off, so it cannot respond to the SETUP message (the target personal station is out of service). To better evaluate case (C), we define the delay in sending messages as C-1, the time span from the moment the personal station receives the SETUP message to the moment it sends the response message as C-2, and the waiting time in the PCH queue as C-3. The values of (B), (C-1), (C-2), and (D) are assumed to be constant regardless of the amount of traffic. To evaluate the relationship between the timeout rate and the traffic load, we need a method for calculating the probability that (A) occurs or that (C-3) exceeds the given time (waiting overtime occurs).

SETUP messages enter the PCH queue and wait in the queue until the forwarding time slot comes. Then one message leaves the queue and the next message waits for the next forwarding time slot. A service time is defined as the time period between the time that a service (message forwarding) starts and the time that the next service is able to start. So the time period between the forwarding time slot and the time slot just before the next forwarding time slot can be regarded as the service time in our system (Fig. 3(a)). If the queue is empty at the forwarding time slot, the message does not leave the queue until the next forwarding time slot comes, even if messages enter the queue between that forwarding time slot and the time slot just before the next one. Namely, it takes a vacation time,

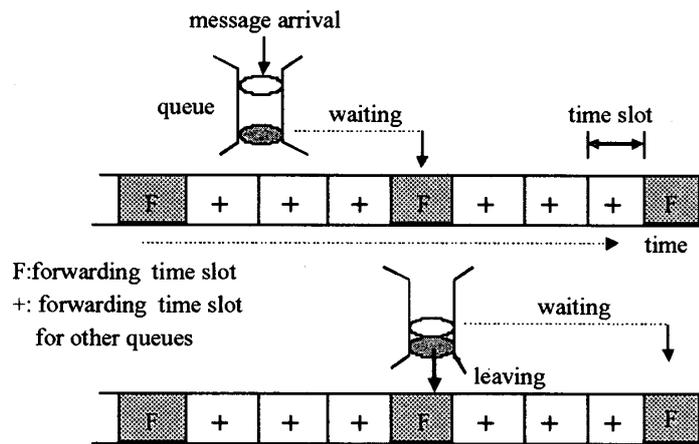


Fig.2 Call-terminating queuing and leaving

which is the same period as the service time (Fig. 3(b)). Moreover, because there are constraints on the response time at the network, the waiting time at the cell station is limited. The number of waiting places is therefore limited. Accordingly, if we assume that the input process to each group is Poissonian with rate λ , our model can be considered an one parent and one child BPP/D/1/m model whose service time and vacation time are the same (m is the number of waiting places).

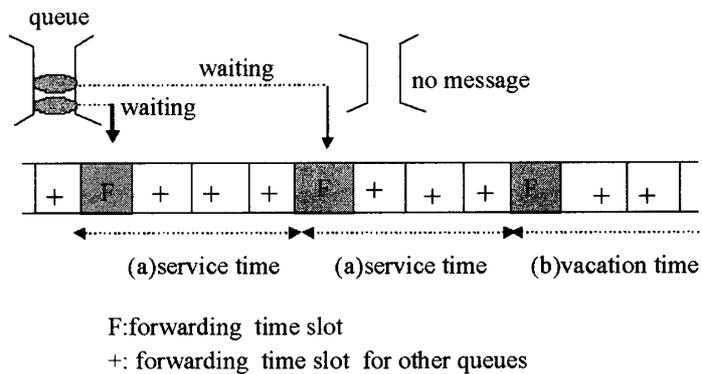


Fig.3 Service time and vacation time

3.2 Timeout rate

Taking into account the transmission error rate (P_{te}) for the SETUP or response message, we can calculate the timeout rate (P_{to}), which is defined as the probability that the network does not receive a response message within the fixed time as

$$P_{to} = 1 - (1 - P_{of}) \cdot (1 - P(W > t)) \cdot (1 - P_{te}) \cdot (1 - P_{te}) \quad (3.1)$$

Here, P_{of} and t respectively stands for the queue overflow probability and timer for response. $P(W > t)$ stands for the probability that the waiting overtime occurs.

3.3 Simulation program

In order to simulate a PCS network environment, we developed a simulation program that simulates the following procedures:(1) Customers arrive at the queue according to the Poisson process and are registered in the queue if the queue is not full.(2) These customers are also registered in the reforwarding queue and the reforwarding timer starts. (3) When the periodic service time slot arrives, the processing server serves the customer registered in the queue. (3) When the queue is empty, the server does not provide service at the service time slot. (4) Customers are reforwarded from reforwarding queue when the reforwarding timer is expired. The number of customers which are not registered in the queue since the queue is full is obtained in this simulation program. And the number of customers which are not served within the fixed time is also obtained.

4 Evaluation of loss probability

4.1 Evaluation procedure

As described above the loss probability (P_{loss}) is defined as the probability that the call cannot be established, although the target personal station is ready to accept it (i.e., the target personal station is not out of service). It can be divided into two probabilities. One is the probability that the first

SETUP message overflows the PCH queue or waits in the PCH queue for longer than the timer for response (except for transmission delays (C-1) + (C-2)) or that a transmission error occurs in the first SETUP or response messages. This probability is given by

$$P_{to1} = 1 - (1 - P_{off}) \cdot (1 - P(W > t_f)) \cdot (1 - P_{te}) \cdot (1 - P_{te}) \quad (4.1)$$

Here, P_{off} , t_f and $P(W > t_f)$ stands for queue overflow probability, timer for response and waiting over time rate for the first SETUP message. The second probability is that the reforwarded SETUP message overflows the PCH queue or waits in the PCH queue for longer than the timer for response, or that a transmission error occurs in the reforwarded SETUP or response messages. This probability is given by

$$P_{to2} = 1 - (1 - P_{ofr}) \cdot (1 - P(W > t_r)) \cdot (1 - P_{te}) \cdot (1 - P_{te}) \quad (4.2)$$

Here, P_{ofr} , t_r , and $P(W > t_r)$ respectively stands for queue overflow probability, timer for response and waiting over time rate for reforwarded SETUP message.

Thus, P_{loss} is

$$P_{loss} = P_{to1} \cdot P_{to2} \quad (4.3)$$

4.2 Evaluation examples

Examples of the evaluated loss probability (P_{loss}) versus the traffic load (λ) are shown in Fig. 4. The curves show the loss probability for the waiting places of 2, 3 or 4 ($m=2, 3, 4$), assuming a 3 reforwarding timelag ($y=3$), a 1.2 service time, 6 and 3 timer values for response for the first and reforwarded messages ($t_f=6$ and $t_r=3$) and a transmission error rate (P_{te}) of 0.001. This figure indicates that the loss probability in the case of smaller waiting places is larger than that in the case of larger waiting places when λ is small. On the other hand when λ becomes larger, the loss probability in the case of larger waiting places becomes larger than that in the case of smaller waiting places. This is because the queue overflow rate has a bigger effect on the loss probability when λ is small, but when λ becomes large the effect of waiting overtime has a bigger effect on the loss probability.

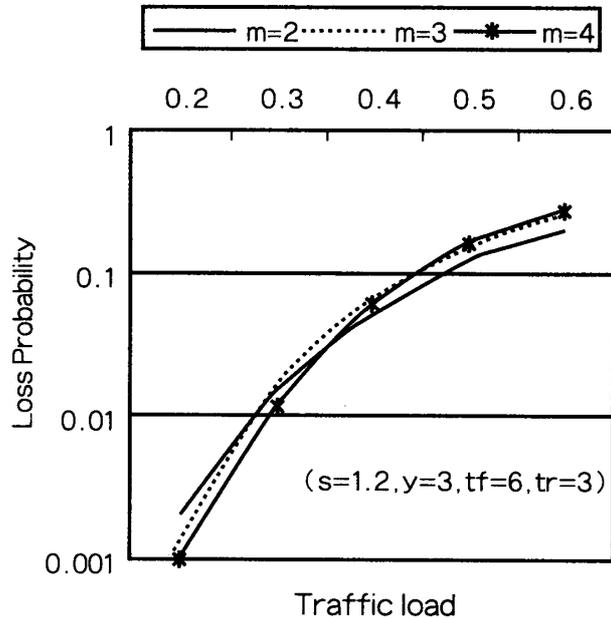


Fig. 4 Loss probability versus traffic load

The evaluated loss probability versus traffic load for the service time of 0.8, 1.0 or

1.2($s=0.8, 1.0, 1.2$), assuming a 3 reforwarding timelag ($y=3$), a 2 waiting places ($m=2$), 6 and a 3 timer values for first and reforwarded messages ($t_f=6$ and $t_r=3$) and a transmission error rate (P_{te}) of 0.001, is shown in Fig. 5. This figure shows that the loss probability becomes larger in proportional to the service time.

Examples of the evaluated overflow probability for first and reforwarded messages versus traffic load (λ), assuming 2 or 4 waiting places ($m=2, 4$), a 0.8 service time ($s=0.8$) and 3 reforwarding timelag ($y=3$), are shown in Fig.6. In this figure the evaluated overflow probability in the case that all messages arrives according to Poissonian process is also shown. These evaluation shows that the difference of the overflow probability between in the case of BPP input and Poissonian input becomes smaller when the number of waiting places becomes smaller.

Examples of the evaluated waiting-time distribution (waiting-overtime probability ($P(W_p > t)$)) for first and reforwarded messages, assuming 2 or 4 waiting places ($m=2, 4$), a 0.8 service time ($s=0.8$) and a 3 reforwarding timelag ($y=3$), are shown in Fig.7. In this figure the waiting-time distribution in the case that all messages arrive in the queue according to Poissonian

process is also shown. These evaluation shows that the difference of the waiting-time distribution between in the case of BPP input and Poissonian input becomes smaller when the number of waiting places becomes smaller. Fig.6 and Fig.7 show the traffic characteristics of one parent and one child BPP/D/1/N ($k=1$) model with vacation time whose service time and vacation time are the same.

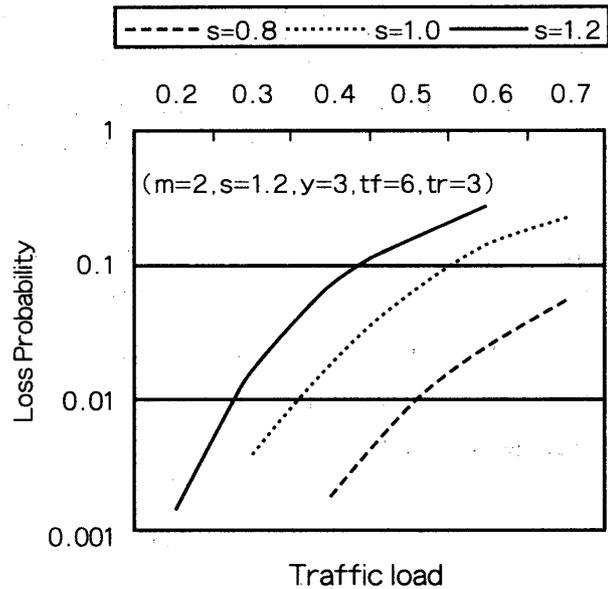


Fig. 5 Loss probability versus traffic load

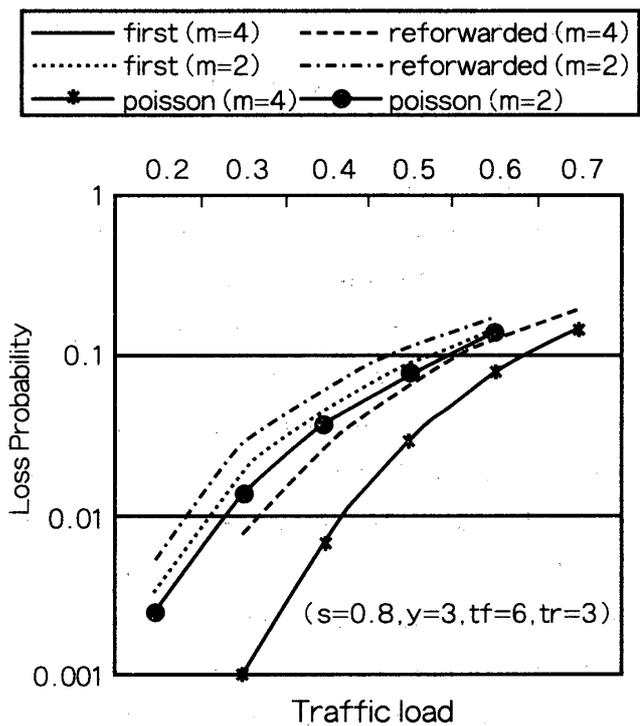


Fig. 6 Loss probability versus traffic load

4.3 Existence of the best reforwarding timelag

As the reforwarding timelag become larger, the overflow probability is considered to become smaller in these reforwarding scheme. On the other hands, the waiting overtime rate of the reforwarded SETUP message is considered to become larger. This is because that the timer t_f is constant independently of reforwarding timelag so when the reforwarding timelag becomes larger, t_r becomes smaller (Fig.8). Total loss probability is obtained by the sum of queue overflow rate and waiting overtime rate. Consequently, the best reforwarding timelag which minimizes the loss probability exists corresponding to the combination of design parameters, such as the number of waiting places, service time, timers for response, and so on.

Examples of the evaluated loss probability (P_{loss}) versus reforwarding timelag are shown in Fig. 9. The curves show the loss probability for the waiting places of 2, 3, 4 or 5 ($m=2, 3, 4, 5$), assuming a 0.5 traffic load ($\lambda=0.5$), a 0.8 service time ($s=0.8$), a 6 timer for response ($t_f=6$) and a transmission error rate (P_{te}) of 0.001. From this figure, we can obtain the best reforwarding timelag. For example, it is 2 when the number of waiting places is 4 and it is 3 when the number of waiting places is 2. This figure indicates that the best reforwarding timelag becomes larger when the number of waiting places becomes smaller.

5. Conclusion

We have presented a call-terminating control in which SETUP messages are forwarded and reforwarded periodically to each terminating group. We described a scheme for evaluating the probability that the network does not receive a

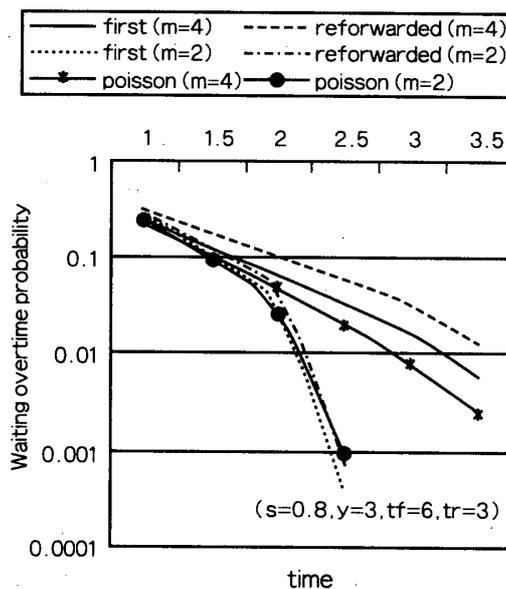


Fig. 6 Waiting overtime probability versus traffic load

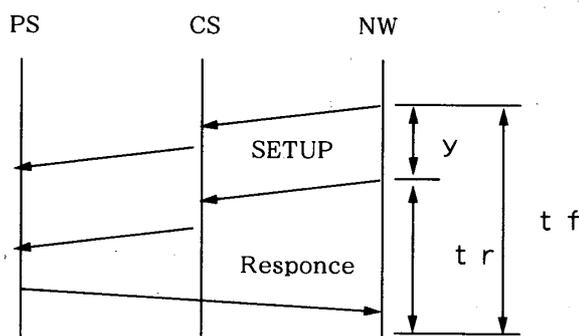


Fig. 8 Network timer

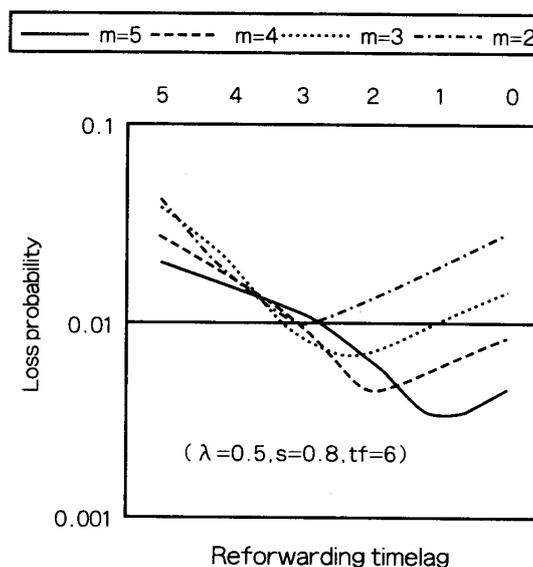


Fig. 9 Loss probability versus reforward timelag

response message within a given time. This queuing model is treated as an one parent and one child BPP/D/1/N model with vacation time. We evaluated the probability that the waiting time exceeds a given time (timeout rate).

Finally, using the proposed methods, we evaluated the relationships among the loss probability and the number of waiting places, the service time, the reforwarding timelag, and clarified the existence of best reforwarding timelag. The evaluation results obtained in this paper can be applied to the quality (loss probability) evaluation of a PCS network.

For further study we intend to perform an approximation analysis of these reforwarding scheme.

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