Talk Burst Control for Push-to-Talk over Cellular

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Abstract—Push-to-talk over Cellular (PoC) is a “walkie-talkie”-like service designed for mobile networks. In this service, the speak permission is arbitrated through the talk burst control (TBC) mechanism. This paper proposes an analytic model to study the performance of the TBC mechanism with queueing and without queueing. This analytic model is validated against simulation experiments. Through numerical examples, our study provides guidelines to set up the parameters for PoC service.

Index Terms—cellular network, Push-to-talk over Cellular (PoC), talk burst control, Voice over IP (VoIP)

I. INTRODUCTION

PUSH-TO-TALK over Cellular (PoC) [1], [2] is a “walkie-talkie”-like service designed for mobile networks. In this service, several predefined PoC group members participate in one PoC session. Since the PoC session is half-duplex, only one PoC member speaks at a time, and the others listen. When a PoC member attempts to speak, he/she presses the push-to-talk button of his/her mobile terminal to ask for the permission. This mobile terminal installed with the PoC application is called the PoC client. The speak permission is arbitrated through the talk burst control (TBC) mechanism defined in the Open Mobile Alliance (OMA) PoC specifications [3]. Based on the OMA specifications, an Open Service Access (OSA)-based PoC system is implemented in National Chiao-Tung University [4], [5].

In the OMA specification, TBC mechanism is implemented by finite state machines (FSMs) in both the client and the server sides. Figs. 1 and 2 illustrate simplified TBC FSMs for PoC server (called FSM_G) and PoC client (called FSM_U), where “U” represents “user” (i.e., for a specific PoC client) and “G” represents “general” (i.e., for the whole group). The prefixes “S:” and “R:” of the transitions represent “send” and “receive”, respectively. For a PoC session, there is one FSM_G in the PoC server and an FSM_U in each of the PoC clients. To clearly describe the PoC procedures, several terms are defined:

- The *session initiator* is the PoC client who initiates a PoC session.
- An *invited PoC client* is a PoC group member other than the session initiator.

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Fig. 1. TBC Finite State Machine for PoC Server (FSM_G).

- A *requesting PoC client* is a PoC client who requests for speak permission.
- The *permitted PoC client* is the PoC client who is allowed to speak.
- A *listening PoC client* is a PoC client who is not permitted to speak.
- A *queued PoC client* is a PoC client whose request is queued in the PoC server.

A PoC session can be initiated by any group member. Session Initiation Protocol (SIP) [6] and Session Description Protocol (SDP) [7] are utilized for session establishment. To support the PoC service, a new parameter “tb_grant” is added in SDP’s attribute field such that PoC server can arbitrate the speak permission during session establishment. If “tb_grant=1”, the PoC client is granted the permission to speak. Otherwise (i.e., “tb_grant=0”), the PoC client is not permitted to talk.

PoC is a new service in cellular networks. To our knowledge, all PoC studies have focused on call setup time and transmission delay of voice packets [8], [9], [10]. These studies did not consider the performance of TBC mechanism. Many TBC-related questions are not answered in these previous studies. These questions include the best setting of revoking time T_R , the maximum number N of group members that a mobile operator should support, etc. Based on the SIP/Real-time Transport Protocol (RTP) [11] protocols, we

 Fig. 2. TBC Finite State Machine for PoC Client (FSM_U).

describe the TBC mechanism, and then propose an analytic model to study the TBC mechanism. Based on our analytic/simulation models, we show how the input parameters affect the performance of the PoC service.

II. TBC MECHANISM

For the PoC clients and the PoC server involved in a PoC session, their FSMs are initialized at the **Start-stop** state (see Figs. 1 and 2). When the session initiator sends a SIP INVITE message to the PoC server, the PoC server broadcasts SIP INVITE messages with “tb_grant=0” to other group members (the invited PoC clients). Each of the invited PoC clients answers with a SIP 200 OK message and its FSM_U enters **U: has no permission** (transition 2 in Fig. 2). This state means that the PoC client is not permitted to speak.

After receiving the first SIP 200 OK message from the invited PoC clients, the PoC server replies a SIP 200 OK with “tb_grant=1” to the session initiator and FSM_G enters **G: TB_Taken** (transition 1 in Fig. 1). This state means that some PoC client (the session initiator in this case) has obtained the permission. FSM_U of the session initiator enters **U: has permission** (transition 1 in Fig. 2). This state means that the PoC client is allowed to speak. The session initiator becomes the permitted PoC client, and the invited PoC clients become listening PoC clients. At this moment, the session initiator speaks and all invited PoC clients listen.

After the PoC session is established, each of the PoC clients has built an RTP session with the PoC server. The TBC messages (with the prefix “TB”) between the PoC clients and the PoC server are carried by RTP Control Protocol (RTCP) packets [11]. After finishing the talk, the permitted PoC client releases the permission by sending the TB_Release message to the PoC server and its FSM_U enters **U: pending TB_Release** (transition 6 in Fig. 2). In this state, the PoC client stops

sending media packets and is waiting for the response from the PoC server. The sequence number of the last delivered media packet is included in the TB_Release message. FSM_G enters **G: pending TB_Release** after receiving the TB_Release message (transition 2 in Fig. 1). In this state, the PoC server keeps forwarding the transient media packets delivered before the TB_Release message is issued from the permitted PoC client. When the last transient media packet has been processed, FSM_G enters **G: TB_Idle** (transition 3 in Fig. 1). This state means that no PoC client is granted the permission to speak. The PoC server broadcasts the TB_Idle message to all PoC clients. FSM_U of the permitted PoC client enters **U: has no permission** upon receipt of the TB_Idle message (transition 7 in Fig. 2). A listening PoC client remains in **U: has no permission** when it receives the TB_Idle message (transition 14 in Fig. 2). At this point, all PoC clients can compete for the permission to speak.

To obtain the permission, a listening PoC client sends the TB_Request message to the PoC server. The PoC client becomes a requesting PoC client, where its FSM_U enters **U: pending TB_Request** (transition 3 in Fig. 2). This state means that the PoC client is waiting for the arbitration from the PoC server. If some other PoC client has been granted the permission, the PoC server sends the TB_Deny message to the requesting PoC client, and FSM_U of the requesting PoC client moves back to **U: has no permission** (transition 4 in Fig. 2). If the PoC server grants the permission to the requesting PoC client, it sends the TB_Granted message to this requesting PoC client and the TB_Taken message to other PoC clients. A timer T2 at the PoC server is started; this timer is used to determine whether the permitted PoC client speaks too long (and therefore should be revoked). FSM_G enters **G: TB_Taken** (transition 4 in Fig. 1), and FSM_U of the requesting PoC client enters **U: has permission** (transition 5 in Fig. 2). When a listening PoC client receives TB_Taken, its FSM_U remains at **U: has no permission**, and is not allowed to request for the permission. The requesting PoC client becomes the permitted PoC client.

If the permitted PoC client speaks longer than the T2 timeout period, the PoC server will start timer T3 and send the TB_Revoke message to stop the permitted PoC client. FSM_U of the permitted PoC client enters **U: pending TB_Revoke** upon receipt of the TB_Revoke message (transition 8 in Fig. 2). In this state, the PoC client can keep sending media packets until T3 expires. FSM_G enters **G: pending TB_Revoke** (transition 5 in Fig. 1). In this state, the PoC server keeps forwarding media packets until T3 expires. Then FSM_G enters **G: TB_Idle** (transition 6 in Fig. 1). The PoC server sends the TB_Idle message to all PoC clients. FSM_U of the permitted PoC client enters **U: has no permission** (transition 9 in Fig. 2) upon receipt of the TB_Idle message. When a listening PoC client receives TB_Idle, its FSM_U remains at **U: has no permission**. At this point, all PoC clients can compete for the permission to speak.

A queueing option is provided in the TBC mechanism. If this option is selected, then the ungranted requests are buffered in the queue at the PoC server instead of being denied. After the permitted PoC client finishes talking, the PoC server grants the next request from the queue. The state **U: queued** (see

Fig. 2 (A)) in FSM_U indicates that a request of the client is queued in the PoC server and will be granted later.

After a PoC client X has obtained the permission, the PoC server may receive the TB_Request message from another requesting PoC client Y. With the queueing option, FSM_G is in the **G: TB_Taken** state, and FSM_U of client Y is in the **U: pending TB_Request** state. The PoC server buffers the TB_Request message in the queue and replies the TB_Queued message to client Y. FSM_G stays in **G: TB_Taken** and FSM_U of client Y enters **U: queued** (transition 10 in Fig. 2). The PoC client of a queued request (called *queued PoC client*) may send the TB_Release message to the PoC server to cancel the request, and its FSM_U moves back to **U: has no permission** (transition 11 in Fig. 2). In this case, the PoC server removes the corresponding request from the queue. After the permission is released (or revoked), FSM_G will enter **G: TB_Idle**, and FSM_U of the permitted PoC client will enter **U: pending TB_Release** (or **U: pending TB_Revoke**). If the queue is not empty, the PoC server processes the next queued request instead of sending out the TB_Idle message. Then the granting procedure is performed at the PoC server. Therefore, the next queued PoC client will receive the TB_Granted message from the PoC server, and its FSM_U enters **U: has permission** (transition 12 in Fig. 2). This queued PoC client becomes the next permitted PoC client. At the same time, all other PoC clients receive the TB_Taken message from the PoC server. The previously-permitted PoC client becomes a listening PoC client, and its FSM_U enters **U: has no permission** (transition 7 or 9 in Fig. 2). FSM_U of every listening PoC client remains at **U: has no permission**, and FSM_U of every queued PoC client remains at **U: queued**.

When a PoC client leaves the PoC session, its FSM_U moves back to **Start-stop** (transition 13 in Fig. 2). The PoC session remains active for other PoC clients. After all PoC clients leave the PoC session, the PoC session is implicitly terminated. FSM_G moves back to **Start-stop** (transition 7 in Fig. 1).

III. ANALYTIC MODELING

This section models the PoC TBC mechanisms with queueing (Approach Q) and without queueing (Approach NQ). Let N be the number of PoC clients in a PoC group. We investigate two timers defined in FSM_G : (1) T2 is used to determine whether the PoC client speaks too long; (2) T3 is used to gracefully terminate the talk burst. For simplicity, we define T_R as the revoking timer where

$$T_R = T2 + T3$$

Three output measures are considered in our study:

- P_D : the probability that the request of a PoC client is not granted because the PoC client is not patient in Approach Q or because the PoC server rejects the request in Approach NQ
- P_R : the probability that a PoC client obtains the permission, but is revoked before it finishes the talk
- W (for Approach Q only): the expected waiting time of a request, i.e., the expected time between when a PoC client issues a request and when it is granted the permission to

speak or when it leaves the queue without being granted the permission

For a PoC client, we define the following input parameters:

- The inter-request time random variable τ_a with mean $1/\lambda$
- The speak time random variable τ_s with mean $1/\mu$ and variance V_s
- The impatient time random variable τ_i with mean $1/\omega$ and variance V_i (note that a queued PoC client will drop the request if it does not receive the permission within τ_i)
- The revoking time T_R (when $\tau_s > T_R$, the permitted PoC client is revoked); T_R is a fixed period

We assume that τ_a , τ_s and τ_i are exponentially distributed (i.e., $V_s = 1/\mu^2$, $V_i = 1/\omega^2$) in this section. The purpose of analytic model is two folds: to validate the simulation model and to provide mean value analysis. Mean value analysis based on exponential assumptions provides understanding on the “trend” of performance. The validated simulation relaxes the exponential assumptions to accommodate more general (and therefore more practical) scenarios such as those described in [12].

A. Modeling for Approach Q

The PoC TBC mechanism is modeled as a stochastic process. Fig. 3 illustrates the state transition rate diagram of the stochastic process where the state $K = k$ denotes that $k-1$ requests are waiting in the queue at the PoC server besides the permitted PoC client. In this figure, we define $\gamma(t)h$ to be the probability that the permitted PoC client is revoked during the interval $(t, t+h)$, where $h \rightarrow 0$. When the process is in state k , where $0 < k \leq N$, there are $N-k$ listening PoC clients, $k-1$ queued PoC clients, and a permitted PoC client. State 0 represents that all PoC clients are listening PoC clients. For any state k , there are $N-k$ listening PoC clients that may request for permission to speak. Therefore, the transition rate from state k to state $k+1$ is $(N-k)\lambda$. For any state k , where $0 < k \leq N$, there are $k-1$ queued PoC clients that may leave the queue with rate $(k-1)\omega$, and the permitted PoC client that may finish the talk with rate μ . Furthermore, the permitted PoC client may be revoked during the interval $(t, t+h)$ with probability $\gamma(t)h$. Therefore, at time t the transition rate from state k to state $k-1$ is $\mu + (k-1)\omega + \gamma(t)$.

Let $\pi_k(t)$ denote the probability that the number of requests in the system is k at time t . Then based on the state transition rate diagram in Fig. 3, we obtain the following differential difference equations [13]:

$$\pi_0'(t) = \pi_1(t)[\mu + \gamma(t)] - \pi_0(t)N\lambda \quad (1)$$

$$\begin{aligned} \pi_k'(t) = & \pi_{k-1}(t)(N-k+1)\lambda + \pi_{k+1}(t)[\mu + k\omega + \gamma(t)] \\ & - \pi_k(t)[\mu + (k-1)\omega + \gamma(t) + (N-k)\lambda] \end{aligned} \quad (2)$$

Under the assumption of statistical equilibrium (i.e., $t \rightarrow \infty$), Equations (1) and (2) are re-written as

$$0 = \pi_1(\mu + \gamma) - \pi_0 N \lambda \quad (3)$$

$$\begin{aligned} 0 = & \pi_{k-1}(N-k+1)\lambda + \pi_{k+1}(\mu + k\omega + \gamma) \\ & - \pi_k[\mu + (k-1)\omega + \gamma + (N-k)\lambda] \end{aligned} \quad (4)$$

Fig. 3. State Transition Rate Diagram for Approach Q.

where $\pi_i = \lim_{t \rightarrow \infty} \pi_i(t)$ and $\gamma = \lim_{t \rightarrow \infty} \gamma(t)$ is the revoking rate in equilibrium and will be derived later. Equations (3) and (4) are re-arranged to yield

$$\pi_1 = \frac{\pi_0 N \lambda}{\mu + \gamma} \quad (5)$$

$$\pi_{k+1} = \left[\frac{\mu + (k-1)\omega + \gamma + (N-k)\lambda}{\mu + k\omega + \gamma} \right] \pi_k - \left[\frac{(N-k+1)\lambda}{\mu + k\omega + \gamma} \right] \pi_{k-1} \quad (6)$$

From (5) and (6), we have

$$\pi_k = \left\{ \frac{\lambda^k \left[\prod_{j=0}^{k-1} (N-j) \right]}{\prod_{m=1}^k [\mu + (m-1)\omega + \gamma]} \right\} \pi_0 \quad (7)$$

where $1 \leq k \leq N$. Since $\sum_{k=0}^N \pi_k = 1$, (7) is solved to yield

$$\pi_0 = \left\{ 1 + \sum_{k=1}^N \frac{\lambda^k \left[\prod_{j=0}^{k-1} (N-j) \right]}{\prod_{m=1}^k [\mu + (m-1)\omega + \gamma]} \right\}^{-1} \quad (8)$$

The revoking rate γ is derived as follows. Let $p(\tau, t)h$ be the probability that the elapsed speak time (i.e., the member has talked for the period τ , and the talk has not been finished yet) is between $(\tau-h)$ and τ (where $h \leq \tau \leq T_R$, and $h \rightarrow 0$) at time t . The probability that the permitted PoC client finishes the talk in any interval h is μh . Since the elapsed speak time can advance from interval $(\tau-h, \tau)$ to interval $(\tau, \tau+h)$ only if the permitted PoC client does not finish the talk (with probability $1 - \mu h$) during the interval $(t, t+h)$, we have

$$p(\tau+h, t+h)h = p(\tau, t)h(1 - \mu h) \quad (9)$$

From (9), we have

$$\frac{p(\tau+h, t+h) - p(\tau, t)}{h} = -\mu p(\tau, t) \quad (10)$$

Let $h \rightarrow 0$, (10) is expressed as

$$\frac{\partial p(\tau, t)}{\partial \tau} + \frac{\partial p(\tau, t)}{\partial t} = -\mu p(\tau, t) \quad (11)$$

When $t \rightarrow \infty$, $\frac{\partial p(\tau, t)}{\partial t} = 0$, and (11) is re-written as

$$\frac{\partial p(\tau, \infty)}{\partial \tau} = -\mu p(\tau, \infty) \quad (12)$$

Equation (12) has the general solution

$$p(\tau, \infty) = A e^{-\mu \tau} \quad (13)$$

From (13) and since $\int_0^{T_R} p(\tau, \infty) d\tau = 1$, we have

$$A = \frac{\mu}{1 - e^{-\mu T_R}} \quad (14)$$

From (13) and (14), we have

$$p(\tau, \infty) = \frac{\mu e^{-\mu \tau}}{1 - e^{-\mu T_R}} \quad (15)$$

For any interval $(t, t+h)$, a permitted PoC client is revoked if and only if the member has talked for the period τ at time t , where $T_R - h < \tau < T_R$. Therefore, for any interval h in equilibrium, the revoking probability γh is equal to $p(T_R, \infty)h$. In other words, the revoking rate $\gamma = p(T_R, \infty)$. From (7), (8) and (15), we have

$$\pi_k = \left\{ \frac{\lambda^k \left[\prod_{j=0}^{k-1} (N-j) \right]}{\prod_{m=1}^k [\mu + (m-1)\omega + \frac{\mu e^{-\mu T_R}}{1 - e^{-\mu T_R}}]} \right\} \times \left\{ 1 + \sum_{k=1}^N \frac{\lambda^k \left[\prod_{j=0}^{k-1} (N-j) \right]}{\prod_{m=1}^k [\mu + (m-1)\omega + \frac{\mu e^{-\mu T_R}}{1 - e^{-\mu T_R}}]} \right\}^{-1} \quad (16)$$

where $1 \leq k \leq N$.

The expected queue length is $E[K] = \sum_{k=0}^N k \pi_k$. From (16), we have

$$E[K] = \left\{ \sum_{k=1}^N \frac{k \lambda^k \left[\prod_{j=0}^{k-1} (N-j) \right]}{\prod_{m=1}^k [\mu + (m-1)\omega + \frac{\mu e^{-\mu T_R}}{1 - e^{-\mu T_R}}]} \right\} \times \left\{ 1 + \sum_{k=1}^N \frac{\lambda^k \left[\prod_{j=0}^{k-1} (N-j) \right]}{\prod_{m=1}^k [\mu + (m-1)\omega + \frac{\mu e^{-\mu T_R}}{1 - e^{-\mu T_R}}]} \right\}^{-1}$$

Let λ^* be the expected request rate to the PoC server. Then

$$\lambda^* = \sum_{k=0}^N (N-k) \lambda \pi_k = \lambda (N - E[K]) \quad (17)$$

Since a PoC client leaves the system without being granted the permission to speak if its waiting time in the queue is longer than its impatient time, P_D can be expressed by

$$P_D = \frac{\text{the number of requests leaving the queue due to impatience}}{\text{the number of total request arrivals}} \quad (18)$$

From (17) and (18), we have

$$P_D = \frac{\sum_{k=1}^N (k-1) \omega \pi_k}{\lambda^*} = \frac{\omega \{E[K] - (1 - \pi_0)\}}{\lambda \{N - E[K]\}}$$

Similarly, P_R can be expressed by

$$P_R = \frac{\text{the number of revoked requests}}{\text{the number of total request arrivals}} \quad (19)$$

Fig. 4. State Transition Rate Diagram for Approach NQ.

From (17) and (19), we have

$$P_R = \frac{\sum_{k=1}^N \gamma \pi_k}{\lambda^*} = \frac{\mu e^{-\mu T_R} (1 - \pi_0)}{\lambda \{N - E[K]\} (1 - e^{-\mu T_R})}$$

Let random variable K_Q be the number of requests in the queue at the PoC server and random variable K_S be the number of permitted PoC clients, then $K = K_Q + K_S$ and

$$E[K] = E[K_Q] + E[K_S] \quad (20)$$

Note that $K_S = 1$ when system is busy (i.e., some PoC client is speaking), and $K_S = 0$ when system is idle (i.e., no PoC client is speaking). Therefore,

$$E[K_S] = 1 \times \left(\sum_{k=1}^N \pi_k \right) + 0 \times \pi_0 = 1 - \pi_0 \quad (21)$$

From Little's result [13], $E[K_Q]$ is expressed as

$$E[K_Q] = \lambda^* W \quad (22)$$

From (17), (20), (21) and (22), we have

$$W = \frac{E[K_Q]}{\lambda^*} = \frac{E[K] - (1 - \pi_0)}{\lambda \{N - E[K]\}}$$

B. Modeling for Approach NQ

Fig. 4 illustrates the state transition rate diagram for Approach NQ. State $K = 0$ represents that no PoC client has the permission, and state $K = 1$ represents that a PoC client is speaking. When the stochastic process is in state 0, there are N listening PoC clients that may request for the permission to speak. Therefore, the transition rate from state 0 to state 1 is $N\lambda$. When the process is in state 1, the permitted PoC client may finish the talk with rate μ , and may be revoked during the interval $(t, t+h)$ with probability $\gamma(t)h$. Therefore, the transition rate from state 1 to state 0 is $\mu + \gamma(t)$ at time t . Similar to the derivation for Approach Q, the following relation at equilibrium is derived:

$$\pi_1 = \frac{N\lambda\pi_0}{\mu + \frac{\mu e^{-\mu T_R}}{1 - e^{-\mu T_R}}} = \frac{N\lambda(1 - e^{-\mu T_R})\pi_0}{\mu} \quad (23)$$

Since $\pi_0 + \pi_1 = 1$, (23) is solved to yield

$$\pi_0 = \frac{\mu}{\mu + N\lambda(1 - e^{-\mu T_R})} \quad \text{and} \quad \pi_1 = \frac{N\lambda(1 - e^{-\mu T_R})}{\mu + N\lambda(1 - e^{-\mu T_R})} \quad (24)$$

Since a requesting PoC client leaves the system as soon as it finds that the system is busy (i.e., some PoC client is speaking), P_D can be expressed by

$$P_D = \frac{\text{number of request arrivals when system is busy}}{\text{number of total request arrivals}} \quad (25)$$

TABLE I
COMPARISON OF ANALYTIC AND SIMULATION MODELS ($V_s = 1/\mu^2$, $N = 10$, $\omega = \mu$, $V_i = 1/\omega^2$, $T_R = 3/\mu$)

(a) Approach Q

λ	0.005μ	0.05μ
$P_D(\text{Analytic})$	0.0205	0.1779
$P_D(\text{Simulation})$	0.0201	0.1755
Error	1.81 %	1.32 %
$P_R(\text{Analytic})$	0.0488	0.0409
$P_R(\text{Simulation})$	0.04881	0.0410
Error	0.02 %	0.24 %
$W(\text{Analytic})$	$0.0205/\mu$	$0.1779/\mu$
$W(\text{Simulation})$	$0.0202/\mu$	$0.1748/\mu$
Error	1.61 %	1.76 %

(b) Approach NQ

λ	0.005μ	0.05μ
$P_D(\text{Analytic})$	0.0410	0.2995
$P_D(\text{Simulation})$	0.0416	0.3003
Error	1.46 %	0.27 %
$P_R(\text{Analytic})$	0.0477	0.0349
$P_R(\text{Simulation})$	0.04775	0.03484
Error	0.10 %	0.16 %

From (17), (24) and (25), we have

$$P_D = \frac{(N-1)\lambda\pi_1}{\lambda^*} = \frac{(N-1)\lambda(1 - e^{-\mu T_R})}{\mu + (N-1)\lambda(1 - e^{-\mu T_R})}$$

Similar to the derivation for Approach Q, we derive P_R from (17) and (24) as

$$P_R = \frac{\gamma\pi_1}{\lambda^*} = \frac{\mu e^{-\mu T_R}}{\mu + (N-1)\lambda(1 - e^{-\mu T_R})}$$

The above analytic model is validated against the discrete event simulation experiments. The discrete event simulation model is similar to that described in [14], and the details are omitted. As shown in Table I (where $V_s = 1/\mu^2$, $N = 10$, $\omega = \mu$, $V_i = 1/\omega^2$, and $T_R = 3/\mu$), the analytic analysis is consistent with the simulation results.

IV. NUMERICAL EXAMPLES

Based on the simulation experiments validated against the analytic model, this section investigates the performance of the TBC mechanism. Suppose that τ_a is exponentially distributed with mean $1/\lambda$ [15], τ_s has the Gamma distribution with mean $1/\mu$ and variance V_s , and τ_i has the Gamma distribution with mean $1/\omega$ and variance V_i . The Gamma distribution is selected because it has been shown that the distribution of any positive random variable can be approximated by a mixture of Gamma distributions (see Lemma 3.9 in [16]). Following the past experience [17], we can measure the PoC speak times and impatience times from the field and then generate the Gamma distribution from the measured data. In our study, the range for N is selected based on commercial operation. For example, ChungHwa Telecom (CHT) has limited N to 20 (that is, at most 20 members can be defined in a group before the PoC session is initiated). Also note that finite population with Poisson arrival is widely used in commercial PoC network planning by mobile operators (e.g., FarEasTone or FET [17])

Fig. 5. Effects of N and λ on P_D ($\omega = \mu$, $V_i = 1/\omega^2$, $V_s = 1/\mu^2$, $T_R = 3/\mu$).

and is followed in this paper. The PoC members are allowed to join in and to leave the PoC session at any time during the session, which can be accommodated in the simulation model. The effects of the input parameters are investigated as follows.

Effects of N and λ on P_D : Under the conditions that $\omega = \mu$, $V_i = 1/\omega^2$, $V_s = 1/\mu^2$, $T_R = 3/\mu$, Fig. 5 indicates that for the same P_D performance, Approach Q can support twice as many clients as Approach NQ does. For example, when $\lambda = 0.003\mu$, to maintain $P_D = 0.05$, $N = 38$ can be supported in Approach Q and $N = 19$ in Approach NQ (therefore, the maximum number N of group members should be set to 38 for Approach Q and 19 for Approach NQ, respectively). For both Q and NQ approaches, when λ increases, the number N supported in the PoC service decreases. For example, to maintain $P_D = 0.05$ in Approach NQ, $N = 51$ can be supported when $\lambda = 0.001\mu$, $N = 27$ when $\lambda = 0.002\mu$, and $N = 19$ when $\lambda = 0.003\mu$. We observe that the discrepancy of the P_D performance between Approach Q and Approach NQ decreases as ω increases. Approach Q is better than Approach NQ for all ω values (not shown in this paper). When $\omega = 0.5\mu$, Approach Q can support 6 times as many clients as Approach NQ does. When $\omega = 100\mu$, Approach Q can only support 1.1 times as many clients as Approach NQ does.

Effects of μ and V_s on P_D and P_R : In the remainder of this section, we only consider Approach Q. Similar results are also observed in Approach NQ. Fig. 6 indicates that both P_D and P_R increase and then decrease as V_s increases (where $\lambda = 0.005\omega$, $N = 10$, $V_i = 1/\omega^2$, and $T_R = 3/\mu$). This phenomenon is explained as follows. When the variance V_s is small (e.g., $V_s \leq 1/100\mu^2$), all speak times are about the same length. As V_s increases, two effects are observed: (I) more speak times longer than T_R are observed. These speak times are revoked and result in larger P_D and P_R , (II) more short speak times are also observed, which result in smaller P_D and P_R . As V_s increases, Effect (I) is more significant when

Fig. 6. Effects of μ and V_s on P_D and P_R for Approach Q ($\lambda = 0.005\omega$, $N = 10$, $V_i = 1/\omega^2$, $T_R = 3/\mu$).

Fig. 7. Effects of ω and V_i on P_D and W for Approach Q ($\lambda = 0.005\mu$, $N = 10$, $V_s = 1/\mu^2$, $T_R = 3/\mu$).

V_s is small, and Effect (II) is more significant when V_s is large. Therefore, both P_D and P_R increase and then decrease as V_s increases.

Effects of ω and V_i on P_D and W : Fig. 7 shows that P_D is an increasing function of V_i , and W is a decreasing function of V_i (where $\lambda = 0.005\mu$, $N = 10$, $V_s = 1/\mu^2$, and $T_R = 3/\mu$). As V_i increases, more short and long impatient times are observed. Short impatient times result in larger P_D and shorter W , while long impatient times result in smaller P_D and longer W . It is observed that the effect of short impatient times is more significant than long impatient times. Therefore, the net effect is that as V_i increases, P_D increases and W decreases. The figure also indicates that when V_i is very large, P_D is not sensitive to the ω values. That is, the effect of ω becomes less significant as V_i increases.

Effect of T_R on P_D : Fig. 8 shows that P_D increases as T_R increases (where $\lambda = 0.005\mu$, $\omega = \mu$, $V_s = 1/\mu^2$, and $V_i = 1/\omega^2$). For a fixed P_D , if more clients are supported, a very short revoking time must be enforced to limit the speak times. For example, to maintain $P_D = 0.021$, the system can support $N = 10$ for $T_R = 4/\mu$ and $N = 30$ for $T_R = 0.75/\mu$.

Fig. 8. Effects of T_R on P_D for Approach Q ($\lambda = 0.005\mu$, $\omega = \mu$, $V_s = 1/\mu^2$, $V_i = 1/\omega^2$).

V. CONCLUSIONS

In PoC service, the speak permission is arbitrated through the TBC mechanism. This paper investigated the performance of the TBC mechanism for PoC service with queueing (Approach Q) and without queueing (Approach NQ). Our study indicates the following:

- As the request rate λ increases, the maximum number N of group members can be supported in the PoC service decreases.
- Both the ungranting probability P_D and the revoking probability P_R increase and then decrease as the variance V_s of speak times increases.
- P_D is an increasing function of the variance V_i of the impatient times. The expected waiting time W of a request is a decreasing function of V_i . The effect of the impatient rate ω on P_D and W becomes less significant as V_i increases.
- For a fixed P_D , if more clients are supported, a very short revoking time must be enforced to limit the speak times.

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