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APPROXIMATE METHOD FOR QoS ANALYSIS OF WIRELESS CELLULAR NETWORKS WITH IMPATIENCE CALLS

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Introduction. It is known that in cellular wireless network (CWN) handover calls (h-calls) are more susceptible to possible losses and delays than new calls (o-calls). That is why a number of different schemes for prioritization of h-calls are suggested in various works, mostly implying use of guard channels for h-calls and/or creating of a queue of h-calls in base station (BS). However joint use of these schemes allows add to the improving QoS metrics of h-calls. The required h-calls queue arranging can be realized in networks where micro-cells are covered by a certain macro-cell, i.e. there exists a certain zone within which mobile subscribers (MS) can be handled in any of the neighboring cells. The time of user crossing the h-zone is called the degradation interval. With user entering the h-zone one checks the availability of free channels in a new cell. If the free channel exists, then it immediately occupy the channel and h-procedure is supposed to be successfully completed on the given stage; otherwise the given h-call keeps on using the channel of old (previous) cell concurrently queuing for a certain channel of a new cell to be empty. If the free channel does not appear in the new cell before completing the degradation interval, then the forced call interruption of h-call occurs.

Here note that the models of single cell in CWN with queue for h-calls are most investigated (see, e.g. [1]-[3] and references therein). In order to compensate chances of o-calls a queue (finite or infinite) is required for them, while keeping high chances for h-calls to access the system via reservation of channels. This scheme allows improve the total throughput of the cell. The models in which queues of o-calls are allowed are investigated in [4], [5] (see references therein also).

Here we consider models of isolated cell of CWN with guard channels for h-calls and queues for both types of impatience calls [6]. In [6] models with finite queues are considered only and approach which is based on Mason's formula to calculation of QoS metrics is proposed. However, the proposed in [6] approach becomes inefficient even for the cell with moderate size of buffers for heterogeneous calls. Therefore, in this paper an efficient and refined approximate method to calculation of QoS metrics is proposed. Our approach is based on state space merging of two-dimensional Markov chains (2-D MC) [7]. As a result the desired QoS metrics can be obtained without any computational problems for the models any dimensions (including infinite queues) since for their calculation the simple-closed expressions are developed.

2. System Model. The cell contains $N>1$ radio channels which are used by Poisson flows of new calls (with intensity λ_o) and handover calls (with intensity λ_h). With user entering the h-zone one checks the availability of free channels in a new cell. If the free channel exists, then it immediately occupy the channel and h-procedure is supposed to be successfully completed on the given stage; otherwise the given h-call keeps on using the channel of old (previous) cell concurrently will be join the queue for a certain channel of a new cell to be empty or blocked due to buffer overflow (if buffer size is finite). If the free channel does not appear in the new cell before completing the degradation interval, then the forced call interruption of h-call occurs. The system provides a buffer with size R_h for h-calls in the h-zone and the degradation interval is assumed to be exponential distributed with mean τ_h^{-1}.

The o-call entered is received only when the number of free channels is greater than g; otherwise it will be put in the buffer with size R_o or blocked due to buffer overflow. At the moment of clearing of the channel the choice of a call from the queue is carried out as follows.

If at this moment number of free channels is greater than g one o-call select from queue (if those are available) for service; otherwise the released channel stands idle even in the presence of queue of o-calls. A channel does not stand idle at presence in queue of h-calls. The queued o-call reneges from the buffer unless it can be successfully served within in patience time which has exponential distribution with mean τ_o^{-1}.

Distribution functions of channel occupancy time of both types of calls are assumed to be exponential with same mean μ^{-1}. If during call handling handover procedure is initiated, the remaining handling time of this call in a new cell (yet as an h-call) is also exponentially distributed with the same mean due to memoryless property of exponential distribution. Our goal is developing an approximate method to calculate the QoS metrics of the described models including blocking (dropping) probability of heterogeneous calls as well as their average queue length.

3. The Method. The state of system at any time is described by two-dimensional vector $\boldsymbol{k}=(k_1, k_2)$, where k_1 is indicate the total number of busy channels and h-calls in the buffer and k_2 is the number of o-calls in the buffer. Then state space of appropriate 2-D MC is given by:

$$S = \bigcup_{i=0}^{R_o} S_i \ , \tag{1}$$

where

$$S_0 := \{\boldsymbol{k} : k_1 = 0,1,\ldots, N + R_h ; k_2 = 0\};\ S_i := \{\boldsymbol{k} : k_1 = N - g, N - g + 1,\ldots, N + R_h ; k_2 = i\}, i \geq 1.$$

Elements of generating matrix of this MC, $\boldsymbol{k},\boldsymbol{k}'\in S$, are determined from following relations:

$$q(\boldsymbol{k},\boldsymbol{k}') = \begin{cases} \lambda_o + \lambda_h, & \text{if } k_1 \leq N - g - 1, k_2 = 0, \boldsymbol{k}' = \boldsymbol{k} + \boldsymbol{e}_1, \\ \lambda_o, & \text{if } k_1 \geq N - g, \boldsymbol{k}' = \boldsymbol{k} + \boldsymbol{e}_2, \\ \lambda_h, & \text{if } k_1 \geq N - g, \boldsymbol{k}' = \boldsymbol{k} + \boldsymbol{e}_1, \\ f(k_1)\mu + (k_1 - N)^+ \tau_h, & \text{if } \boldsymbol{k}' = \boldsymbol{k} - \boldsymbol{e}_1, \\ (N-g)\mu\delta(k_1, N-g) + k_2\tau_o, & \text{if } \boldsymbol{k}' = \boldsymbol{k} - \boldsymbol{e}_2, \\ 0 & \text{in other cases,} \end{cases} \tag{2}$$

where $\boldsymbol{e}_1=(1,0)$, $\boldsymbol{e}_2=(0,1)$, $f(x)=min(x,N)$, $x^+=\max(0,x)$ and $\delta(i,j)$ are Kronecker's symbols.

Average number of o-calls (L_o) and h-calls (L_h) in queue as well as average number of busy channels (N_{av}) are determined as following marginal distributions of initial 2-D MC:

$$L_o = \sum_{k_2=1}^{R_o} k_2 \sum_{k_1=N-g}^{N+R_h} p(k_1, k_2), \tag{3}$$

$$L_h = \sum_{k_1=N+1}^{N+R_h} (k_1 - N) \sum_{k_2=0}^{R_o} p(k_1, k_2), \tag{4}$$

here $p(\boldsymbol{k})$ – stationary probability of state $\boldsymbol{k}\in S$.

To calculate the blocking probability of o-calls (P_o) the following approach can be used. As it was mentioned above, blocking of o-calls might be occurring in following cases: (i) at the moment of arriving of o-calls the buffer is full; (ii) waiting time of o-call in buffer exceeds a given threshold τ_o^{-1}. Therefore, the desired QoS metric is defined as follows:

$$P_o = \sum_{k_1=N-g}^{N+R_h} p(k_1, R_o) + \frac{1}{\lambda_o} \sum_{k_2=1}^{R_o} k_2 \tau_o \sum_{k_1=N-g}^{N+R_h} p(k_1, k_2). \tag{5}$$

In (5) first term of sum indicate probability of the event (i) while second one is probability of the event (ii). By same way we conclude that dropping of h-calls might be occurring in following cases: (iii) at the moment of arriving of h-calls the buffer is full; (iv) degradation interval is finished earlier than h-call get admission to channel. Therefore, this metric is calculated as

$$P_h = \sum_{k_2=0}^{R_o} p(N+R_h, k_2) + \frac{1}{\lambda_h} \sum_{k_1=N+1}^{N+R_h} (k_1 - N)\tau_h \sum_{k_2=0}^{R_o} p(k_1, k_2). \tag{6}$$

The formula (6) has comments analogically to formula (5). Stationary distribution $p(\boldsymbol{k})$, $\boldsymbol{k} \in S$ is determined as a result of solution of an appropriate set of equilibrium equations (SEE) of the given 2-D MC (see [6]). For this SEE no analytic solution for state probabilities can be found and application of the method proposed in [6] has a lot of computational difficulties even at moderate values of R_o and R_h. To overcome the mentioned difficulties, new approach for calculation of QoS metrics of the investigated model is suggested below.

In presentation (1) transition intensities within classes S_i are essentially higher than those between states of different classes. Stationary distribution within class S_j is determined as

$$\rho_0(i) = \begin{cases} \dfrac{\nu^i}{i!} \cdot \rho_0(0), & 1 \le i \le N-g, \\ \left(\dfrac{\nu}{\nu_h}\right)^{N-g} \cdot \dfrac{\nu_h^i}{i!} \cdot \rho_0(0), & N-g+1 \le i \le N, \\ \dfrac{\nu^{N-g}}{N!} \cdot \nu_h^g \cdot \prod\limits_{j=N+1}^{i} \dfrac{\lambda_h}{N\mu + (j-N)\tau_h} \cdot \rho_0(0), & N+1 \le i \le N+R_h, \end{cases} \tag{7}$$

where $\nu_x := \lambda_x/\mu$, $x \in \{o,h\}$,

$$\nu := \nu_o + \nu_h, \; \rho_0(0) = \left(\sum_{i=0}^{N-g} \frac{\nu^i}{i!} + \left(\frac{\nu}{\nu_h}\right)^{N-g} \cdot \sum_{i=N-g+1}^{N} \frac{\nu_h^i}{i!} + \frac{\nu^{N-g}}{N!} \cdot \nu_h^g \cdot \sum_{j=N+1}^{N+R_h} \prod_{i=N+1}^{j} \frac{\lambda_h}{N\mu + (i-N)\tau_h} \right)^{-1}.$$

All split models with state space S_i, $i \ge 1$ represents same 1-D BDP in which birth rates are constant and equal λ_h while death rates are state-dependent and for state j, $j = N-g, \ldots, N+R_h$ is defined as $f(j)\mu + (j-N)^+ \tau_h$. Thus, stationary distribution within class S_i, $i \ge 1$ is defined as follows (since all models have same distributions below subscript is omitted):

$$\rho(j) = \begin{cases} \dfrac{\nu_h^{\,j}}{j!} \cdot \dfrac{(N-g)!}{\nu_h^{N-g}} \cdot \rho(N-g), & N-g+1 \le j \le N, \\ \nu_h^g \cdot \dfrac{(N-g)!}{N!} \cdot \prod\limits_{i=N+1}^{j} \dfrac{\lambda_h}{N\mu + (i-N)\tau_h} \cdot \rho(N-g), & N+1 \le j \le N+R_h, \end{cases} \tag{8}$$

where $\rho(N-g) = \left(1 + \nu_h^g \cdot (N-g)! \left(\sum_{i=N-g+1}^{N} \frac{\nu_h^{i-N}}{i!} + \frac{1}{N!} \cdot \sum_{j=N+1}^{N+R_h} \prod_{i=N+1}^{j} \frac{\lambda_h}{N\mu + (i-N)\tau_h} \right) \right)^{-1}$.

Then, from (2), (7) and (8) elements of generating matrix of a merged model are found:

$$q(<i'>, <i''>) = \begin{cases} \tilde{\lambda}_o, & \text{if } i'=0, i''=1, \\ \lambda_o, & \text{if } i'>0, i''=i'+1, \\ ((N-g)\mu + i'\tau_o)\rho(N-g) + i'\tau_o(1-\rho(N-g)), & \text{if } i''=i'-1, \\ 0 & \text{in other cases}, \end{cases} \tag{9}$$

where $\tilde{\lambda}_o := \lambda_o \left(1 - \sum_{i=0}^{N-g-1} \rho_0(i) \right)$.

Consequently, stationary distribution of a merged model is determined as follows:

$$\pi(< j >) = \frac{\tilde{\lambda}_o \lambda_o^{j-1}}{\prod_{i=1}^{j} q(< i >, < i-1 >)} \cdot \pi(< 0 >),\ j = 1, ..., R_o, \tag{10}$$

where $\pi(< 0 >) = \left(1 + \tilde{\lambda}_o \sum_{i=1}^{R_o} \frac{\lambda_o^{i-1}}{\prod_{j=1}^{i} q(< i >, < i-1 >)}\right)^{-1}$.

Finally, by using (7)-(10) we can obtain stationary distribution of an initial model. Thus, from (3) we conclude that the average number of o-calls in buffer can be approximately calculated as follows:

$$L_o \approx \sum_{i=1}^{R_o} i \sum_{j=N-g}^{N+R_h} \rho(j)\pi(< i >) = \sum_{i=1}^{R_o} i\pi(< i >) \sum_{j=N-g}^{N+R_h} \rho(j) = \sum_{i=1}^{R_o} i\pi(< i >).$$

The approximate value of an average number of h-calls in buffer is calculated as (see (4)):

$$L_h \approx \sum_{i=1}^{R_h} i \sum_{j=0}^{R_o} \rho_j (N+i)\pi(< j >) = \sum_{i=1}^{R_h} i(\rho_0 (N+i)\pi(< 0 >) + \rho(N+i)(1 - \pi(< 0 >))).$$

Blocking probability of o-calls approximately can be calculated as (see (5))

$$P_o \approx \sum_{i=N-g}^{N+R_h} \rho_{R_0}(i)\pi(< R_o >) + \frac{\tau_o}{\lambda_o} \sum_{j=1}^{R_o} j \sum_{i=N-g}^{N+R_h} \rho(i)\pi(< j >) = \pi(< R_o >) + \frac{\tau_o}{\lambda_o} \sum_{j=1}^{R_o} j\pi(< j >).$$

By same way we have (see (6))

$$P_h \approx \rho_0 (N + R_h)\pi(< 0 >) + \rho(N + R_h)(1 - \pi(< 0 >)) +$$
$$+ \frac{\tau_h}{\lambda_h} \sum_{i=1}^{R_h} i(\rho_0 (N+i)\pi(< 0 >) + \rho(N+i)(1 - \pi(< 0 >))).$$

5. Conclusion. In this paper a simple-closed expression for approximate calculation of QoS metrics of isolated cell of wireless networks with finite queues of both new and handover calls are developed. It is assumed that the degradation interval of h-calls is random variable with finite mean and o-calls in queue are impatience. The developed approach allows design these networks without any computational difficulties. Also note that it help us to solve the problems related to finding the both optimal sizes of buffers for heterogeneous calls and/or optimal number of guard channels in order to satisfy given constrains to QoS metrics. These kinds of problems are subject to further works.

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