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ANALYZING MEAN BIT RATE OF MULTICAST VIDEO CONFERENCE IN LTE NETWORK WITH ADAPTIVE RADIO ADMISSION CONTROL SCHEME*

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The concept of getting services and applications at "any time" and at "any place" requires the corresponding development of cellular networks, namely in LTE networks. At present, there is a lack of quality of service related recommendations describing various popular services, e.g., video conferencing. The problem is to find the optimal bit rate values for this service while not affecting the background lower priority services. In this paper we propose an instrument for solving this problem. First, we obtain mathematical model in the form of a queueing system with multicast high-priority traffic and unicast background traffic. The admission control assumes the adaptive bit rate change of multicast traffic and unicast traffic interruption. Second, we obtain the recursive algorithm for calculating mean bit rate and other performance measures. Third, we study the problem of optimizing mean bit rate.

1. Introduction

Fourth-generation cellular LTE (long term evolution) and LTE-Advanced networks deployment is inseparably connected with maintaining the quality of service (QoS) and enhancing the customer base [10]. Meeting the corresponding radio resource related requirements is the primary aim of radio resource management (RRM). Managing radio resources encompasses radio admission control (RAC), dynamic resource allocation, inter-cell interference coordination (ICIC), etc. RAC schemes are closely related to the types of services provided to customers. The 3rd Generation Partnership Projet (3GPP) specifications (TS 36.300, TS 23.401, TS 23.203) for LTE and LTE-Advanced networks specify nine service classes (QoS class identifier, QCI) that differ in terms of the bit-rate, priority level, and packet error loss.

Each of the nine service classes could be provided on guaranteed bit rate (GBR) or on non-guaranteed bit rate (non-GBR). The first four classes are GBR services, e.g., video on demand (VoD), and the other five classes are non-GBR services, e.g., web browsing, email. GBR services could be provided not only on one value of bit rate. Its bit rate can change from a maximum value, the so-called maximum bit rate (MBR), to a minimum value, GBR, depending on the cell load and RAC scheme. These bit rate changes do not alter the service duration, whereas the bit rate changes for non-GBR services result in varying the service duration. According to these principles, in terms of teletraffic and queuing theories, services provided on GBR correspond to streaming traffic [5], and services provided without GBR correspond to elastic traffic. In accordance with the two communication technologies point-to-point and point-to-multipoint, streaming traffic is divided into two subtypes: unicast and multicast traffics. Unlike unicast traffic, multicast traffic has a network resources saving nature, which is achieved through employing multicast technology. Thus, overall LTE traffic may be divided into three types: unicast streaming, multicast streaming, and elastic traffics.

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Each of the service classes is associated with a key attribute called the allocation and retention priority (ARP). The value of ARP is used by the RAC as a flag for admitting or rejecting requests of users for service. According to 3GPP TS 23.203: "The range of the ARP priority level is 1 to 9 with 1 as the highest level of priority. The pre-emption capability information defines whether a service data flow can get resources that were already assigned to another service data flow with a lower priority level. The pre-emption vulnerability information defines whether a service data flow can lose the resources assigned to it in order to admit a service data flow with a higher priority level." In accordance with this definition, ARP contains three information fields, namely, priority value, pre-emption capability, and pre-emption vulnerability. The priority value is used for differentiation purposes and ensures that the request for service with a higher priority level will be accepted. Note that the highest priority, which is equal to 1, is assigned to signalling traffic, followed by GBR services, priority values from 2 to 5, and the last non-GBR services has the lowest priority from the sixth to the ninth.

From the above 3GPP definition of "pre-emption," it is evident that during a lack of radio resources, assigning it to lower priority services could be realized, at best, through service degradation, which is also referred to as bandwidth adaptation or partial pre-emption, or, at worst, through service interruption, which is also referred to as cutoff process or full pre-emption. The 3GPP specifications do not specify RAC schemes, and operators have to develop and select an optimal scheme accounting for the service level agreement. Researchers have proposed various RAC schemes [1,8,9,11,12] with different approaches to pre-empting. Nevertheless, the basic principle of service degrading and interrupting holds.

The admission control is realized on a bit rate basis [8,9,11] or on a cell load basis [1,12]. Pre-emption algorithms optimize some objective function, e.g., maximize the number of users in a cell [9] or minimize the number of users perceiving service degradation [11]. In turn, the service degradation could be specific to a particular service class [8] or egalitarian to them [12]. Service interrupting generally goes with service degradation and represents the so-called second phase of pre-empting [8,12]. The performance analysis of RAC schemes requires mathematical methods, primarily mathematical teletraffic and queuing theories [3,6]. These methods are widely applied for modelling and analysing not only the last mentioned RAC problem [4,14], but also dynamic resource allocation [7] and ICIC [2] problems.

The remaining part of this paper is organized as follows. In Section 2, we propose a model of RAC scheme for two GBR services: video conference (QCI = 2, multicast multi-rate, higher priority) and video on demand (QCI = 4, unicast, lower priority). In Section 3, we derive a recursive algorithm for calculating model QoS parameters. In Section 4, we conduct a numerical analysis. Finally, we conclude the paper in Section 5.

2. Model of radio admission control scheme

2.1. Assumptions and parameters

We consider a single cell with a total capacity of C bandwidth units (b.u.) supporting two GBR services: multicast video conference (VC) service and unicast video on demand (VoD) service. The VoD service is provided on single GBR d b.u. Without loss of generality, we assume $d = 1$ b.u. The VC service is a multi-rate service, i.e., its bit rate can adaptively change from a maximum value of b_1 b.u. to a minimum value of b_K b.u. according to a given set of values $b_1 > \ldots > b_k > \ldots > b_K$ that depends on the cell load expressed in the number of users.

Let arrival rates λ [1/time unit] (VC) and ν [1/time unit] (VoD) be Poisson distributed and let the service time be exponentially distributed with means μ^{-1} [1/time unit] (VC) and κ^{-1} [1/time unit] (VoD). Then we denote the corresponding offered loads as $\rho = \lambda/\mu$ and $a = \nu/\kappa$. Let us introduce the following notations:

- $n \in \{0, 1, \ldots, \lfloor C/d \rfloor\} = \{0, 1, \ldots, C\}$ — number of VoD users ($d = 1$ b.u.);
- $\mathbf{m} = (m_1, \ldots, m_K)$ — state of a multicast session, where m_k can be equal to 1 if the session is active on bit rate b_k, i.e., multicast VC service is provided at least to one user on bit rate b_k, or

m_k can be equal to 0 if the session is not active on bit rate b_k, i.e., multicast VC service is not provided to users on bit rate b_k, $k = 1, \ldots, K$;

- $(\mathbf{m}, n)$ — state of the system;
- $b(\mathbf{m})$ — bit rate for VC service, when the state of a multicast session is $\mathbf{m}$,

$$b(\mathbf{m}) = \begin{cases} 0, & \text{if } \mathbf{m} = \mathbf{0}, \\ b_k, & \text{if } \mathbf{m} = \mathbf{e}_k, \quad k = 1, \ldots, K; \end{cases}$$

- $c(\mathbf{m}, n) = b(\mathbf{m}) + n$ — capacity occupied, when the system is in state $(\mathbf{m}, n)$.

2.2. RAC scheme

The VC priority level is higher than the VoD one. First, this fact is realized by the adaptive change of the VC bit rate. Second, the RAC is achieved in the way that a new VC request is accepted by the so-called pre-emption owing to the lack of free radio resources. Pre-empting refers to the release of radio resources occupied by VoD service (Table 1, Fig. 1). VoD users to be interrupted are selected randomly.

Given the above considerations, when a new VC request arrives, two scenarios are possible.

- The VC request will be accepted on bit rate b_k and the number of VoD users will not be changed, which is possible if the request finds a cell having greater than or equal to b_k b.u. free, $k = 1, \ldots, K$.
- The VC request will be accepted on bit rate b_K, and $b_K - (C - n)$ VoD users will be pre-empted, which is possible if the request finds a the cell having less than b_K b.u. free and n VoD users.

Similarly, when a new VoD request arrives, three scenarios are possible.

- The VoD request will be accepted on bit rate $d = 1$ b.u. without any effect on VC users, which is possible if the request finds a cell having greater than or equal to $d = 1$ b.u. free.
- The VoD request will be accepted on bit rate $d = 1$ b.u. with degrading VC service, which is possible if the request finds a cell having less than $d = 1$ b.u. free and VC service is provided at least to one user on bit rate b_k b.u., $k = 1, \ldots, K - 1$.
- Otherwise, the VoD request will be blocked without any after-effect on the corresponding Poisson process arrival rate.

Table 1. Fields of ARP for VC and VoD services

	Pre-emption capable	Pre-emption vulnerable
VC (multicast)	Yes (interrupt VoD)	Yes (degraded by VoD)
VoD (unicast)	Yes (degrade VC)	Yes (interrupted by VC)

2.3. QoS parameters

According to the above considerations, we denote the system state space as

$$\begin{aligned} \mathcal{X} = \{(\mathbf{m}, n) : \quad & \mathbf{m} = \mathbf{0},\ n = 0, \ldots, C,\ \ \mathbf{m} = \mathbf{e}_1,\ n = 0, \ldots, C - b_1, \\ & \mathbf{m} = \mathbf{e}_k,\ n = C - b_{k-1} + 1, \ldots, C - b_k,\ k = 2, \ldots, K\}, \end{aligned} \tag{1}$$

where $\mathbf{e}_k = \left(0, \ldots, 0, \overset{k}{1}, 0, \ldots, 0\right)$.

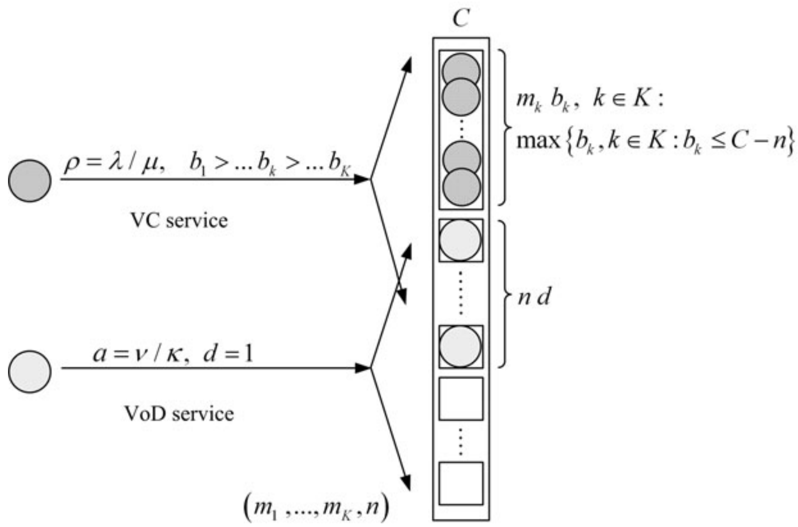

Fig. 1. Multi-rate model of RAC scheme.

The process representing the system states is described by system of equilibrium equations

$$\Big(\lambda \cdot \sum_{k=2}^{K} 1\{\mathbf{m}=\mathbf{0}, C-b_{k-1} < n \leqslant C-b_k\} + \lambda \cdot 1\{\mathbf{m}=\mathbf{0}, n \leqslant C-b_1\} + \lambda \cdot 1\{\mathbf{m}=\mathbf{0}, n > C-b_K\} +$$
$$+ \nu \cdot 1\{\mathbf{m}=\mathbf{0}, n < C\} + \nu \cdot \sum_{k=1}^{K} 1\{\mathbf{m}=\mathbf{e}_k, n < C-b_k\} + \nu \cdot \sum_{k=1}^{K-1} 1\{\mathbf{m}=\mathbf{e}_k, n = C-b_k\} +$$
$$+ \mu \cdot \sum_{k=1}^{K} 1\{\mathbf{m}=\mathbf{e}_k\} + n\kappa \cdot 1\{\mathbf{m}=\mathbf{0}, n>0\} + n\kappa \cdot \sum_{k=1}^{K} 1\{\mathbf{m}=\mathbf{e}_k, n>0\}\Big) p(\mathbf{m}, n) =$$
$$= \mu p(\mathbf{e}_1, n) \cdot 1\{\mathbf{m}=\mathbf{0}, n \leqslant C-b_1\} + \mu \sum_{k=2}^{K} p(\mathbf{e}_k, n) \cdot 1\{\mathbf{m}=\mathbf{0}, C-b_{k-1} < n \leqslant C-b_k\} +$$
$$+ (n+1)\kappa p(\mathbf{0}, n+1) \cdot 1\{\mathbf{m}=\mathbf{0}, n<C\} + (n+1)\kappa \sum_{k=1}^{K} p(\mathbf{e}_k, n+1) \cdot 1\{\mathbf{m}=\mathbf{e}_k, n < C-b_k\} +$$
$$+ (n+1)\kappa \sum_{k=1}^{K-1} p(\mathbf{e}_{k+1}, n+1) \cdot 1\{\mathbf{m}=\mathbf{e}_k, n = C-b_k\} + \lambda \sum_{k=1}^{K} p(\mathbf{0}, n) \cdot 1\{\mathbf{m}=\mathbf{e}_k\} +$$
$$+ \lambda \cdot 1\{\mathbf{m}=\mathbf{e}_K, n = C-b_K\} \sum_{i=1}^{b_K} p(\mathbf{0}, C-b_K+i) + \nu p(\mathbf{0}, n-1) \cdot 1\{\mathbf{m}=\mathbf{0}, n>0\} +$$
$$+ \nu p(\mathbf{e}_1, n-1) \cdot 1\{\mathbf{m}=\mathbf{e}_1, n>0\} + \nu \sum_{k=2}^{K} p(\mathbf{e}_k, n-1) \cdot 1\{\mathbf{m}=\mathbf{e}_k, n > C-b_{k-1}+1\} +$$
$$+ \nu \sum_{k=2}^{K} p(\mathbf{e}_{k-1}, n-1) \cdot 1\{\mathbf{m}=\mathbf{e}_k, n = C-b_{k-1}+1\}, \quad (\mathbf{m}, n) \in \mathcal{X}. \tag{2}$$

Having found probability distribution $p(\mathbf{m}, n)$, $(\mathbf{m}, n) \in \mathcal{X}$ of the multi-rate model of the RAC scheme for VC and VoD services, one may compute its performance measures, namely:

- blocking probability for VoD service

$$B = \sum_{(\mathbf{m},n)\in\mathcal{X}:\ c(\mathbf{m},n)=C} p(\mathbf{m},n)\,; \tag{3}$$

- pre-emption probability for VoD service

$$\Pi = \sum_{(\mathbf{0},n)\in\mathcal{X}:\ n>C-b_K} \Pi_n \cdot p(\mathbf{0},n)\,, \tag{4}$$

$$\Pi_n = \begin{cases} \dfrac{\lambda}{\lambda+\nu+n\kappa}\cdot\dfrac{\begin{pmatrix} n-1 \\ b_K-(C-n)-1 \end{pmatrix}}{\begin{pmatrix} n \\ b_K-(C-n) \end{pmatrix}}, & n = C-b_K+1,\dots,C-1, \\ \dfrac{\lambda}{\lambda+C\kappa}\cdot\dfrac{\begin{pmatrix} C-1 \\ b_K-1 \end{pmatrix}}{\begin{pmatrix} C \\ b_K \end{pmatrix}}, & n = C; \end{cases}$$

- mean bit rate for VC service

$$\overline{b} = \sum_{(\mathbf{m},n)\in\mathcal{X}:\mathbf{m}\neq\mathbf{0}} b(\mathbf{m})\cdot\frac{p(\mathbf{m},n)}{\sum_{(\tilde{\mathbf{m}},\tilde{n})\in\mathcal{X}:\tilde{\mathbf{m}}\neq\mathbf{0}} p(\tilde{\mathbf{m}},\tilde{n})}; \tag{5}$$

- utilization factor of the cell, i.e., mean load per bandwidth unit

$$\mathrm{UTIL}\cdot C = \sum_{(\mathbf{m},n)\in\mathcal{X}} c(\mathbf{m},n)\cdot p(\mathbf{m},n)\,. \tag{6}$$

It is possible to determine the system probability distribution only by means of numerical methods for solving systems of equilibrium equations.

3. Model performance measures

We consider a simplified model with state of the system (m,n) because the solution of the system of equilibrium equations for the model described above is time-consuming. The system state space $\mathcal{X}$ transforms to

$$\mathcal{Y} = \{(0,n)\,,\ \ n:\ \ (\mathbf{0},n)\in\mathcal{X}, \quad (1,n)\,,\ \ n:\ \ (\mathbf{e}_k,n)\in\mathcal{X},\ \ k=1,\dots,K\}\,. \tag{7}$$

Since the state of a multicast session can be equal to 0 or to 1, the number of VoD users allow one to uniquely determine a bit rate b_k, $k=1,\dots,K$: $\max\{b_k,\ k=1,\dots,K:\ b_k\leqslant C-n\}$, and to establish the following conformities:

$$m(\mathbf{m}) = \begin{cases} 0, & \text{if } \ \mathbf{m}=\mathbf{0}, \\ 1, & \text{if } \ \mathbf{m}=\mathbf{e}_k,\ \ k=1,\dots,K, \end{cases} \tag{8}$$

or

$$\mathbf{m}(m) = \begin{cases} \mathbf{0}, & \text{if } \ m=0,\ \ 0\leqslant n\leqslant C, \\ \mathbf{e}_1, & \text{if } \ m=1,\ \ 0\leqslant n\leqslant C-b_1, \\ \mathbf{e}_k, & \text{if } \ m=1,\ \ C-b_{k-1}<n\leqslant C-b_k,\ \ k=2,\dots,K. \end{cases} \tag{9}$$

So we emphasize again that VC bit rates are not considered in the simplified model for the formation of system states. It could be shown that the process representing the system states is not a reversible Markov process, and for determination of system probability distribution $P(m,n)$ we need to get a recursive algorithm.

Lemma 1. 1) *The values of unnormalized probabilities* $q(m,n)$ *are calculated by the formulas*

$$q(0,0)=1,\quad q(1,0)=x, \tag{10}$$

$$q(m,n)=\alpha_{mn}+\beta_{mn}\cdot x,\ \ (m,n)\in\mathcal{Y}:\ n>0, \tag{11}$$

$$x=\frac{\nu\alpha_{0,C-1}-(\lambda+C\kappa)\,\alpha_{0,C}}{(\lambda+C\kappa)\,\beta_{0,C}-\nu\beta_{0,C-1}}. \tag{12}$$

2) *The coefficients* α_{mn} *and* β_{mn} *are calculated by the recursive formulas*

$$\alpha_{00}=1,\quad \beta_{00}=0,\quad \alpha_{10}=0,\quad \beta_{10}=1, \tag{13}$$

$$\alpha_{01}=\frac{\upsilon+\lambda}{\kappa},\quad \beta_{01}=-\frac{\mu}{\kappa},\quad \alpha_{11}=-\frac{\lambda}{\kappa},\quad \beta_{11}=\frac{\upsilon+\mu}{\kappa}, \tag{14}$$

$$n\alpha_{0n}=(\alpha_{01}+(n-1))\,\alpha_{0,n-1}+\beta_{01}\alpha_{1,n-1}-a\alpha_{0,n-2},\ n=2,\dots,C-b_K+1, \tag{15}$$

$$n\beta_{0n}=(\alpha_{01}+(n-1))\,\beta_{0,n-1}+\beta_{01}\beta_{1,n-1}-a\beta_{0,n-2},\ n=2,\dots,C-b_K+1, \tag{16}$$

$$n\alpha_{1n}=(\beta_{11}+(n-1))\,\alpha_{1,n-1}+\alpha_{11}\alpha_{0,n-1}-a\alpha_{1,n-2},\ n=2,\dots,C-b_K, \tag{17}$$

$$n\beta_{1n}=(\beta_{11}+(n-1))\,\beta_{1,n-1}+\alpha_{11}\beta_{0,n-1}-a\beta_{1,n-2},\ n=2,\dots,C-b_K, \tag{18}$$

$$n\alpha_{0n}=(\alpha_{01}+(n-1))\,\alpha_{0,n-1}-a\alpha_{0,n-2},\ n=C-b_K+2,\dots,C, \tag{19}$$

$$n\beta_{0n}=(\alpha_{01}+(n-1))\,\beta_{0,n-1}-a\beta_{0,n-2},\ n=C-b_K+2,\dots,C. \tag{20}$$

Remark 1. The probability distribution $P(m,n)$ is calculated by the formula

$$P(m,n)=\frac{q(m,n)}{\sum_{(i,j)\in\mathcal{Y}}q(i,j)},\quad (m,n)\in\mathcal{Y}. \tag{21}$$

Corollary 1. *The main performance measures of the pre-emption based model, the blocking probability* B*, the pre-emption probability* Π*, the mean bit rate* $\overline{b}$*, and the utilization factor of the cell* UTIL*, can be computed as follows*:

$$B=P(0,C)+P(1,C-b_K), \tag{22}$$

$$\Pi=\sum_{n=C-b_K+1}^{C-1}\frac{b_K-C+n}{n}\frac{\lambda}{\lambda+\nu+n\kappa}P(0,n)+\frac{b_K}{C}\frac{\lambda}{\lambda+C\kappa}P(0,C), \tag{23}$$

$$\overline{b}=\left(b_1\sum_{n=0}^{C-b_1}P(1,n)+\sum_{k=2}^{K}b_k\sum_{n=C-b_{k-1}+1}^{C-b_k}P(1,n)\right)\cdot\left(\sum_{n=0}^{C-b_K}P(1,n)\right)^{-1}, \tag{24}$$

$$\mathrm{UTIL}\cdot C=\sum_{n=1}^{C}nP(0,n)+\sum_{n=0}^{C-b_1}(b_1+n)\,P(1,n)+\sum_{k=2}^{K}\sum_{n=C-b_{k-1}+1}^{C-b_k}(b_k+n)\,P(1,n). \tag{25}$$

4. Optimization problem for video conference bit rates

4.1. Problem formulation

According to forecasts by Cisco Systems [2], mobile applications providing video services will generate most of the global mobile data traffic by 2018, namely about 69 percent. However, not only in the future, but also in the beginning of 2012, mobile video represents more than half of the global mobile data traffic, and even now, in 2015, its volume should be about 59 percent. Let us consider an example of a single cell supporting VC and VoD services to illustrate the performance measures defined above, namely blocking and pre-emption probabilities for VoD service, mean bit rate for VC service, and utilization factor of the cell. To calculate these characteristics a recursive algorithm was proposed.

The obtained results allow us to perform numerical experiments to further the development of recommendations for fourth and next generation wireless networks. These recommendations will provide the opportunity to make a choice of services parameter values depending on the user QoS requirements. To achieve this goal it is necessary to solve the optimization problem. The objective functions of this problem are all the performance measures listed above.

Getting the solution of this multi-objective problem is time-consuming. Therefore one resorts to the optimization of one of the QoS parameters subject to constraints on other parameters. Let us consider an example of such optimization problem. The task is to maximize the mean bit rate $\overline{b}$ of the VC service with the blocking probability and pre-emption probabilities for VoD service not exceeding values B^* and Π^* respectively, and the bit rate for VC service being not smaller than b^*. The mean VC bit rate depends on the initial set $\mathcal{D} = \{d_1, d_2, \dots, d_M\}$ of values and their number K. Hereafter the problem for optimizing VC bit rates can be formulated as follows:

$$\begin{aligned}
&\overline{b}\,(K; b_1, \dots, b_K) \to \max,\\
&\text{VC}: \begin{cases} b_k \in \mathcal{D} = \{d_1, d_2, \dots, d_M\}, \; k = 1, \dots, K,\\ b_1 > b_2 > \dots > b_K,\\ b_K \geqslant b^*,\end{cases}\\
&\text{VoD}: \begin{cases} B\,(K; b_1, \dots, b_K) \leqslant B^*,\\ \Pi\,(K; b_1, \dots, b_K) \leqslant \Pi^*.\end{cases}
\end{aligned}$$

In handling numerical optimization problem for VC and VoD services, the recommended values of bit rates for VC service depending on different values of parameters b^*, B^*, and Π^* can be found.

4.2. Analyzing performance measures of pre-empting admission control

In order to illustrate the solution of the optimization problem, let us consider the initial bit rate value set $\mathcal{D} = \{8\,\text{Mbps},\ 6\,\text{Mbps},\ 4\,\text{Mbps}\}$ meeting the requirements of the program Skype [13], being recommended for provision of VC service by seven and more participants. Having such initial set we can distinguish seven variants of bit rate sets $(K; b_1, \dots, b_K)$: $(1;\ 4)$, $(1;\ 6)$, $(1;\ 8)$, $(2;\ 6, 4)$, $(2;\ 8, 4)$, $(2;\ 8, 6)$, $(3;\ 8, 6, 4)$ (we omit units of measurement). For the choice of capacity C, given for provision of video content, let us take the forecast Cisco Systems for 2015; accordingly we will consider not the whole capacity of the cell equal to 100 Mbps but only its part, namely 59 percent. Let us summarize the initial data of the example in the Table 2. Note that 1 b.u. for the example under consideration makes 2 Mbps, wherefore $C = 29$ b.u. $= 58$ Mbps.

Table 2. Numerical data

Traffic type	Service	Traffic rate	Initial set of requirements	Resource occupation
Unicast	Video on demand	90 %	2 Mbps	2 hours
Multicast	Video conference	10 %	8 Mbps, 6 Mbps, 4 Mbps	1 hour

Let us illustrate the behavior of each of the model performance measures under examination: the blocking probability B (Fig. 2), the pre-emption probability Π (Fig. 3), and the mean $\overline{b}$ bit rate (Fig. 4), depending on various bit rate sets. Figures 2 and 3 show that all seven bit rate sets can be combined according to the minimum bit rate b_K for VC service into three groups; here it is obvious that the larger the minimum bit rate the larger the blocking and pre-emption probabilites. Figure 4 shows also a combination of bit rate sets into three groups but already according to the maximum bit rate b_1. The curve order (mean bit rates of VC service) is observed in each group from the largest to the smallest value of the minimum bit rate.

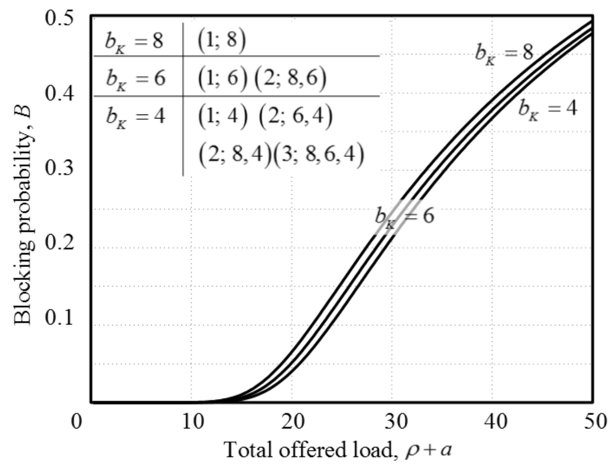

Fig. 2. Dependence of VoD service blocking probability B from sets of bit rates.

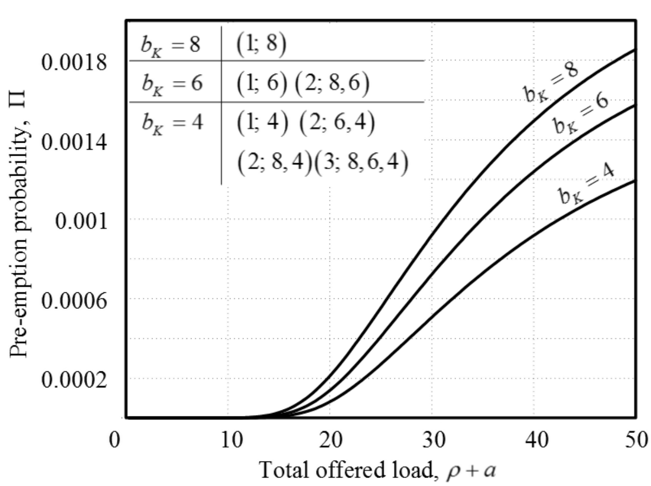

Fig. 3. Dependence of VoD service pre-emption probability Π from sets of bit rates.

The maximum mean bit rate is achieved when using the set (1; 8), but the blocking and pre-emption probabilities achieve their maximum values. Limitations b^*, B^*, and Π^* result in the fact that VC service cannot be provided at 8 Mbps for the whole range of the suggested load. Accordingly, we should consider also other bit rate sets. Following Fig. 4 the maximum mean bit rate decreases in the following order – bit rate with any of the following sets: (1; 8), (2; 8, 6), and (3; 8, 6, 4), etc. For further solution of the optimization problem we will consider not all seven sets but only three of them: (1; 8), (2; 8, 6), and (3; 8, 6, 4) as mean bit rates are maximum with the use of these sets and they cover also all three groups of blocking (Fig. 2) and pre-emption (Fig. 3) probabilities.

For graphic illustration of the optimization problem solution, let us consider the following case in

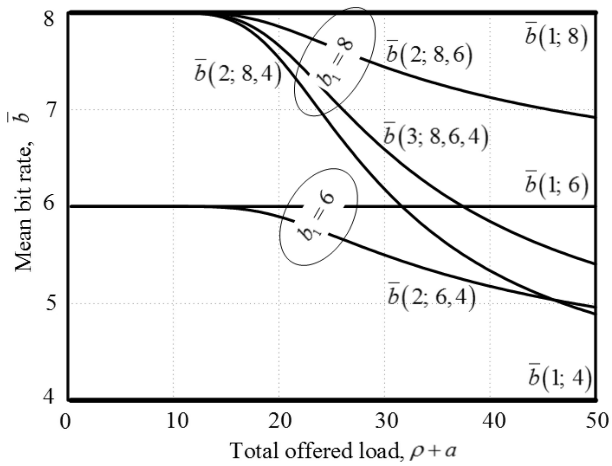

Fig. 4. Dependence of VC service mean bit rate $\bar{b}$ Mbps on sets of bit rates.

detail: $B^* = 10^{-1}$ (Fig. 5), $\Pi^* = 10^{-4}$ (Fig. 6), and $b^* = 7.5$ (Fig. 7). The obtained results (Fig. 8) allow obtaining the recommended values of bit rates set for VC service for $b^* = 7.5$ Mbps, $B^* = 10^{-1}$, and $\Pi^* = 10^{-4}$. Figure 8 shows the pairwise and triple influence of limitations on bit rate choice and allows determining the load ranges with the optimal bit rate set where each of the sets under examination is used.

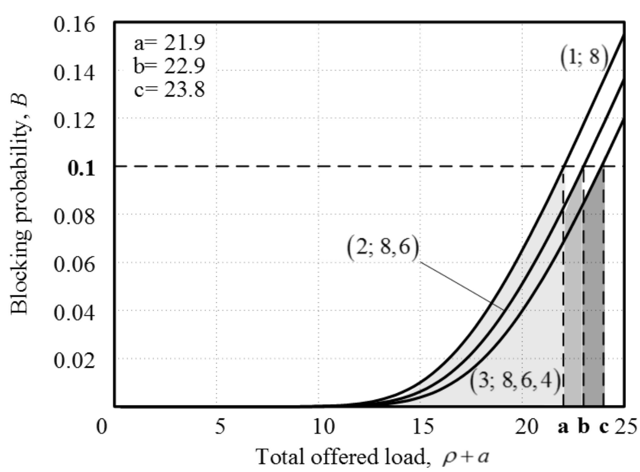

Fig. 5. Choosing bit rate set for blocking probability constraint $B^* = 10^{-1}$ for VoD service.

5. Conclusion

In this paper, we addressed an admission control problem for a multi-service LTE network, and we presented a new multi-rate model for two guaranteed bit rate services: video conference and video on demand. The RAC scheme is based on the VC quality degradation from high to standard definition. The scheme assumes that a VC user can pre-empt high definition VoD users. We suggest a recursive algorithm to calculate the system probability distribution, by means of which we analyze the main model performance measures. We formulate the optimization problem for VC service mean bit rate subject to constraints on the blocking and pre-emption probabilities for VoD service. We also propose an example of the numerical solution of this problem.

The results of numerical analysis can be used for planning standards for next generation wireless

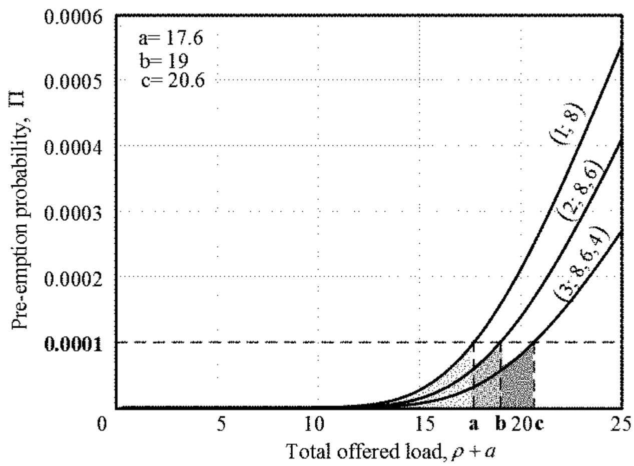

Fig. 6. Choosing bit rate set for pre-emption probability constraint $\Pi^* = 10^{-4}$ for VoD service.

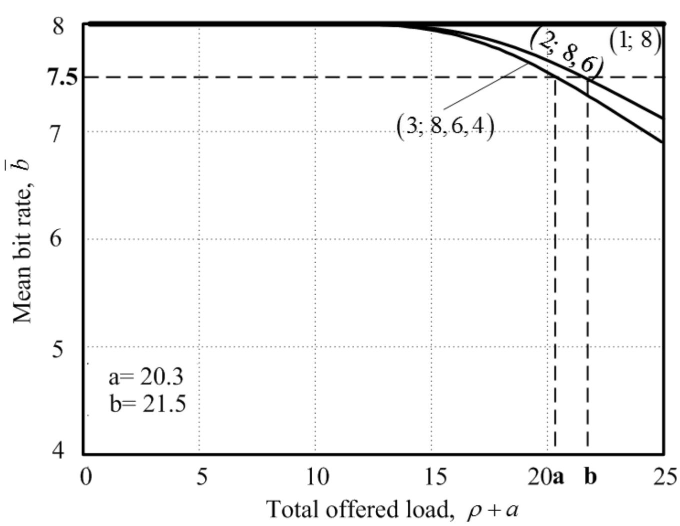

Fig. 7. Choosing bit rate set for mean bit rate constraint $b^* = 7.5$ Mbps for VC service.

cellular networks. They can be used for developing software responsible for radio resources management, namely for developing RAC schemes. The results of solving the optimization problem for VC mean bit rate can be used to assess the optimal bit rate set for network resources required to provide multicast service. An interesting task for future studies is the development of a simulation model for verifying results accuracy.

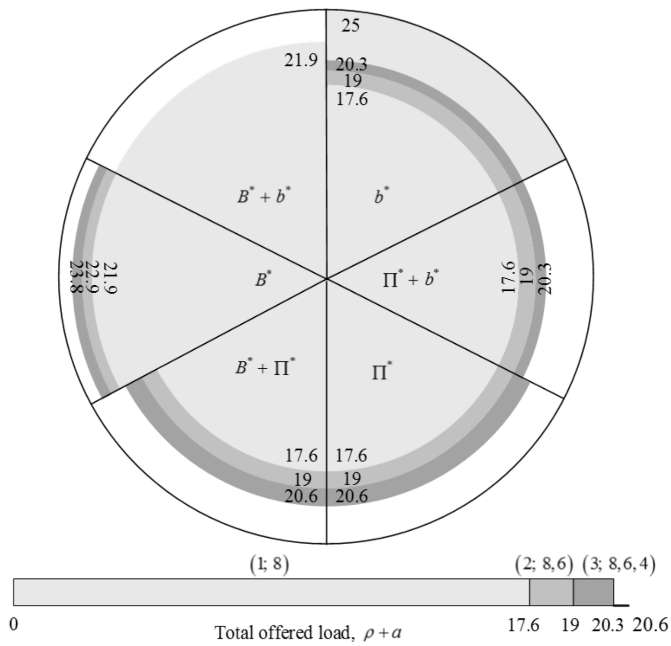

Fig. 8. Choosing bit rate set for blocking probability, pre-emption probability, and mean bit rate constraints, $B^* = 10^{-1}$, $\Pi^* = 10^{-4}$ and $b^* = 7.5$ Mbps.

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