ANALYSIS OF BROADBAND CELLULAR NETWORKS WITH VARIABLE BIT-RATE CONNECTIONS*

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ABSTRACT

As multimedia applications are becoming reality in wireless/mobile environments new analytical modelling techniques are required that can handle the variable bit-rate nature of such applications. This paper presents an analytical method to examine channel occupancy and blocking properties of radio base stations serving VBR connections. This method is based on an approximation that makes possible the computation of above properties despite the huge complexity of the problem. Two service disciplines of handling calls arriving with too big bandwidth demand are analysed.

Keywords: variable bit rate service, traffic analysis, Phase Type Distribution.

1. INTRODUCTION

The main role of today's field of telecommunications is to combine mobility with broadband access. The rapidly growing computational capacity of laptop-sized computers increases the demand of using high bit-rate applications in mobile/wireless environment. Although the accessibility of very high data rates (e.g. several tens of Mbps) is not anticipatory in the 3G mobile networks, wireless LANs (such as Hyperlan2) and wireless ATM systems are able to provide large bandwidth.

If the broadband wireless access becomes available for the large public it is no far to seek the explosive spreading of the number of mobile users of Internet. The IETF mobile extension of IP protocol is available since few years ago and IPv6 essentially contains mobility support. It can be stated without exaggeration that in any type of broadband wireless network the majority of carried traffic will be Internet data.

Considering that broadband applications (such as video) are often coded with variable bit-rate it is reasonable to assume the existence of VBR connections in wireless environment. Due to the strictly limited bandwidth available in wireless networks it is not worth assigning a user its peak required bandwidth. Moreover, to exploit statistical multiplexing of VBR connections the wireless MAC protocol should allow the dynamic change of physical channel resources used by a customer.

Considering users that dynamically change their amount of occupied capacity in a shared radio channel during a connection may seem not trivial. However, MAC protocols that serve VBR users are widely proposed in the literature [1]-[4].

The most plausible approach is to apply TDMA/TDD MAC protocols. The TDMA channel is reasonable to serve packet communications with fixed packet lengths. The TDD approach allows the protocol to adaptively change the uplink/downlink capacity according to traffic parameters, by simply changing the length of the uplink/downlink phase of the MAC frame. Every TDMA wireless MAC frame should contain a contention phase (ALOHA type), where new connections can be set-up. The variability of a connection's used amount of capacity is fulfilled by means of the variable number of time slots it may use in different time frames. A scheduler has to be placed in the base station that allocates time slots to users, according to their instantaneous need. Determination of the number of needed time slots may be performed at the mobile, than this case this number is submitted to the base station via either a control channel or in-band or via the contention period. If the base station determines the number of assigned time slots to a user it may use previously negotiated information about the user or the customer may submit state information (buffer saturation, instantaneous bit-rate, etc.) according to which the scheduler distributes the time slots among users.

During the 90s several working wireless ATM testbeds were built [5]-[8]. These are intended to provide the QoS guarantees and service classes (thus VBR

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either).

As we have seen, variable bit-rate users are becoming reality in mobile environment. Although a number of papers proposing models of cellular networks with multiple service classes were published recently [9]-[11], [13], analytical models of cellular networks did not consider VBR connections so far. All the cited literature considers connections with constant capacity requirements. In [1]-[4] the performance of MAC protocols with VBR connections was analysed by means of several performance parameters, but a more general modelling framework that takes the versatility of a user's occupied bandwidth into account is needed.

This paper proposes a new modelling technique to analyse cellular networks with VBR connections. A Markovian model of a single base station is proposed. Two different service discipline is investigated to handle the event when the base station has not enough free capacity to serve a new call's actual demand.

This paper is organised as follows. In Section 2 the general description of the modelling environment is given. In Section 3 the abstract model of the base station and its solution method is investigated. This is followed by numerical results and conclusions.

2. MODELLING ASSUMPTIONS

2.1. User behaviour

We suppose that the number of users roaming under the coverage area of an examined radio cell is large and they initiate calls independently of each other in the cell. Therefore the incoming flow of new calls initiated in the cell forms a Poisson process. Moreover, we assume that the number of active users within the vicinity of the cell under consideration is large enough, so the number incoming calls during a time interval due to handover also has a Poisson distribution.

The mobility of the user is described by means of its time spent within the cell. This time amount is usually referred as dwell time, sojourn time or residence time. The most common approach in the literature to suppose an exponentially distributed dwell time. More sophisticated dwell time distributions were suggested in [12]-[14]. Here we assume a very general type of sojourn time distribution, namely this paper assumes the dwell time to have a phase type (PH) distribution.

A phase type distributed time is a mixture of a number of exponentially distributed phases [16]. The PH is characterized by the number of its phases, the parameter of each exponential phase and the probability of moving between the phases upon completing one phase. The PH distributed process may finish upon completing any phase, these completion probabilities also has to be known for the description of the PH. Moreover, the probability of beginning the PH with a given phase also has to be known.

As it is well known from probability theory a Markov chain spends exponentially distributed times in its states and the probability of the next state is determined by the rates among states. Thus a PH distributed time may be viewed as the amount of time elapses until a Markov chain reaches an absorbing state. So a PH is determined by the infinitesimal generator matrix and the initial distribution of the describing Markov chain.

The use of PH distribution has two advantages. One is that PH distributions are widely use to approximate other distributions [15], or to fit a distribution to a series of statistical data according to the moments of the series. The other advantage is that while it makes the use of any distributions possible it still allows us to exploit the memoryless property of the exponential distribution.

Since by PH distributions any other distributions can be approximated with arbitrary accuracy and PH distributions can easily be fitted to measurement statistics of user describing time, applying the PH can contain all former models with other distributions.

One of the simplest type of PH is the so-called Coxian distribution. This consist of a number of phases with different parameters connected serially and from each phase the process may finish with a given probability or proceed to the following phase. The simplest Coxian with two phases is often used to approximate distributions, according to the first two or three moments.

In our model the PH distributed dwell time may be a result of distribution fitting if statistical data of user movements is available, or an approximation of the sojourn time determined according to any mobility model.

It is common in teletraffic modelling theory to assume the call length distribution to be exponentially distributed. Although this assumption applies when only speech connections are considered, mixed type of traffic (video, data, speech) does not have this property. Therefore our model deals with a more general assumption, the call duration is also considered to be PH distributed. Note that the call length modelling PH distribution must also contain information on users who arrive to the cell by handover! This means that our model supposes that by the approximation of the call length distribution the remaining time of calls arriving by handover was also taken into account, which is in general not the same as the call length. A more accurate model is now under investigation to take the remaining time of handover calls into account more precisely.

The channel occupancy time of the mobile (the time it spends communicating in a cell) is the minimum of the dwell time and the call duration. If the dwell time period is shorter the mobile releases channel due to a handover, in the other case due to call termination. Sometimes it is reasonable to assume that the channel occupancy time is itself known. If we assume the channel occupancy time to be PH (according to approximation by PH fitting), this approach causes no differences. Namely, in Section 3 we show that in case of PH dwell times and call duration the channel occupancy time is also PH distributed.

The variability of a user's required bandwidth is characterized in terms of a set of different amounts of capacity demands. During a connection the mobile changes its required capacity choosing one value of the set of possible capacities. The time a user spends using a given amount of bandwidth is assumed to be exponentially distributed. After completing this exponential time it chooses another transmission speed randomly among the possible values. It is well-known from probability theory that a Markov chain spends exponentially distributed times in its states. Therefore the VBR nature of calls is modelled with a Markov chain with a given capacity requirement assigned to each of its states. These kind of VBR models are not unknown in the literature [17]-[19]. For the sake of simplicity we assume in this paper that every capacity is expressed in bit/second units. To make the VBR description complete, the probability that a new connection starts with a given capacity requirement is also needed.

The model assumes that the state of the user's capacity demand is independent of both the dwell time and the call length.

2.2. Base station model

The base station is modelled as a channel pool of C_0 units of capacity. Customers share this capacity without any priorities or dedicated reservations. A user is admitted to the base station if there is enough unused capacity to fulfill its actual capacity requirement. For a new connection the first required level of bandwidth is determined by the initial distribution of the VBR describing Markov chain.

In case of not enough capacity for admitting the new call the base station may block the new call or force the mobile to start transmission with a lower capacity demand. In the latter case the call is only blocked when there is less free capacity than the lowest possible capacity demand of the user.

Due to the existence of VBR connections, the amount of occupied capacity may change without the initiation of new or handover call or call termination. In the case when a mobile tries to switch to a higher bit-rate but there is not enough free capacity to do this, it is reasonable to assume that the call is not dropped but the user is able to continue its transmission with the previous speed. However, at packet layer this event may cause packet losses or the increase of queueing delay. Thus the probability of this event is also an important performance parameter of the system, along with the call blocking probabilities.

3. ANALYTICAL MODEL OF THE BASE STATION

According to the previous section a base station can be modelled as a system with C_0 servers. The service time of each user is the channel occupancy time. The number of occupied servers by a customer depends on the state of the VBR describing Markov chain.

3.1. Service time distribution

A service time distribution is needed, that has the following properties: it has the same distribution as the channel occupancy time (i.e. the minimum of the dwell time and the call duration) and contains the information about the state of the VBR describing Markov chain. To obtain the service time distribution from the dwell time, call length and the VBR states, let us introduce the following notations. The PH dwell time is described by $\boldsymbol{D}$, $\underline{d}$ and $\boldsymbol{D^0}$, where matrix $\boldsymbol{D}$ contains the rates among the phases of the PH dwell time, $\underline{d}$ is the vector containing at position i the probability of beginning the dwell time distribution with phase i and $\boldsymbol{D^0}$ is the column vector containing the rates of finishing the dwell time from each state (and according to its definition $\sum_j D_{ij} = D_i^0$). Let the descriptors of the call length distribution be denoted by $\boldsymbol{L}$, $\underline{l}$ and $\boldsymbol{L^0}$ with the same meanings.

The channel occupancy time, that also has a PH distribution can be composed as follows. The phases of the call duration time is taken as many times as many phases the dwell time has, with the rates of $\boldsymbol{L}$ among the phases within a group. Between the appropriate states of these groups the rate is equal to the rates between the corresponding phases of the dwell time. This means, that the rate between phase i of group k and phase j of group l (that corresponds to state k and l of the PH dwell time) is:

- $\boldsymbol{L}_{ij}$ if $k = l, i \neq j$,
- $\boldsymbol{D}_{kl}$ if $i = j, k \neq l$,

for $i, j = 0, ... \ D-1, k, l = 0, ...\ , L-1$, where D and L denotes the number of phases of the dwell time and the call duration respectively. According to this composition of the channel occupancy time, its descriptors are:

$$\boldsymbol{T} = \boldsymbol{D} \oplus \boldsymbol{L}, \quad T^0 = D^0 \oplus L^0, \quad \underline{t} = \underline{d} \otimes \underline{l}, \qquad (1)$$

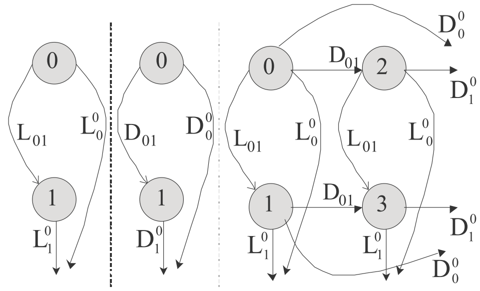

Figure 1: Construction of the channel occupancy time distribution

where $\oplus$ and $\otimes$ denotes the Kronecker sum and product, respectively.

It is easy to see that the PH composed this way and has its descriptors according to (1) has the same distribution as the minimum of the two PH that it was composed from.

A simple example of constructing the channel occupancy distribution is shown in Figure 1. In this case both the call duration (leftmost graph) and the dwell time (middle) has a two phase Coxian distribution. The graph on the right side shows the phases of the channel occupancy time. According to the description this is constructed by taking the call duration twice and connecting the two group with the rates of the dwell time.

If we want the states of the VBR describing Markov chain to be taken into consideration a similar operation has to be performed. Let $\boldsymbol{Q}$ denote the infinitesimal generator matrix of the Markov chain and $\underline{\beta}$ its initial distribution vector.

A phase type distribution that contain the state of the transmission speed of the user and the channel occupancy time as well can be constructed exactly the same way as the channel occupancy time. During this procedure the role of dwell time must be replaced with the VBR describing Markov chain and the role of call length with the channel occupancy distribution.

It follows from the construction of the service time distribution that its descriptors are given as:

$$\hat{\boldsymbol{T}} = \boldsymbol{Q} \oplus \boldsymbol{T}, \quad \hat{T}^0 = \underline{h_N} \otimes T^0, \quad \underline{\hat{\alpha}} = \underline{\beta} \otimes \underline{\alpha}, \quad (2)$$

where $\underline{h_N}$ denotes the N dimensional vector with 1s in each position. It is again not difficult to show that this has the same distribution as the channel occupancy time.

This distribution has $D \cdot L \cdot N$ phases, where N denotes the number of states of the transmission speed.

3.2. Solving the system

We showed that the service time of this system with C_0 servers has a PH distributions given by (2) and (1). Since the input process is Poisson formally we have an M/PH/C_0 queue with phase dependent capacity requirements.

The state of the describing process is the vector $\underline{n}$ of $D \cdot L \cdot N$ dimensions, n_i denotes the number of users receiving phase i of their service. Let $\underline{c}$ denote the vector containing the capacity demands associated with the phases of the service time. It is clear according to the composition of the service time that $c_0 = c_1 = \cdots = c_{DL-1}$, $c_{DL} = c_{DL+1} = \cdots = c_{2DL-1}$, $\ldots$,$c_{(N-1)DL} = c_{(N-1)DL+1} = \cdots = c_{NDL-1}$. This means that at every $D\dot{L}$ phase that corresponds to a given state of the VBR describing Markov chain, the capacity demand is the same.

The valid states of the system are those, where $\underline{nc}^T \leq C_0$, i.e. $\sum_i n_i \cdot c_i \leq C_0$. This simply means that the total amount of occupied capacity can not be larger than the maximum capacity.

Assuming the phase type structure defined by $\underline{\hat{\alpha}}$ and $\hat{\boldsymbol{T}}$ is not redundant the Markov chain describing the variation of system states is finite and irreducible, hence its steady state distribution exists.

3.3. Obtaining the steady state distribution

In order to obtain the distribution in equilibrium the global balance equations have to be solved. The balance equations of this multi dimensional Markov chain are coming from the possible state transitions. The state transitions are different for the two service disciplines outlined in the previous sections.

If the base station rejects calls arriving with a capacity demand higher than the available and force the user to continue transmission at the same bit-rate when there is not enough free capacity to switch to a higher, the state transitions are the following:

- state transition due to a new call arrival:
  this event results in a state transition from state $\underline{n}$ to state $\underline{n} + \underline{e_i}$ at rate $\lambda\hat{\alpha}_i$, where e_i is the $D \times L \times N$ vector filled with 0s and one 1 at its ith position;

- state transition due to a call termination (by handover out of the cell or by connection termination):
  this event results in a state transition from state $\underline{n}$ to state $\underline{n} - \underline{e_i}$ at rate $n_i\hat{T}^0_i$;

- state transition due to a phase change from phase i to j:
  this event results in a state transition from state $\underline{n}$ to $\underline{n} + \underline{e_j} - \underline{e_i}$ at rate $n_i\hat{\boldsymbol{T}}_{ij}$.

where λ denotes the joint incoming rate of handover and new calls.

To classify the state transitions applying the other service discipline (the mobile is forced to transmit with a lower bit-rate in case of not enough capacity) we need some further notations. Let the idle capacity of the base station at any state $\underline{n}$ be denoted by C_I. Only the state transition due to call arrival changes, namely a call arrival result in a transition from state $\underline{n}$ to state $\underline{n} + \underline{e_i}$ with the rate of:

$$\lambda \sum_{j : c_j \geq C_I} \hat{\alpha}_j. \tag{3}$$

Observing the difference of the two state transitions clearly show what can be intuitively known, i.e. the latter service discipline allows more users to admit to the base station. However, this results in an increased degradation of QoS parameters since the customers forced to transmit at a lower speed than that they need.

Based on the state transitions, the balance equations that has to be satisfied in equilibrium has the following form:

$$\begin{gathered} \lambda p(\underline{n}) + \\ p(\underline{n}) \sum_i \sum_{j, j \neq i} n_i \hat{T}_{ij} + \\ p(\underline{n}) \sum_i n_i p(\underline{n}) \hat{T}_i^0 = \\ \lambda \sum_i \underline{\hat{\alpha}}_i p(\underline{n} - \underline{e_i}) + \\ \sum_i \sum_{j, j \neq i} (n_i + 1) p(\underline{n} + \underline{e_i} - \underline{e_j}) \hat{T}_{ij} + \\ p(\underline{n}) \sum_i (n_i + 1) p(\underline{n} + \underline{e_i}) \hat{T}_i^0. \end{gathered} \tag{4}$$

Solving this set of linear equations the equilibrium distribution $p(\underline{n})$ can be obtained. Given the steady state distribution, the performance parameters of the system can be calculated as follows. The call blocking probability in case of applying the simple blocking discipline with the condition that the call arrives with the capacity demand c_i is:

$$p_B^{c_i} = Pr(\underline{n}\ \underline{c}^T > C_0 - c_i) = \sum_{\underline{n}\ :\ \underline{n}\ \underline{c}^T > C_0 - c_i} p(\underline{n}). \tag{5}$$

The total call blocking probability is then:

$$p_B = \sum_{i=1}^{N} p_B^{c_i} \beta_i, \tag{6}$$

where β_i is the probability of call arrival with capacity requirement c_i.

The probability of service degradation due to lack of idle capacity when a mobile tries to switch from c_j to $c_i (c_i > c_j)$ is given as:

$$\begin{gathered} p_D^{c_j c_i} = p_B^{c_i - c_j} = Pr(\underline{nc}^T > C_0 - c_i + c_j) = \\ \sum_{\underline{n}\ :\ \underline{nc}^T > C_0 - c_i + c_j} p(\underline{n}). \end{gathered} \tag{7}$$

If we denote the minimum possible capacity requirement of a call with c_{min}, the call blocking probability applying the second service discipline has the form of:

$$\hat{p}_B = \sum_{\underline{n}\ :\ \underline{nc}^T > C_0 - c_{min}} p(\underline{n}). \tag{8}$$

The probability of QoS degradation upon call arrival applying the second service discipline given that the user arrives with the demand of $c_i > c_{min}$ is given as:

$$\hat{p}_D^{c_i} = \sum_{\underline{n}\ :\ \underline{nc}^T > C_0 - c_i\ ;\ \underline{nc}^T > C_0 - c_{min}} p(\underline{n}) \tag{9}$$

The total probability of degradation is calculated as (6).

3.4. Approximate blocking probability calculation

Due to the multiple dimensions of the resulting Markov chain its state space may become extremely large. Obtaining the steady state distribution simply means solving a set of linear equations. However, when the number of equations reaches the order of 10^6, serious difficulties arises to solve them. The approximation proposed here has negligible computational complexity and causes reasonable error in computing blocking probabilities.

If we assume the base station capacity C_0 to be infinitely large, the Markov chain of the problem has the nice property that its equilibrium distribution has a product form. This means that each state's probability can be calculated as the product of one of its neighbour's probability and a given factor. Moreover, if all the capacity demands were the same (CBR connections), this property would hold even in case of finite base station capacity.

The Markov chain has a product form solution if and only if local balance equations apply throughout the whole state space. While global balance equations has the meaning that state transitions from a state hold balance with state transitions into that state from its surrounding, local balance means that state transitions crossing a given "surface" in the state space hold balance.

In our problem at the majority of the state space the local balance equations hold. Only blocking states are those, where this nice property breaks down. However, we suppose that our system works mainly not in the proximity of blocking states, i.e. the load conditions of the base station are such that blocking rarely occur. Thus the "non-product form" part of the state space has negligible probability mass compared to the product form space.

Kaufman [20] and Roberts [21] proposed a recursive formula to compute channel occupancy distribution in a shared channel. They considered connections with constant capacity requirements. Their method provides exact values in case of a product form Markov chain. However, as described above assuming local balance equations to be valid a modified version of their method can be applied to calculate capacity occupations and therefore blocking probabilities as well.

At the non-blocking sub-space the rates into a phase of the service time due to arrivals and transmission rate changes hold the local balance with the rates out of the phase due to call termination or again transmission rate change. Translating it into formulas, the local balance equations for any state $\underline{n}$ are:

$$\begin{aligned}\lambda\hat{\alpha}_i p(\underline{n}) + \textstyle\sum_{j,j\neq i} p(\underline{n}+\underline{e_j})\hat{T}_{ji}(j+1) = \\ p(\underline{n}+\underline{e_i})(i+1)\cdot(\hat{T}_i^0 + \textstyle\sum_{j,j\neq i}\hat{T}_{ij}).\end{aligned} \quad (10)$$

Using that $\hat{T}_i^0 + \sum_{j,j\neq i}\hat{T}_{ij} = -\hat{T}_{ii}$ and writing the equations into vector form, we get:

$$\begin{aligned}&-\lambda\hat{\alpha}p(\underline{n}) = \\ &[(n_0+1)p(\underline{n}+\underline{e_0})\cdots(n_i+1)p(\underline{n}+\underline{e_i})\cdots \\ &(n_{M-1}+1)p(\underline{n}+\underline{e_{M-1}})]\boldsymbol{T},\end{aligned} \quad (11)$$

where for the sake of simplicity, the number of phases of the service time ($D\cdot L\cdot N$) is denoted by M. Introducing the vector $\underline{K} = (\frac{(n_0+1)p(\underline{n}+\underline{e_0})}{p(\underline{n})},\ldots\frac{(n_{M-1}+1)p(\underline{n}+\underline{e_{M-1}})}{p(\underline{n})})$, we have

$$\underline{K} = -\lambda\underline{\hat{\alpha}}\hat{\boldsymbol{T}}^{-1}. \quad (12)$$

The vector defined by (12) plays the role of the multiplying factor between the probabilities of two neighboring states.

Blocking states are those, where n_i must be equal to 0, because the free capacity at that state is less then c_i. This blocking state results in the change of the service time descriptors, $\underline{\hat{\alpha}}$ and $\hat{\boldsymbol{T}}$. I.e those elements of $\boldsymbol{T}$ that represent an illegal phase transition because of lack of capacity are set to 0 and the diagonal elements of $\boldsymbol{T}$ are updated such that $\sum_j \hat{\boldsymbol{T}}_{ij} + T_i^0 = 0$. If call blocking discipline is applied, the arrival of calls with a capacity demand higher than the available bandwidth is restricted, thus those elements of $\underline{\hat{\alpha}}$ are set to 0 as well. If the mobiles are forced to transmit with a lower speed then the elements of $\underline{\hat{\alpha}}$ are changed as follows: for all i where $c_i > C_I$ the values $\hat{\alpha}_i$ are added to the value at position j for which c_j is the largest capacity demand such that $c_j \leq C_I$ and for these i values $\hat{\alpha}_i = 0$. This may be represented as the descriptors of the service time depend on the value of the available capacity $x = C_0 - \underline{n}\underline{c}_T$.

As an approximation we suppose that the local balance holds in blocking sub-spaces as well, with the modified transition rates. Then the factor of (12) depends on the available capacity as well, therefore (12) gets the general form of

$$\underline{K}(x) = -\lambda\underline{\hat{\alpha}}(x)\hat{\boldsymbol{T}}^{-1}(x). \quad (13)$$

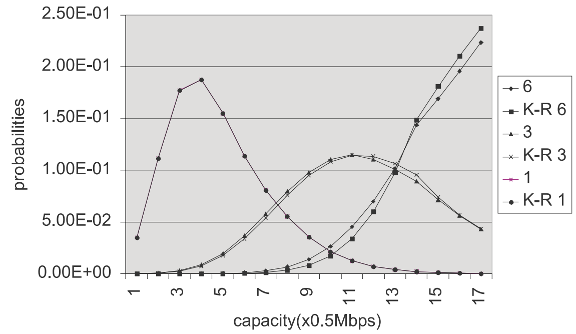

Figure 2: Accuracy of the proposed approximation method

Given these equations supposing local balance, the approximate numerical calculation of the blocking probability follows the pattern proposed by Kaufman and Roberts [20],[21]. Define $\tilde{v}(m)$ and $v(m)$, the relative and the normalized probability of m channel occupancy. $\tilde{v}(m)$ is computed as $\tilde{v}(m) = 0$ for $m < 0$, $\tilde{v}(0) = 1$, and for $m > 0$

$$\tilde{v}(m) = \sum_i \tilde{v}(m-c_i)\frac{c_i}{m}K_i(C_0 - m + c_i), \quad (14)$$

and

$$v(m) = \tilde{v}(m)\frac{1}{\sum_{m=0}^{C_0}\tilde{v}(m)}. \quad (15)$$

Finally, the blocking probabilities are obtained as (5), (6), (7), (8) and (9) knowing that

$$v(m) = \sum_{\underline{n}\,:\,\underline{n}\underline{c}^T=m} p(\underline{n}). \quad (16)$$

4. NUMERICAL EXAMPLES

4.1 Accuracy of the approximation

Figure 2 gives insight to the accuracy of the approximation based on (15) and (14) with respect to the accurate results based on (5). A system with two capacity demands (0.5 and 2 Mbps) and $C_0 = 8$Mbps was considered. This process has nearly 20000 states. The solution of this Markov chain was obtained by the Gauss-Seidel method [22]. The graph shows the occupancy distribution as the total arrival rate increases. Curves denoted by K-R show the results obtained by the approximation. It is clear that under light load conditions the error of the approximation is negligible (the curves of the approximation and the exact solution are indistinguishables when the incoming rate is 1).

4.2 Numerical example of a larger state space

A single cell is examined with the proposed approximation method (Eq. (12) and (14)). Call blocking

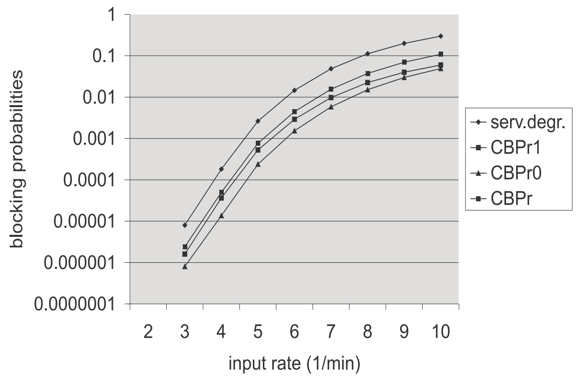

Figure 3: Call blocking probabilities

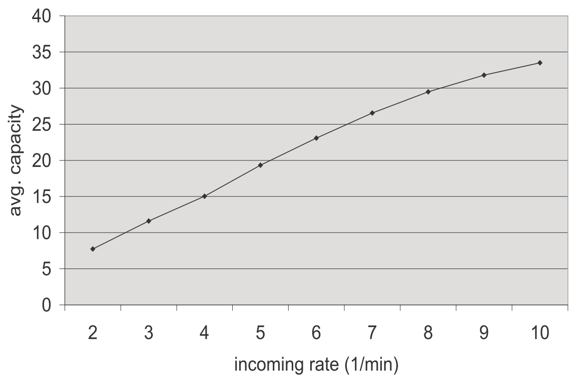

Figure 4: Average occupied capacity

in case of insufficient idle capacity was applied. We consider a cell in which the average dwell time is measured to be 7 minutes, the relative variation of this time is assumed to be 0.7347. The mean call duration is supposed to be 5 minutes, with a relative variation of 0.5476. The cell has 20 Mbps capacity (as in WAND [5]) and the customers are supposed to use a videophone application with two bit rates: 500 kbps and 2 Mbps. The 2 Mbps bursts has the mean of 0.1 minutes, while the average length of the 0.5 Mbps bursts is 2 minutes. The initial probability of 0.5 Mbps speed is 0.8, that of 2 Mbps is 0.2. This system has a large state space with more than 3.5 million states, therefore obtaining its exact solution (if possible) would need huge amount of numerical computations.

On Figure 3 the blocking probabilities are plotted as the function of incoming rate. CBPr0, CBPr1, CBPr and serv.degr. denotes the probabilities of call blocking if a customer arrives with transmission speed of 0.5 Mbps, 2 Mbps, the total call blocking probability and the probability of service degradation if a customer unsuccessfully tries to switch to 2 Mbps, respectively.

Figure 4 shows the average occupied capacity as the function of the incoming rate. Comparing Figure 3 and 4 shows that for a reasonable level of blocking probability (0.01) an average capacity occupation of 27 units (13.5 Mbps) belongs, that means a 67.5% utilization. If the load is high enough to reach higher utilization the blocking probability increases to a level that is not acceptable.

5. CONCLUSIONS AND FUTURE WORKS

An approximate analysis method is proposed that makes possible to analyze realistic cellular networks with VBR connections. This method can be used to help the process of cell dimensioning or to calculate expected loads of mobile networks. With the approximation proposed in section 3 a single cell can be examined in isolation. The proposed approximate method has the great advantage of negligible computational complexity even in case of very large state spaces and causes reasonable degradation of the accuracy.

The generalization for different user mobility types and ATM service classes is also possible in the proposed modeling framework. E.g., the co-existence of CBR and VBR calls can easily be handled with this approach. However this would result in the growth of the state space.

A queuing network model of a group of radio cells working together is currently being elaborated by the authors. This model will be able to handle the residual time problem of handover calls and also will make it possible to calculate the handover flow between cells accurately.

In the near future simulation studies will also be done to verify the applicability of the proposed numerical method for systems with huge state-spaces.

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