Performance Analysis of GSM Traffic Channel Capacity With(out) High Speed Circuit Switched Data

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Abstract

Analytical techniques for the analysis of the traffic channel capacity in the Global System for Mobile (GSM) Communications are studied in this paper. The results are represented for High Speed Circuit-Switched Data (HSCSD) traffic channels co-existing with the voice traffic channels in a GSM cell. In a GSM system the base station has a finite number of traffic channels, from which one voice terminal occupies one traffic channel. The admission priority for voice services is higher than that of the HSCSD data. On the other hand, one HSCSD terminal can occupy multiple number of channels if needed, provided that they are available. The HSCSD terminal will release its reserved traffic channels only after the data transmission is completed. The presence of HSCSD services slightly increases the blocking probability of the voice terminals. The results in this paper show the steady-state channel utilization and blocking probability of voice terminals under the constraints where voice terminals occupy one traffic channel at a time and data terminals can occupy multiple number of traffic channels. The results show that for a defined acceptable voice blocking probability, the overall channel utilization increases with the higher number of HSCSD terminals allowed per base station as well as with the higher number of channels allowed to be allocated for each HSCSD terminal. The traffic channel utilization also increases if the acceptable blocking probability for voice terminals is allowed to increase. The analytical model represented herein is general. Therefore, the channel utilization and the voice blocking probability results are calculated both with and without the HSCSD traffic channels. These numerical cases can be obtained by appropriate parameter setting from the same process model.

1. Introduction

Expectations show increasing demands for a wide range of services from voice, from low to high bitrate data and advanced data services for cellular communication system. In the beginning of the century, the mobile subscribers will enjoy various kinds of data services along with the regular voice service. The worldwide activities are defining third generation mobile radio systems: International Mobile Telecommunications by the year 2000 (IMT-2000), in the International Telecommunication Union (ITU), or Universal Mobile Telecommunication System (UMTS), in Europe. The implemented 3rd generation system will provide service to anyone, anytime anywhere in all radio environments. The WCDMA based third generation system will provide the services: voice, low rate data (144 kb/s) in vehicular, medium rate data (384 kb/s) for outdoor and indoor and up to 2 Mb/s for indoor environment [1].

Currently, more than 1 billion subscribers worldwide use the three most successful 2nd generation TDMA based cellular systems: GSM, TDMA (136) and PDC, where speech is the main teleservice. Mobile communication network operators are facing the demand for new mobile subscribers, and they are expanding their networks continuously. Some operators may not be able to get license to 3rd generation spectrum to support the new services, like high-speed data. Some operators are not willing to consider jump to the 3rd generation system due to its large investment in the current 2nd generation technology. Therefore they are looking for possible solutions to achieve the services comparable

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to the 3rd generation in the existing 2nd generation systems [2].

The European Telecommunications Standard Institute (ETSI) is defining two new technologies for data services, called General Packet Radio Services (GPRS) and High Speed Circuit-Switched Data (HSCSD) over the existing GSM system as the phase 2+ standard. In the existing GSM system each mobile terminal can occupy a single traffic channel for the whole transmission period. The GPRS and HSCSD terminals will occupy multiple number of slots. The existing voice transmission is a circuit-switched based on the other hand GPRS is a packet based data transmission system. The data packet created from GPRS can be transmitted through the unused voice traffic channels. Therefore the traffic channel efficiency with GPRS is always higher than that of the without GPRS. Since the traffic channels are used to transmits GPRS packets when they are unused by the voice terminals, the voice terminals do not suffer any blocking for GPRS terminals [3-5].

In HSCSD, one data terminal may occupy multiple number of traffic channels, if needed and if the network has resource available [6]. The data terminals occupy these multiple number of channels up to completing their data transmission time. The higher priority voice connections suffer higher blocking probability when HSCSD terminals are working in the network. The blocking probabilities with HSCSD are discussed extensively in [7] using multi-dimensional Markov chain. The blocking probabilities and their properties with multi-dimensional Markov model are also discussed in [8-10]. Stasiak carried an excellent work in [11], where he developed the determined distributions using combinatorial method. The determined distribution enable calculation of blocking probabilities in multi-stage switching networks carrying different multi-channel traffic streams.

Traffic channel utilization is an important measure for the operators. The operators are charging depending on the traffic channel utilization among the other things. One of the most important criteria for the operators is to keep the blocking probabilities under a certain limit. The GPRS is an effective solution, where one data terminal can transmit the data using multiple number of traffic channels without increasing voice blocking probability and with higher traffic channel efficiency. Unfortunately, it may suffer high delay during congestion period of the network. Some services like video stream need to transmit their data using multiple traffic channels almost with constant delay. In this case, the HSCSD provides the solution [12]. The HSCSD increases the voice blocking probability, but the impacts of the overall channel utilization are expected to be positive. This important issue is the main concern of this paper. A simulation study regarding a similar matter was carried out by Neale et al [13]. An analytical approach is developed in this paper using multi-dimensional Erlang loss formula [14-15].

The multi-dimensional Erlang loss model can be converted to one-dimensional model [16]. Here we used this technique, which makes the calculation for overall traffic channel utilization as well as the voice blocking probability easier and is presented in section 2.

One of the main concerns of the mobile operators is to achieve the higher traffic channel utilization while keeping the voice blocking probability under a certain limit. In section 4 the result show the channel utilization for a defined value of the voice blocking probability. Finally, in section 5 the conclusions indicate the HSCSD and the GPRS to potentially meet the future data transmission needs.

2. Analysis

A. State probabilities

Let us consider a base station having M number of traffic channels. Assuming two types of connections: voice terminals (VTs) and data terminals (DTs). The call arrival process of voice terminals is independent with an average rate of λ_v, and the duration of each voice call is exponential with mean $1/\mu_v$. The voice traffic intensity of *all* voice terminals is thus $\rho_v = \lambda_v / \mu_v$.

The maximum allowed data terminals in a given base station is K, and each data terminal can occupy maximum N slots (or N channels). In the multi-dimensional system model K data terminals will make K dimensions and another dimension will be for voice terminals. Thus, the system has K+1 dimensions overall. Since each data terminal represents one separate dimension, the traffic of each data terminal has to be considered separately. One special assumption was made here. Each data terminal occupies a multiple number of traffic channels at a time. We assumed that the multiple arrival of *each* data terminal into different traffic channels is independent and exponentially distributed with mean λ_d. Similarly, each data terminal will release multiple number of traffic channels at a time. It was assumed that the departure of a given data terminal from its traffic channel is independent and exponentially distributed with average rate μ_d. The call intensity of *each* data terminal is thus $\rho_d = \lambda_d / \mu_d$.

Let us consider that there is K number of DTs is in the system. Since the DTs calls are limited by the number of channels N. So $0 \le n_i \le N$, for $0 \le \sum_{i=1}^{K} n_i \le M$, where M is the total number of traffic channels in a given base station. The number of VTs is not limited. If j defines the number of VTs in that system, then $0 \le j \le M$.

The state ($n_1, n_2, \ldots n_K$, j) defines the probability that K number of DTs occupying $n_1, n_2, \ldots n_K$, channels and j number of VTs is in the system.

Let us consider the state ($n_1, 0, \ldots 0$, 0), i.e., the probability that the only one DT is in the system and is occupying n_1 channels and no other terminals are active, which can be shown [19]

$$p(n_1, 0, \ldots 0, 0) = \frac{\rho_d^{\,n_1}}{n_1!} p(0, 0, \ldots 0, 0) \qquad 0 \le n_1 \le N \tag{1}$$

Similarly, the probability that j number of VT calls but no DT calls is

$$p(0, 0, \ldots 0, j) = \frac{\rho_v^{\,j}}{j!} p(0, 0, \ldots 0, 0) \qquad 0 \le j \le M \tag{2}$$

yielding the probability that K number of DT calls and j number of VT calls are in the system is

$$p(n_1, n_2, \ldots, n_K, j) = \frac{\rho_d^{\,n_1}}{n_1!} \frac{\rho_d^{\,n_2}}{n_2!} \cdots \frac{\rho_d^{\,n_K}}{n_K!} \frac{\rho_v^{\,j}}{j!} p(0, 0, \ldots, 0, 0)$$

$$0 \le n_i \le N,\; 0 \le j \le M, \quad 0 \le \sum_{i=1}^{K} n_i + j \le M \tag{3}$$

Let us consider this K+1 dimensional state probability model as a one-dimensional state probability model. Since there are M number of traffic channels, the system states will be from 0 to M.

Assuming $Q(k)$ as the probability that K number of DTs and j number of VTs occupies k channels.

The probability that the system is idle can be written as

$$Q(0) = p(0, 0, \ldots, 0, 0) \tag{4}$$

Probability that 1 channel is occupied by either K DTs or by j VTs is

$$Q(1) = p(1, 0, \ldots, 0, 0) + p(0, 1, \ldots, 0, 0) + \ldots + p(0, 0, \ldots, 1, 0) + p(0, 0, \ldots, 0, 1)$$

$$= Q(0)[\rho_d + \rho_d + \ldots + \rho_d + \rho_v]$$

$$= Q(0)\left[\sum_{n_1=0}^{1} \frac{\rho_d^{\,n_1}}{n_1!} \sum_{n_2=0}^{1-n_1} \frac{\rho_d^{\,n_2}}{n_2!} \cdots \sum_{n_K=0}^{1-\sum_{i=1}^{K-1} n_i} \frac{\rho_d^{\,n_K}}{n_K!} \cdot \frac{\rho_v^{\,1-\sum_{i=1}^{K} n_i}}{\left(1-\sum_{i=1}^{K} n_i\right)!}\right] \tag{5}$$

Probability that 2 channels are occupied by either K DTs or by j VTs calls are:

$$Q(2) = p(2, 0, \ldots, 0, 0) + p(1, 1, \ldots, 0, 0) + \ldots + p(1, 0, \ldots, 1, 0) + p(1, 0, \ldots, 0, 1) + p(0, 2, \ldots, 0, 0) + \ldots + p(0, 1, \ldots, 1, 0) + p(0, 1, \ldots, 0, 1) + \ldots + p(0, 0, \ldots, 2, 0) + p(0, 0, \ldots, 1, 1) + p(0, 0, \ldots, 0, 2)$$

$$= Q(0)\left[\sum_{n_1=0}^{2} \frac{\rho_d^{\,n_1}}{n_1!} \sum_{n_2=0}^{2-n_1} \frac{\rho_d^{\,n_2}}{n_2!} \cdots \sum_{n_K=0}^{2-\sum_{i=1}^{K-1} n_i} \frac{\rho_d^{\,n_K}}{n_K!} \frac{\rho_v^{\,2-\sum_{i=1}^{K} n_i}}{\left(2-\sum_{i=1}^{K} n_i\right)!}\right] \tag{6}$$

For the range $0 \le k \le N$, it can be shown applying the same procedure as from Eq. (5) and (6), that the probability of k channels are occupied by K data terminals and or j voice terminals calls is

$$Q(k) = Q(0)\left[\sum_{n_1=0}^{k} \frac{\rho_d^{\,n_1}}{n_1!} \sum_{n_2=0}^{k-n_1} \frac{\rho_d^{\,n_2}}{n_2!} \cdots \sum_{n_K=0}^{k-\sum_{i=1}^{K-1} n_i} \frac{\rho_d^{\,n_K}}{n_K!} \frac{\rho_v^{\,k-\sum_{i=1}^{K} n_i}}{\left(k-\sum_{i=1}^{K} n_i\right)!}\right]$$

$$0 \le k \le N \tag{7}$$

Let us consider the case where $k > N$. The probability that N+1 channels are occupied is given by

$$Q(n+1) = p(N, 1, \ldots, 0, 0) + p(N-1, 2, \ldots, 0, 0) + \ldots + p(0, N, \ldots, 1, 0) \ldots + p(0, 0, \ldots, N, 1) + \ldots + p(0, 0, \ldots, 1, N) + p(0, 0, \ldots, 0, N+1)$$

$$= Q(0) \sum_{n_1=0}^{N} \frac{\rho_d^{\,n_1}}{n_1!} \sum_{n_2=0}^{\min(N, N+1-n_1)} \frac{\rho_d^{\,n_2}}{n_2!} \cdots \sum_{n_K=0}^{\min\left(N, N+1-\sum_{i=1}^{K-1} n_i\right)} \frac{\rho_d^{\,n_K}}{n_K!} \frac{\rho_v^{\,N+1-\sum_{i=1}^{K} n_i}}{\left(N+1-\sum_{i=1}^{K} n_i\right)!} \tag{8}$$

Similarly the probability that N+2 channels are occupied

$$Q(n+2) = p(N,2,...,0.0) + p(N-1,3,...,0,0) + ... + p(0,N,...,2,0) + ... + p(0,0,...,N,2) + ... + p(0,0,...,1,N+1) + p(0,0,...,0,N+2)$$

$$= Q(0)\sum_{n_1=0}^{N}\frac{\rho_d^{\,n_1}}{n_1!}\sum_{n_2=0}^{\min(N,N+2-n_1)}\frac{\rho_d^{\,n_2}}{n_2!}\cdots\sum_{n_K=0}^{\min\left(N,N+2-\sum_{i=1}^{K-1}n_i\right)}\frac{\rho_d^{\,n_K}}{n_K!}\frac{\rho_v^{\,N+2-\sum_{i=1}^{K}n_i}}{\left(N+2-\sum_{i=1}^{K}n_i\right)} \tag{9}$$

In general for the values of k in between $N \le k \le M$ as Eqs. (8) and (9) we obtain

$$= Q(0)\sum_{n_1=0}^{N}\frac{\rho_d^{\,n_1}}{n_1!}\sum_{n_2=0}^{\min(N,k-n_1)}\frac{\rho_d^{\,n_2}}{n_2!}\cdots\sum_{n_K=0}^{\min\left(N,k-\sum_{i=1}^{K-1}n_i\right)}\frac{\rho_d^{\,n_K}}{n_K!}\frac{\rho_v^{\,k-\sum_{i=1}^{K}n_i}}{\left(k-\sum_{i=1}^{K}n_i\right)}$$

$$N \le k \le M \tag{10}$$

Combining the Eqs. (7) and (10) the probability that k channels out of M channels are occupied is

$$Q(k) = \begin{cases} Q(0)\sum_{n_1=0}^{k}\frac{\rho_d^{\,n_1}}{n_1!}\sum_{n_2=0}^{k-n_1}\frac{\rho_d^{\,n_2}}{n_2!}\cdots\sum_{n_K=0}^{k-\sum_{i=1}^{K-1}n_i}\frac{\rho_d^{\,n_K}}{n_K!}\frac{\rho_v^{\,k-\sum_{i=1}^{K}n_i}}{\left(k-\sum_{i=1}^{K}n_i\right)} & 0 \le k \le N \\ Q(0)\sum_{n_1=0}^{N}\frac{\rho_d^{\,n_1}}{n_1!}\sum_{n_2=0}^{\min(N,k-n_1)}\frac{\rho_d^{\,n_2}}{n_2!}\cdots\sum_{n_K=0}^{\min\left(N,k-\sum_{i=1}^{K-1}n_i\right)}\frac{\rho_d^{\,n_K}}{n_K!}\frac{\rho_v^{\,k-\sum_{i=1}^{K}n_i}}{\left(k-\sum_{i=1}^{K}n_i\right)} & N \le k \le M \end{cases} \tag{11}$$

and from Eq. (7)

$$Q(0) = p(0,0,...,0,0)$$

$$= \left[\sum_{n_1=0}^{N}\frac{\rho_d^{\,n_1}}{n_1!}\sum_{n_2=0}^{N}\frac{\rho_d^{\,n_2}}{n_2!} --- \sum_{n_K=0}^{N}\frac{\rho_d^{\,n_K}}{n_K!}\sum_{j=0}^{M-\sum_{i=1}^{K}n_i}\frac{\rho_v^{\,j}}{j!}\right]^{-1} \tag{12}$$

We claimed that the analysis is so general that it can be validate without HSCSD with a very simple modification. The equation for voice only transmission can be obtained from the Eqs. (11) and (12) by three different ways. (1) Set the number of data terminals $K = 0$, (2) Set the maximum number of allowed channels per data terminal $N = 0$, and finally, (3) Set the data traffic intensity for every data terminal $\rho_d = 0$.

B. *Channel Utilization and Voice Blocking Probability*

The channel utilization can be defined as the ratio of the average number of channels used to the total number of channels in the system. So the channel utilization can be written as

$$U = \frac{1}{M}\sum_{k=0}^{M} kQ(k) \tag{13}$$

If all M channels are occupied, a new VT call will be blocked. The probability for that is termed as *blocking probability for VT terminals,* B_v, and can be written from Eqs. (11) as

$$B_v = Q(M)$$

$$= Q(0)\sum_{n_1=0}^{N}\frac{\rho_d^{\,n_1}}{n_1!}\sum_{n_2=0}^{\min(N,M-n_1)}\frac{\rho_d^{\,n_2}}{n_2!}\cdots\sum_{n_K=0}^{\min\left(N,M-\sum_{i=1}^{K-1}n_i\right)}\frac{\rho_d^{\,n_K}}{n_K!}\frac{\rho_v^{\,M-\sum_{i=1}^{K}n_i}}{\left(M-\sum_{i=1}^{K}n_i\right)} \tag{14}$$

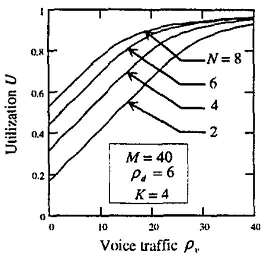
Where the probability that all channels are free $Q(0)$ can be found from Eq. (12).

3. Numerical Analysis and Discussions

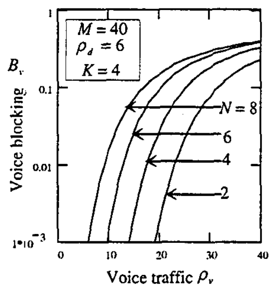
A. *Channel Utilization and Voice Blocking Probability*

Channel utilization and the voice blocking probability is calculated with the variation of voice traffic intensity, ρ_v, for different values of the maximum allowed channels for one data terminal N, where the total number of traffic channels in the base station, $M = 40$ has been assumed. Figure 1 & Figure 2 are shown for two different values of data traffic intensity, ρ_d.

It is obvious, when data traffic intensity ρ_d is zero, there is no effect on the channel utilization nor on voice blocking probability with the variation of maximum number of channels occupied by one data terminal, N. If we set the number of the maximum channels occupied by one data terminal N equal to zero, only voice terminals will be in the system. It is obvious that channel utilization increases with the increase of the maximum number of allowed channels for one data terminal, N. But it also increases the blocking probability for the voice terminals.

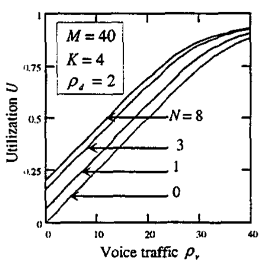


(a)

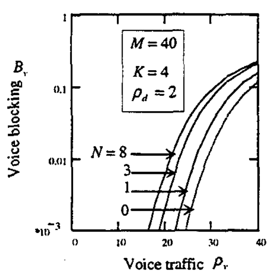


(b)

Figure 1: (a) Channel utilization U and (b) voice blocking probability vs. voice traffic intensity ρ_v, for different values of maximum number of channels allowed for one data terminal. The data traffic intensity $\rho_d = 6$.

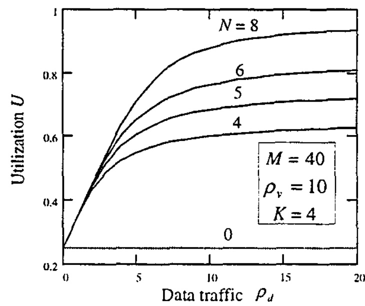


(a)

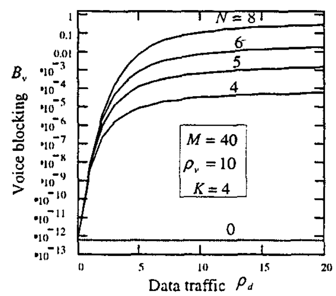


(b)

Figure 2: Channel utilization U and voice blocking probability B_v vs. voice traffic intensity ρ_v, for different values of maximum number of channels allowed for one data terminal, N. The data traffic intensity $\rho_d = 2$. The dotted line shows the characteristics without HSCSD.



(a)



(b)

Figure 3: (a) Channel utilization U and (b) voice blocking probability B_v vs. data traffic intensity ρ_d, for different values of maximum number of channels allowed for one data terminal, N. The voice traffic intensity $\rho_v = 10$. The dotted line shows the characteristics without HSCSD.

Channel utilization U and the voice blocking probabilities are shown in Figures 3 and 4 with the variation of data traffic intensity ρ_d. The average voice traffic intensity ρ_v is set to 10 and 25 respectively. If the maximum allowed number of channels per data terminal, equals to 0, i.e., whatever the value of voice traffic intensity, ρ_v, channel utilization is the same. The reason is that, no DT can get a service, if DTs are completely blocked by setting N = 0. The same will happen if the data traffic intensity $\rho_d = 0$, whatever the value of maximum allowed channel per data terminal. The linear curves of channel utilization and voice blocking probability is shown in Figs. 3 and 4 when only the voice terminals are present in the system.

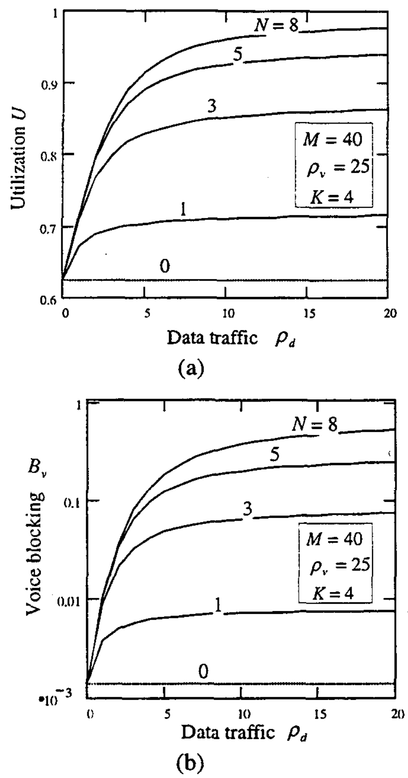


Figure 4: Channel utilization U and voice blocking probability B_v vs. data traffic intensity ρ_d, for different values of maximum number of channels allowed for one data terminal, N. The voice traffic intensity $\rho_v = 25$. The dotted line shows the characteristics without HSCSD.

4. Optimum Number of Traffic Channels Per Base Station

The optimum number of traffic channels per base station will give the higher channel utilization as well as keep the blocking probability under a defined value. The voice call blocking probability is defined to account either 1% [17] or 2% [18]. We used these values of blocking probabilities in Eq. (14) and found the channel traffic utilization using Eq. (13). The results are depicted in Figure 5. The Figure 5 shows that the channel utilization with the HSCSD is higher than that without HSCSD pertaining to the acceptable voice blocking probability. The channel utilization also increases with the increased number of HSCSD terminals, K for an acceptable limit of voice blocking probability.

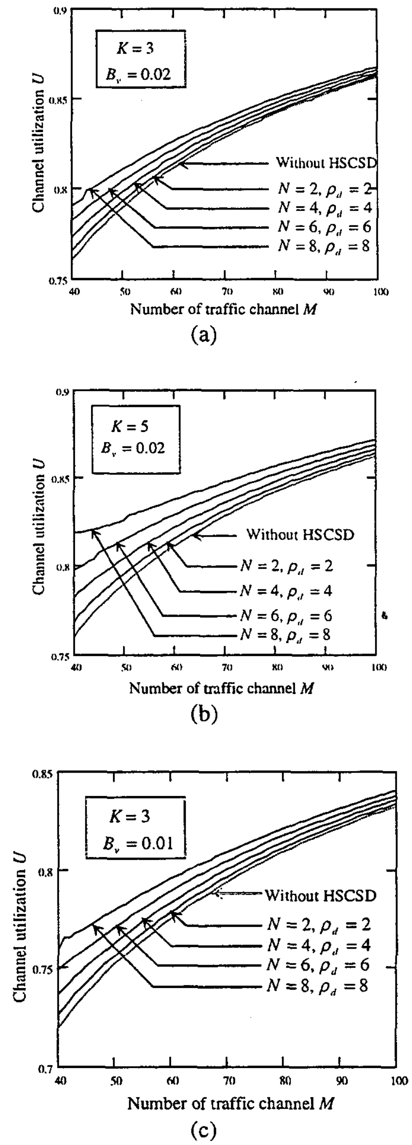


Fig. 5: Channel utilization vs. the total number of traffic channels in a base station.

Table 1 shows higher overall channel utilization with increasing HSCSD number of channels. If the number of HSCSD channels increases, the maximum amount of voice traffic intensity ρ_v, decreases, for a given blocking probability. The overall traffic channel utilization increases because of higher channel occupied by HSCSD terminals.

Table 1: The maximum voice traffic intensity ρ_v decreases with the increase of HSCSD channels, but the overall corresponding traffic channel utilization U increases. The allowed voice terminal blocking probability is limited to 2%. The number of data terminals is K = 5.

$K = 5 \quad B_v = 0.02$

	No HSCSD		$\rho_d = 2, N = 2$		$\rho_d = 4, N = 4$		$\rho_d = 6, N = 6$		$\rho_d = 8, N = 8$	
M	ρ_v	U	ρ_v	U	ρ_v	U	ρ_v	U	ρ_v	U
40	31.012	0.76	25.276	0.768	17.974	0.782	10.203	0.798	2.372	0.819
50	40.322	0.79	34.542	0.796	27.093	0.805	19.243	0.815	11.117	0.826
60	49.703	0.812	43.884	0.816	36.37	0.822	28.431	0.829	20.291	0.838
70	59.182	0.828	53.334	0.831	45.774	0.836	37.775	0.842	29.558	0.848
80	68.736	0.842	62.865	0.844	55.27	0.848	47.228	0.852	38.957	0.857
90	78.35	0.853	72.461	0.855	64.839	0.858	56.763	0.861	48.451	0.865
100	88.012	0.862	82.109	0.864	74.465	0.866	66.362	0.869	58.019	0.872

5. Conclusions

GSM must extend its services particularly the HSCSD services. An analytical approach was carried out to show the channel utilization with and without the HSCSD. The results showed that the overall traffic channel utilization increases with the increase of HSCSD channels. Therefore, depending this results operators can be deployed to implement HSCSD along with the GPRS to achieve the 3rd generation capability.

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