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オンデマンド型チャネル割り当て法を用いた DS-CDMA マルチホップバーチャルセルラーネットワークにおける許容最大最適ホップ数に関する検討

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あらまし: 次世代移動通信ネットワークを実現するためマルチホップバーチャルセルラーネットワーク(VCN)が提案されている.チャネル割り当て法にはプリアサイン型とオンデマンド型がある．本論文では,これら２つの方法の比較を行い，オンデマンド型チャネル割り当て法の方が良好な呼損率を得られることを示す．ところで，許容最大ホップ数を増やすと，マルチホップリンクの送信電力を小さくでき，干渉電力も小さくできるものの，リンク数が増えるために呼損が生じる可能性が大きくなってしまう．本論文では,このトレードオフについての検討を行い，許容最大ホップ数が呼損率に与える影響を計算機シミュレーションにより明らかにしている.

キーワード バーチャルセルラーネットワーク，マルチホップネットワーク，オンデマンド型チャネル割り当て，ホップか図，呼損率

On the Optimum Number of Hops in a Multi-Hop DS-CDMA Virtual Cellular Network using On-Demand Channel Assignment

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Abstract: A multi-hop virtual cellular network (VCN) was proposed for future mobile communication systems. In VCN, there are two methods of channel assignment; the pre-assignment and on-demand channel assignment. In this paper we will give a simple comparison of the two methods and give a reason why we will focus our research on the on-demand channel assignment from now-on. In a multi-hop VCN using on-demand channel assignment, increasing the number of hops leads to a less transmit power of the multi-hop links and hence to a decreased interference to other users, this can decrease the call blocking probability. On the other hand, increasing the number of the call links might increase the blocking probability of this call. In this paper, we give an analysis about this tradeoff and show the impact of the number of hops on the blocking probability of a DS-CDMA multi-hop VCN. Simulation results are presented to show that there is an optimum value of number of hops depending on some network conditions.

Keywords: virtual cellular network, multi-hop network, on-demand channel assignment, number of hops, blocking probability

1. Introduction

Growing number of wireless users and high data rate multimedia applications with varying QoS requirements for 3G and beyond wireless systems, are demanding novel wireless communication techniques and network architectures. A multi-hop virtual cellular network (VCN) [1] is one such an architecture, which was proposed to reduce the large peak transmit power resulting from the high transmission rates expected for mobile communication systems beyond 3G. In the VCN, the multi-hop route from each wireless port (WP) is decided a priori and when a mobile terminal (MT) wants to make a call, it is connected to its nearest WP then the multi-hop route from this receiver WP is used in order to relay the signal of this MT to the central port (CP).

The channel assignment is an important issue in the multi-hop VCN. There can be two methods of channel assignment that can be thought of; one is the pre-assignment which allocates first the channels to the multi-hop links between the WPs and when an MT wants to make a call, only one channel has to be allocated to the link between this MT and its nearest WP, if the channels already allocated to the other links of the multi-hop route can still carry this new traffic. The other method is the on-demand channel assignment, which allocates the channels to all the links between the MT and the CP after the MT asks to make a call. The choice of an adequate channel assignment algorithm is also an important issue for the multi-hop VCN. Channel segregation-dynamic channel allocation (CS-DCA) [2], which was proposed for the cellular network, seems to be promising for the multi-hop VCN ([3] and [4]).

The pre-assignment analysis, using CS-DCA, was first considered in [3], where the channel allocation of the multi-hop links between the WPs was carried out. However, the channel assignment of the MT link was not considered in that work yet. The on-demand channel assignment, using CS-DCA, was already proposed and discussed in [4]. In this paper, we will give a comparison between the two channel assignment methods from different aspects in Sect.3. A comparison between the blocking probabilities of the two cases will be also given.

Because the on-demand channel assignment can significantly decrease the blocking probability compared to the pre-assignment. Therefore, we would like to focus our research on the on-demand channel assignment from now-on.

In the on-demand channel assignment in the multi-hop VCN, there is an important trade-off to be studied. Increasing the number of hops leads to a less transmit power of the multi-hop links and hence to a decreased interference to other users, this can decrease the call blocking probability. On the other hand, increasing the number of hops increases the number of the call links that have to be successfully allocated before a call can be successful and hence this might increase the blocking probability of this call. In this paper, we will also examine this trade-off between decreased interference and increased number of hops in relation to its effect on the blocking probability of a multi-hop VCN using on-demand channel assignment that uses CS-DCA as algorithm.

In 3G mobile communication systems, direct-sequence code division multiple access (DS-CDMA) is adopted as an access technique [5]. DS-CDMA can also be applied to the multi-hop VCN. In this paper, we consider a DS-CDMA multi-hop VCN.

This paper is organized as follows. We first describe the DS-CDMA multi-hop VCN in Sect.2. In Sect.3, a comparison between the pre-assignment and the on-demand channel assignment is given. The blocking probability is evaluated by computer simulation to compare the two methods. In Sect.4, the impact of the number of hops on the performance of the multi-hop VCN using on-demand channel assignment is discussed. Finally, we give some conclusions in Sect.5.

2. Wireless Multi-Hop VCN Description

The network architecture of the multi-hop VCN is illustrated in Fig.1. Each virtual cell (VC) consists of many distributed WPs, which work as relays used to forward the traffic of the MTs having poor coverage to the CP, which is the gateway to the core network. All the multi-hop routes from each WP to the CP are constructed based on the total transmit power minimization criterion ([6], [7] and [8]).

In the conventional multi-hop uplink, the signal transmitted from the MT is received by its nearest WP. Then, the received signal is relayed to the CP via the constructed route. The major advantage of multi-hopping in the VCN is that it requires lower transmit power than that of (MT-BS) direct link (or single-hop) in the present cellular networks for the same required signal-to-interference plus noise power ratio (SINR). This is because multi-hop routes have short range links to the destination, which leads to low path loss and as a result, lower transmit power is required to achieve the desired signal strength [1]. However, there are some technical issues associated with multi-hop communication to be solved, such as complex routing and channel assignment schemes.

With using DS-CDMA in a multi-hop VCN, the same benefits as in other wireless access schemes such as FDMA and TDMA, including enlargement of area coverage and reduction of transmit power, can be expected. However, if the same frequency band is used for multi-hop transmission, it may be a source of high interference causing the degradation of the system capacity. In order to avoid the interference in the multi-hop links, the available frequency band is divided into several frequency channels and different frequency channels are allocated to the adjacent multi-hop links. In what follows, a channel refers to a frequency channel.

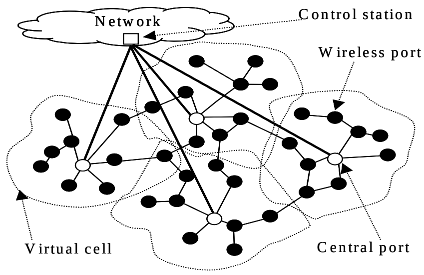


Fig. 1 Wireless multi-hop VCN system.

3. Comparison between the pre-assignment and the on-demand channel assignment for uplink multi-hop VCN

In this paper, only the multi-hop uplink is considered. We assume that a user in a cell can only take relaying assistance from WPs in this cell. The signal transmitted from the mobile terminal is received by its nearest WP, in order to fix the multi-hop route to the CP.

There are two methods of channel assignment that can be considered in the multi-hop VCN; the pre-assignment and the on-demand channel assignment.

In the pre-assignment case, in a way similar to what was described in [3] channels are first allocated to the multi-hop links between the WPs. Fig.2 shows the order of links in the pre-assignment process of one VC. The number on the link refers to the order of the channel allocation of this link in this VC. This order is set to maximize the use of one channel by one WP. The pre-assignment process is established a priori and when an MT wants to communicate, if the pre-assigned channels to the multi-hop links between the nearest WP and the CP are still available for this new user then only one channel should be allocated to the link between the MT and its nearest WP. However, if one of these pre-assigned channels can not be used anymore then the call is blocked.

There are also some other causes of the call blocking in the pre-assignment case; Because the number of available channels is fixed in the network, then in some cases channel allocation failure occurs in the pre-assignment phase of the multi-hop links between the WPs and the CP. In this case, if the nearest WP of an MT has a multi-hop route that has a link failure, then we consider that this user is blocked from the beginning. Another thing about the pre-assignment is that once the number of channels available is enough to allocate all the multi-hop links between the WPs and the CP then increasing the number of channels over this number does not affect much the blocking performance of the network. This is because most of the blockings occur because of the degradation of the multi-hop links between the WPs as one channel would not be enough to allocate so many users. In the computer simulation section, we had investigated also about the maximum number of channels needed to realize the pre-assignment of the multi-hop links between the WPs and the CP in one VC, with the maximum number *N* of allowable hops as parameter.

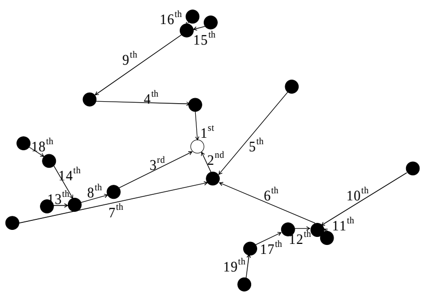


Fig.2 Model of the order of the links in the pre-assignment process of one VC.

On the other hand, as was described in detail in [4], in the on-demand channel assignment case, channels for all the multi-hop links of a call are assigned after the call request comes. The single hop assignment procedure is repeated in a sequence over the multi-hop route and if there is no channel available at one link of the multi-hop path, the call is blocked. The detailed procedure was described in [4].

What we can see from this first comparison is that the time of channel assignment and complexity is somehow reduced in the pre-assignment case. However, there is a waste of resources in the pre-assignment case as the channels are not used by users, which will also cause higher blocking probability compared to the on-demand channel assignment case. Below we evaluated, by using computer simulation, the blocking probability of the multi-hop VCN using the two ways of channel assignment.

A. Computer Simulation

First a computer simulation was carried out to measure the maximum number of channels needed to realize the pre-assignment of the multi-hop links between the WPs and the CP in one VC, with the maximum number *N* of allowable hops as parameter. A total of 19 VCs of hexagonal layout (the center VC is the cell of interest) are considered. Similar to the present cellular network, the CP of each VC is set in the middle of the cell.

In the pre-assignment part as well CS-DCA is used to allocate the channels to the multi-hop links between the WPs and the CP in each VC. For a more efficient frequency reuse, the initial priority table is similar for all the WPs. The channel assignment procedure of one multi-hop link is similar to what was described in [4].

In CS-DCA, the measurement of the signal-to-interferrence plus noise power ratio (SINR) is necessary. The SINR is affected by distance dependent path loss, shadowing loss and fading. We assume *L*-path Rayleigh fading with uniform power delay profile. The SINR formula used in our simulation is the same as the one derived in [4]. Assuming QPSK data modulation and an ideal fast TPC, for a required BER of 10^{-2}, the required SINR Λ_{target} is given by 7.3dB [9].

Another computer simulation was carried out to measure the blocking probabilities of the multi-hop VCN using both the pre-assignment and on-demand channel assignment with CS-DCA [2] as algorithm. The present cellular network performance was also investigated.

In each cell, the same number *U* of users is generated. All these calls go through call admission procedure, as it was described before.

B. Simulation results and discussions

Fig.3 shows the maximum number of channels needed to realize successfully the pre-assignment of all the multi-hop links between the WPs and the CP in one VC, with the maximum number *N* of allowable hops as parameter. The simulation was repeated for 1000times. The number of WPs in each VC is set to *K*=20 and other parameters are *SF*=16, α=3.5, σ=6dB and *L*=2. We can see that increasing *N* leads to decreasing the transmit power and therefore decreasing the interference to other links. Decreasing the interference leads to decreasing the number of channels needed to allocate all the multi-hop links connecting the WPs to the CP.

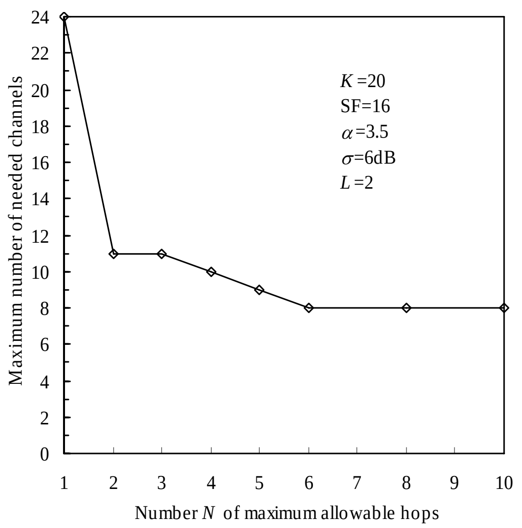


Fig.3 Maximum number C of channels needed for the pre-assignment of the multi-hop links between the WPs and the CP in one VC.

Based on Fig.3 and assuming that the pre-assignment process was successful with a minimum N and C, we give a comparison of the blocking probabilities of the two methods, for C= 8 when SF=16, N=6, α=3.5, σ=6dB and L=2. The result is shown in Fig.4. For comparison the performance of the present cellular network is also plotted. It can be seen that the blocking probability of the multi-hop VCN using the on-demand method is significantly reduced compared to the pre-assignment case and also the present cellular network. This is because as discussed in Sect.3 in the pre-assignment case there is an increase of the interference caused by the multi-hop links between the WPs, even not used by other MTs.

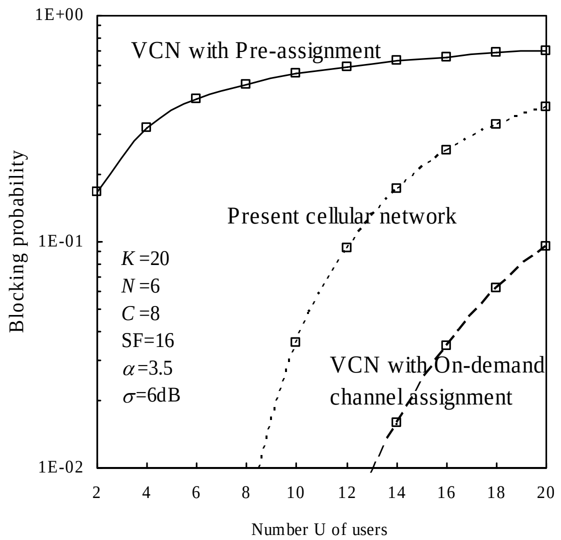


Fig.4 Blocking probabilities of the multi-hop VCN, using the pre-assignment and on-demand channel assignment, and the present cellular network.

From the result got and this first comparison between the two methods we can see that the on-demand channel assignment is more attractive to be used for the multi-hop VCN. Therefore, we would like to focus our research on the on-demand channel assignment from now-on.

4. Impact of the number of allowable hops on the blocking probability of the multi-hop VCN using on-demand channel assignment

There is an interesting tradeoff to discuss concerning a multi-hop VCN using on-demand channel assignment; increasing the number of the links can decrease the transmit power and hence decrease the interference to some other links, therefore the blocking probability can be decreased. On the other hand, increasing the number of hops increases the number of links that have to be successfully allocated to consider a call successful. Therefore, this may increase the call blocking probability of this call. This can be understood also from the following blocking probability (p_{bl}) formula of a call with N links, where $p_{failure}(l)$ refers to the failure probability of link #l, where $1 \le l \le N$.

$$\begin{aligned} p_{bl} &= p_{failure}(1) + [1 - p_{failure}(1)] p_{failure}(2) \\ &\quad + [1 - p_{failure}(1)][1 - p_{failure}(2)] p_{failure}(3) + \ldots\ldots \\ &= p_{failure}(1) + \sum_{l=2}^{N} \left\{ \prod_{l'=1}^{l-1} [1 - p_{failure}(l')] \right\} p_{failure}(l) \end{aligned} \quad (1)$$

In the multi-hop VCN, as it was discussed in [4], the blocking can occur because of two major contributing factors: poor coverage ($SINR < SINR_{target}$) and unavailability of free channels (because they are used in the adjacent links). Therefore, In Eq.(1) $p_{failure}(l)$ depends on both the number of channels available in the network and also the interference power. All this suggests that there should be an optimum value of N that might depend on the number C of available channels and some other parameters. Therefore, we investigated about this optimum value for different simulation conditions.

First we made some investigations about the interference power in the multi-hop VCN. As the WPs in the same VC can be close to each other, which might cause high intra-cell interference, so we have made some investigations related to intra-cell interference power between the links connecting two WPs. Fig.5 shows an example of interference caused from a link between two WPs to other similar link. We assume that a channel f_0 is used in the link connecting the WPs #k and #$r(k)$ and that we want to use it also in the link connecting the WPs #i and #$r(i)$. We assume also that $r(i) \neq k$ and $r(k) \neq i$. In this case, the transmitting WP #k may cause interference to the receiving WP #$r(i)$. The interference power can be given as

$$I = P^{t}_{k\_r(k)} r^{-\alpha}_{k\_r(i)} 10^{-\frac{\eta_{k\_r(i)}}{10}} \sum_{l=0}^{L-1} \left| h_{k\_r(i)} \right|^2 = \Lambda_{\mathrm{target}} \frac{r^{-\alpha}_{k\_r(i)} 10^{-\frac{\eta_{k-r(i)}}{10}} \sum_{l=0}^{L-1} \left| h_{k\_r(i)} \right|^2}{r^{-\alpha}_{k\_r(k)} 10^{-\frac{\eta_{k\_r(k)}}{10}} \sum_{l=0}^{L-1} \left| h_{k\_r(k)} \right|^2}, \quad (2)$$

where $P^{t}_{k\_r(k)}$ is the transmit power of the WP #*k*, α is the path loss exponent and r_{i_j}, η_{i_j} and $h_{i\_j}(l)$ are respectively the distance, log normally distributed shadowing loss with the standard deviation σ in dB and the *l*-th (l=0~L-1) path's complex path gain between the WPs #*i* and #*j*. $\{h_{i\_j}(l);i,j,l\}$ are characterized by time-invariant independent (but location-dependent) complex Gaussian variables with zero-mean and a variance of 1/*L*. Signal-to-noise power ratio (SNR)-based ideal TPC is assumed. where $\Lambda_{\mathrm{target}}$ is the target SNR.

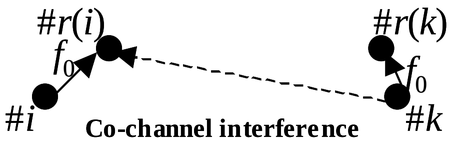


Fig.5 Co-channel interference of a link (WP-WP).

We plot in Fig.6 the cumulative distribution function (cdf) of *I* normalized by $\Lambda_{\mathrm{target}}$, for different *N*, when *K*=20, α=3.5, σ=6dB and *L*=2. We can see that the interference power decreases with the increase of *N*. This is because the routes from each WP to the CP are constructed based on the total transmit power minimization criterion and increasing *N* leads to a further decrease in the transmit power of the multi-hop links [1] and hence decreased interference to other links. We can see also that for *N*>4 the cdf doesn't change much.

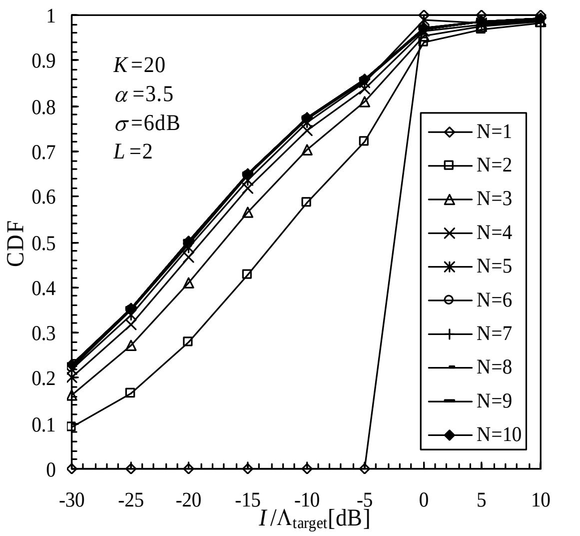
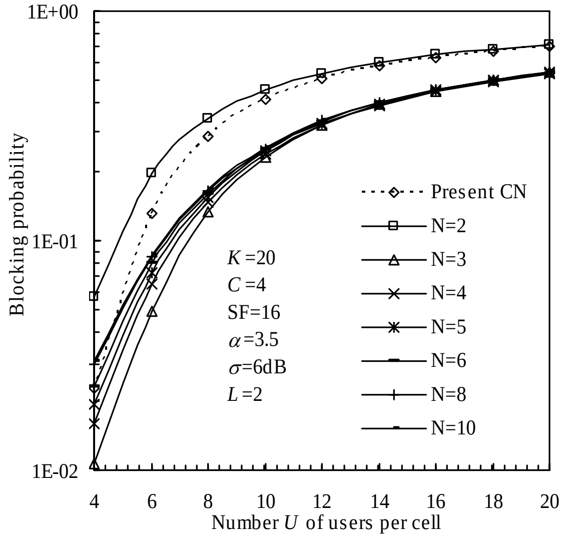
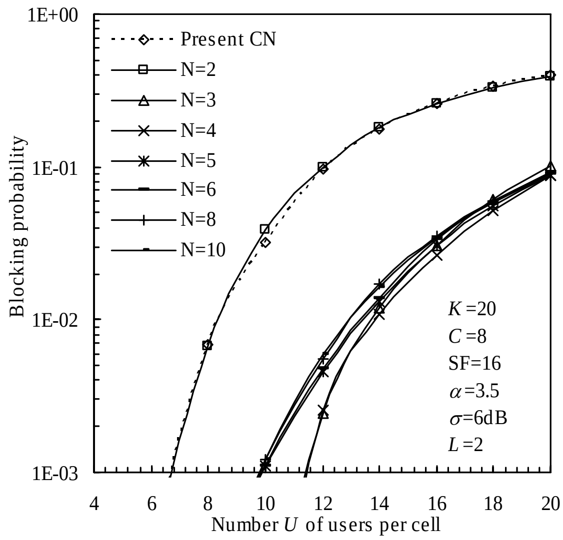


Fig.6 CDF of co-channel interference power of a link (WP-WP) to a similar link.

Another computer simulation similar to what was described in Sect.3 was carried out to investigate the relation between the number *C* of available channels and the impact of *N* on the blocking probability of a multi-hop VCN. Fig.7(a)&(b) shows the blocking probability of the multi-hop VCN with *N* as a parameter for *C*=4 and *C*=8 cases when *K*=20, α=3.5, σ=6dB and *L*=2. It is seen that an optimum value of *N* is equal to N_{opt}=3 when *C*=4 and N_{opt}=4 when *C*=8 where the blocking probability starts to increase a bit if you increase *N* above this optimum value. However the increase is very small. We can conclude that increasing *C* leads to increasing N_{opt}. This is because increasing *C* decreases $p_{\mathrm{failure}}(l)$ of Eq.(1).



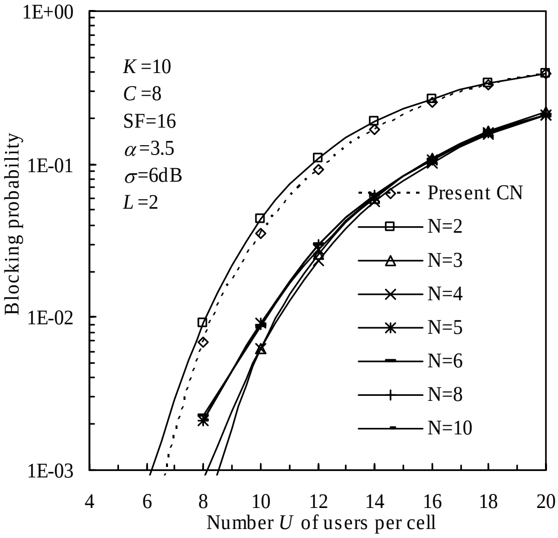
(a) C=4.



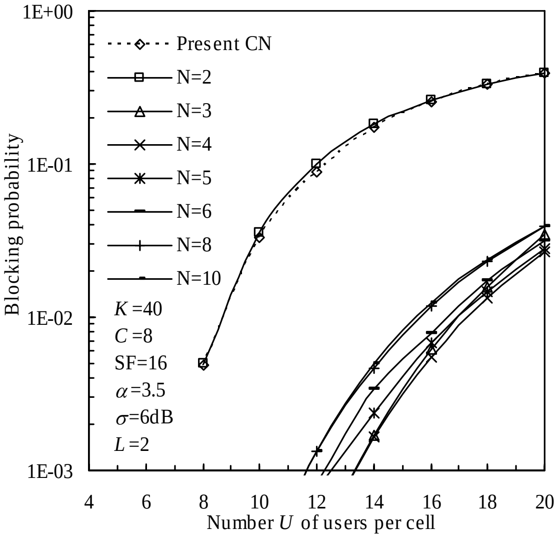
(b) C=8.

Fig.7 Blocking probability of the multi-hop VCN using on-demand channel assignment for different *C*.

The impact of K on this optimum value of N was also investigated for C=8, α=3.5, σ=6dB and L=2. Fig.8(a)&(b) show the blocking probabilities of the multi-hop VCN with N as a parameter for K=10 and K=40 cases. It is seen that N has the same optimum value as when K=20, N_{opt}=4, which means that this optimum value depends only on C.



(a) K=10.



(b) K=40.

Fig.8 Blocking probability of the multi-hop VCN using on-demand channel assignment for different K.

5. Conclusions

In this paper, a comparison between the pre-assignment and the on-demand channel assignment from different aspects was made. A comparison between the blocking probabilities of the two ways was also given. Because the on-demand channel assignment can significantly decrease the blocking probability compared to the pre-assignment. Therefore, we focused our research on the on-demand channel assignment from now-on.

In the on-demand channel assignment in the multi-hop VCN there is an important trade-off concerning the impact of the number N of allowable hops in a multi-hop VCN; increasing N can decrease the transmit power and hence decrease the interference to some other links, therefore the blocking probability can be decreased. On the other hand, increasing the number of hops increases the number of links that have to be successfully allocated to consider a call successful. Simulation results showed that there is an optimum value of N varying between 3 and 4 depending on the number C of available channels. So we can suggest that the maximum number of allowable hops can be limited to this optimum value in order to avoid degradation of the blocking probability and also unnecessary long time delay.

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