A Relay Skipping Method For a Multi-Hop DS-CDMA Virtual Cellular Network

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***Abstract*—** A multi-hop virtual cellular network (VCN) was proposed for future mobile communication systems. In VCN, the transmitted signal from a mobile terminal is relayed via multi-hop links to the central port, which is the gateway to the core network. In the original multi-hop VCN, a call is blocked when there is no channel available at one link over the multi-hop route. However, the use of a sub-route when a link failure occurs can be a solution to avoid the blocking of this call. In this paper, we propose a relay skipping method to avoid the call blocking in a DS-CDMA VCN. Computer simulation is conducted to evaluate the impact of the proposed method on the blocking probability of the multi-hop VCN and make comparison with the present cellular network as well.

Keywords- *virtual cellular network, multi-hop network, channel assignment, call blocking*

I. 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 an MT wants to make a call, it is connected to its nearest WP and then the multi-hop route from this receiver WP is used in order to relay the signal of this mobile terminal (MT) to the central port (CP). In the original VCN, channels for the multi-hop call can be assigned by repeating the single hop assignment procedure in a sequence over the multi-hop route and if there is no channel available at one link of the multi-hop route, the call is blocked. However, the use of a sub-route, when a channel allocation failure occurs at some link over the multi-hop route of one call, can be thought of as one solution to avoid the blocking of this call.

In this paper, we propose a relay skipping method to avoid the call blocking when a channel allocation failure occurs. In the proposed method, the channel assignment procedure of a multi-hop call is assumed to be starting from the last link connecting the CP. If there is no channel available at one link over the multi-hop route, the multi-hop relay is skipped as what follows. The MT is informed, using the control channel, to send its signal directly, in a sequence, to the receiver side WP of the multi-hop links over the multi-hop route, starting from the link where the channel allocation failure has occurred toward the last link connected to the CP. The establishment of this call will depend on the result of the channel allocation of this MT link. The worst case would be to connect the MT directly to the CP, which is similar to the case of the present cellular network. The proposed method can avoid the call blocking and hence decrease the blocking probability of the system. However the use of our proposed method may increase the transmit power of the MT. In this paper, computer simulation is conducted to evaluate the impact of our proposed method on the blocking probability of a multi-hop VCN and also on the transmit power of the MT.

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 multi-hop DS-CDMA VCN.

This paper addresses the following issues. We first describe the multi-hop DS-CDMA VCN in Sect.II. In Sect.III, we present a relay skipping method to avoid the call blocking in the multi-hop VCN. In Sect.IV, the blocking probability is evaluated by computer simulation. The impact of the proposed method on the performance of the multi-hop VCN is discussed. Finally, we give some conclusions in Sect.V.

II. WIRELESS MULTI-HOP VCN DESCRIPTION

A. VCN concept

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 users 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 original 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, a 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 channel assignment schemes.

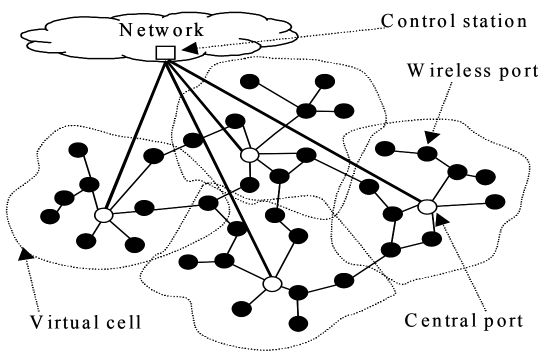


Fig. 1 Wireless multi-hop VCN system.

B. Channel assignment for uplink multi-hop VCN

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

The choice of an adequate channel assignment algorithm is an important issue for the multi-hop VCN. Channel segregation-DCA (CS-DCA) [2], which was proposed for the cellular network, seems to be promising for the multi-hop VCN ([3] and [4]). The channel allocation of the original multi-hop VCN, using CS-DCA, was discussed in [4]. In the original multi-hop VCN, channels for the multi-hop call can be assigned by repeating the single hop assignment procedure 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.

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 [4]. In what follows, a channel refers to a frequency channel.

III. Relay Skipping Method

In this section, the proposed relay skipping method to avoid the call blocking is described.

A. Method description

In our model, the signal transmitted from the MT is received first by its nearest WP in order to fix the first route to the CP. Then the channel allocation of the multi-hop call starts from the link connected to the CP. The multi-hop channel assignment procedure in the original multi-hop VCN was described in details in [4]. The difference with [4] is seen when a channel allocation failure occurs at some link over the multi-hop route. Fig.2 shows the process of our proposed method for a call with N=4 where the channel allocation failure has occurred at link l_2 after succeeding in allocating channels to links l_3 and l_4. In this case, this call is blocked for the original multi-hop VCN [4], while in our proposed method we will try to save this call from being blocked as what follows. The MT is informed, using the control channel, to send its signal directly, in a sequence, to the receiver side WP of the multi-hop links l_i with $2 \le i \le N$.

The establishment of this call will depend on the result of the channel allocation of this MT link. If this allocation is successful, then the call is successfully established. If in the worst case, the MT tried to connect to the CP, similar to the present cellular network, and the allocation failed then this call is blocked.

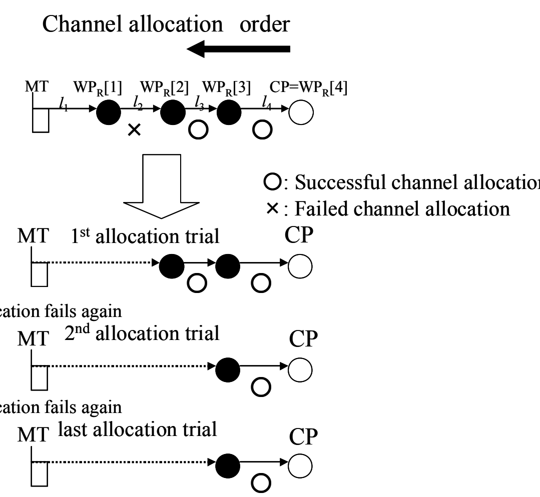
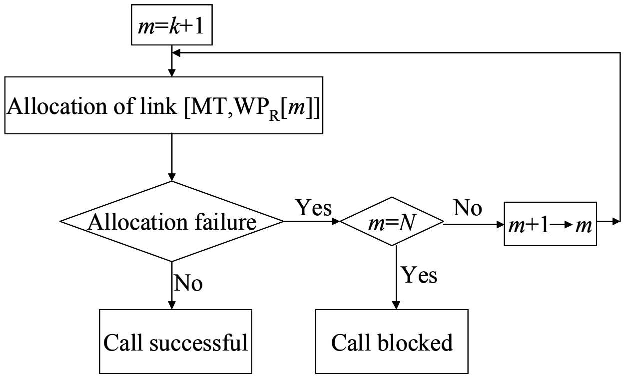


Fig.2 Allocation failure case model.

Flowchart.1 describes our proposed method for a call with N hops, where the first channel allocation failure occurs at link $[WP_R[k],WP_R[k+1]]$. In this case, we try in a sequence the allocation of the link between the MT and $WP_R[m]$, where m is between k and N. If the allocation of this link is successful, then the call is successfully established. However, if all the allocations, even the one between the MT and the CP ($WP_R[N]$ in this example), failed then the call is blocked.

Flowchart.1 Channel allocation procedure after a link allocation failure.



B. Discussions

One main reason why our proposed method would improve the performance of the multi-hop VCN is the increase of the number of available channels to sense for the user link; this is because, as was discussed in [4], the use of several channels in the adjacent links can degrade the multi-hop VCN blocking probability performance.

The use of our proposed method can decrease the blocking probability and also avoid longer time delay before starting the data transmission. However, it can increase the user transmit power, which can lead to higher interference to other calls.

IV. Computer Simulation

A computer simulation was carried out to measure the blocking probabilities of the multi-hop VCN after the original channel assignment and our proposed method. The present cellular network performance was also investigated. A total of 19 VCs of hexagonal layout (the center VC is the cell of interest) are considered. For a fair comparison, the CP of each VC is set in the middle of the VC.

In each VC, U users with uniformly distributed locations are generated. All these randomly generated calls go through call admission procedure and their channel assignment process is performed as what was described in the previous sections.

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

A. Simulation results and discussions

The impact of our proposed method on the blocking probability of the multi-hop VCN is shown in Fig.3 with the number C of available channels in the network as a parameter. The number K of WPs in each VC is set to K=20, and the maximum number N of allowable hops is limited to 4, for a spreading factor SF=16, α=3.5, σ=6dB and L=2. The performance of the present cellular network is also plotted. It can be seen that our proposed method can decrease significantly the blocking probability compared to the original multi-hop VCN and also compared to the present cellular network. This is because of the increase of the number of channels to sense for the user link. However, for a big number of users the performance of our proposed method degrades (can be seen from the curves of C=2 and 4) but it is still better than the present cellular network performance. This is because of the increased interference due to the increase of the transmit power of the users.

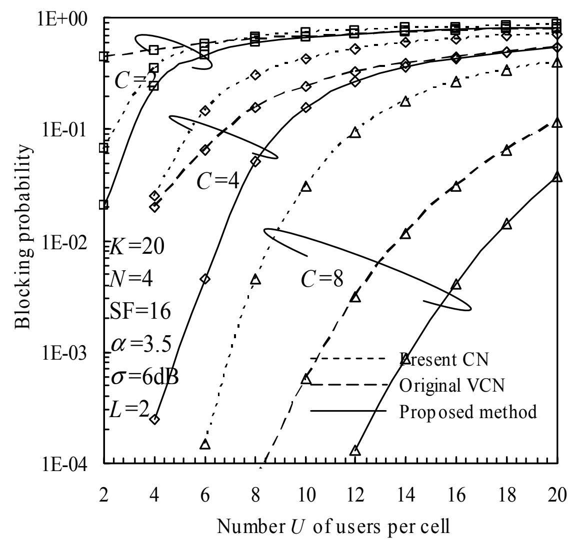
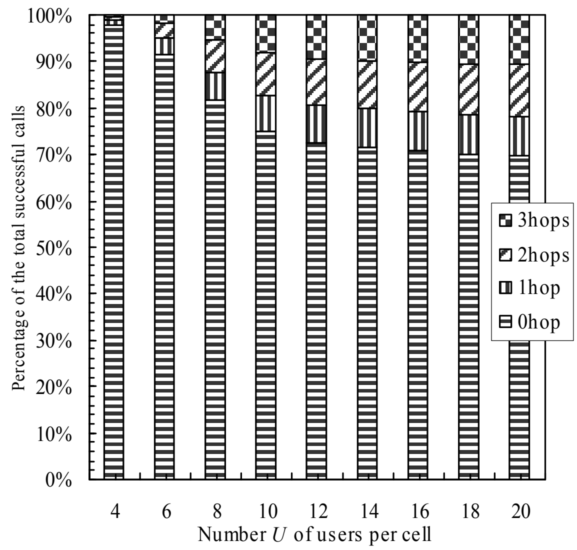


Fig.3 Impact of the proposed method on the blocking probability of the multi-hop VCN for different C.

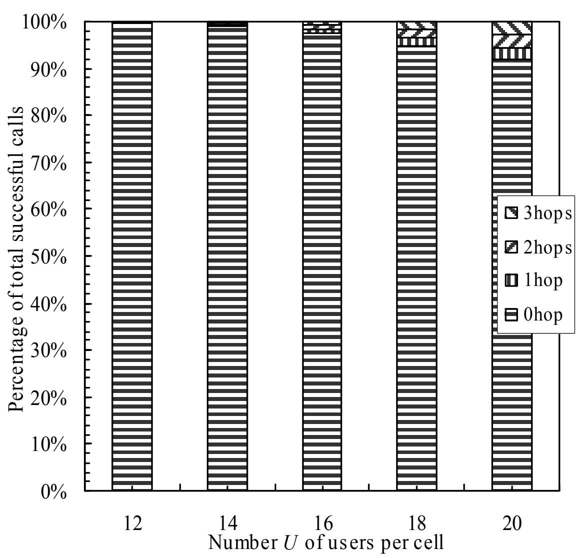
The blocking analysis in the multi-hop VCN is discussed below. In the original multi-hop VCN, as it was discussed in [4], the blocking can occur because of two major contributing factors: poor coverage ($SINR<SINR_{target}$) and unavailability of free channels (because they are used in the adjacent links). It was shown in [4] that the unavailability of several channels, because they are used in the adjacent links, affects the original multi-hop VCN performance. This is why with using our proposed method the blocking can be decreased. This is because we make use of the channels used in the adjacent links as well. The only factor behind the blocking in the multi-hop VCN after using our proposed method is the poor coverage.

With using our proposed method, the number of hops of each communication decreases compared to the original multi-hop VCN. We investigated the distribution of the number of hops decreased in the successful calls, when

K=20, C=4 and 8, N=4, SF=16, α=3.5, σ=6dB and L=2. Fig.4 shows the percentage of the successful calls where j hops were decreased to avoid the call blocking. Fig.4 (a) shows the case of C=4 and Fig.4 (b) is for the case of C=8. The j explained above is shown in the j hops written on the right of the graph. 0hop case is similar to the original multi-hop VCN. It can be seen that more than 70% (90%) of the calls were allocated similarly to the original multi-hop VCN for C=4 (8). When the number of users increases, the interference from other users increases and the number of the channels used in the adjacent links increases as well. Therefore, the number of the decreased hops to avoid the call blocking also increases.



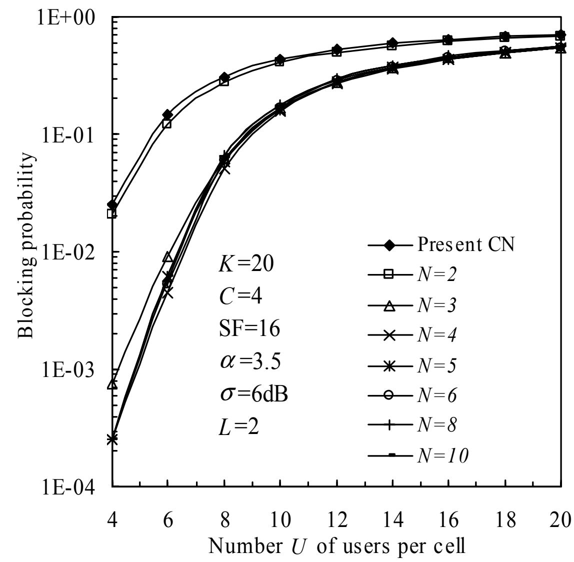
(a) C=4



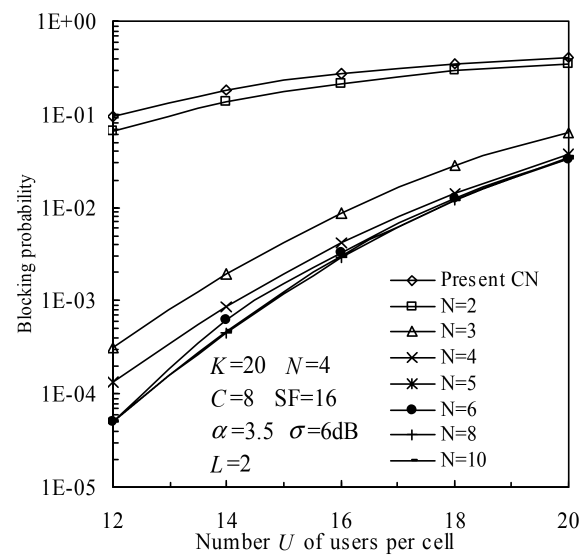
(b) C=8

Fig.4 The distribution of the number of decreased hops for different C.

As the proposed method seems to have relation with the number of hops, so we investigated the impact of the number N of maximum allowable hops on the blocking probability after using our proposed method. Fig. 5 shows the impact of N on the blocking probability of a multi-hop VCN after using the proposed relaying skipping method, when K=20, C=4 and 8, SF=16, α=3.5, σ=6dB and L=2. Fig.5 (a) shows the case of C=4, while Fig.5 (b) shows the case of C=8. It can be seen that increasing N leads to a decreased blocking probability. However, after a certain optimum value of N the performance doesn't change much. When C=4, the optimum value of N is 4 and when C=8 the optimum value is equal to 6.



(a) C=4



(b) C=8

Fig.5 Impact of number N of maximum allowable hops on the blocking probability of the proposed method for different C.

As the proposed method needs to increase the MT transmit power, so we investigated the increase of the MT transmit power. Fig.6 plots the average transmit power of the MT normalized by that in the present single-hop cellular network, when K=20, C=4 and 8, N=4, SF=16, α=3.5, σ=6dB and L=2. It can be seen that the transmit power of the MT is increased compared to the original multi-hop VCN. However, it is still decreased compared to the present cellular network. We can see also that this result depends on the number of users in the network and the number of channels available in the network. We investigated also the instantaneous transmit power of the MT normalized by that in the present single-hop cellular network, when U=20, K=20, C=4 and 8, N=4, SF=16, α=3.5, σ=6dB and L=2, the result is shown in Fig.7. We can see that more than 90% of the powers are less than the case of the present single-hop cellular network.

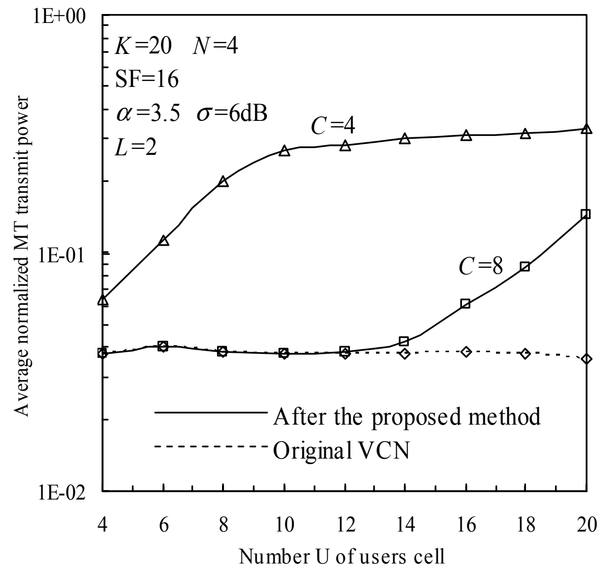


Fig.6 Average normalized MT transmit power.

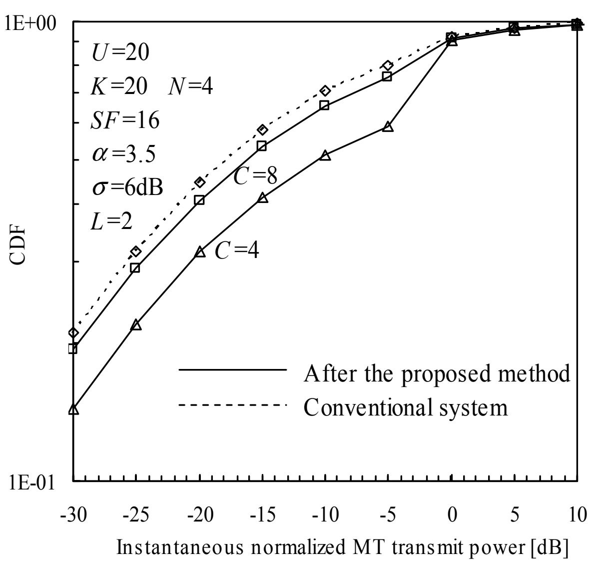


Fig.7 Instantaneous normalized MT transmit power.

V. Conclusion

In this paper, a relay skipping method to avoid the call blocking in the original multi-hop DS-CDMA virtual cellular network (VCN) was proposed. The impact of the proposed method on the blocking probability of the multi-hop VCN was discussed. A comparison with the present cellular network was also made.

It was shown that our proposed method can significantly decrease the blocking probability of the multi-hop VCN compared to the original VCN and also to the present cellular network. However, the MT's transmit power increases with the use of our method. However, it is still decreased compared to the present cellular network.

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