DS-CDMA

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On-Demand Channel Assignment for Multi-Hop DS-CDMA Virtual Cellular Network using Channel Segregation algorithm

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Abstract: A multi-hop virtual cellular network (VCN) was proposed for future mobile communication systems. In VCN, transmitted signal from a mobile terminal is relayed via multi-hop links to the central port, which is a gateway to the core network. In this paper, an "on-demand" channel assignment strategy, using the channel segregation dynamic channel allocation (CS-DCA) algorithm, is proposed for multi-hop DS-CDMA VCN. Computer simulation is conducted to evaluate the blocking probability performance and make a comparison between the VCN and the present cellular network.

Keywords: virtual cellular network, multi-hop network, dynamic channel assignment, channel segregation

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) 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 [1]. In the VCN a multi-hop call is regarded as a sequence of single hop calls, where the first call arrives on the first link, between a mobile terminal (MT) and its nearest wireless port, followed by an arrival on the second link and so on until the last link to the central port. Channels for the multi-hop call can be assigned by repeating the single hop assignment procedure in a sequence over the multi-hop path. Therefore, if there is no channel available at any link of the multi-hop path, the call is blocked.

In a cellular network, the communication is with the nearest base-station over a single wireless link. The problem of dynamic channel assignment (DCA), in the context of cellular networks, has been extensively considered ([2], [3] and other references). Channel segregation-DCA (CS-DCA) [4] which was proposed for the cellular network, seems to be promising for the multi-hop VCN [5]. CS-DCA was carried out to allocate channels to multi-hop links between the wireless ports and the central port [5], this time we consider the channel allocation of the link between the user and the wireless port as well.

In this paper, direct sequence code division multiple access (DS-CDMA) is considered using multi-hop VCN and the CS-DCA algorithm is implemented, with some modifications to meet with the wireless constraints in the VCN, to allocate channels to multi-hop up-links between the MT and the CP. Multi-hop downlink study is left for a future work.

This paper addresses the following issues. We first describe the DS-CDMA multi-hop VCN in Sect. . We then present a channel allocation procedure using CS-DCA in Sect. . In Sect. , the blocking probability is evaluated by computer simulation. The performance of multi-hop VCN is compared with that of present cellular network. Finally, we give some conclusions in Sect. .

2. Wireless Multi-Hop VCN Description

The multi-hop VCN [1], as shown in Fig.1, consists of a central port, which is a gateway to the network, and many distributed wireless ports, which work as relays used to forward the traffic of the users having poor coverage to the central port. A cluster of distributed wireless ports acts as one virtual base station (BS). The functional complexity of a wireless port is less than that of a BS.

In DS-CDMA, transmit power control (TPC) is an indispensable technique [6]. However, it may make the transmission power between some wireless ports and the central port very large. To avoid this, the multi-hop communication [7], [8] was introduced to the VCN [1]. The major advantage of multihopping in the VCN is that it requires lower transmit power than that of (MT-BS) direct link (or single hop) in traditional cellular networks for the same SINR. This is because multi-hop routes have short range links to the destination, which leads to low path loss and as a result, smaller transmit power is required to achieve the desired signal strength [1]. This results in reduced co-channel interference, leading to increased system capacity. However, there are some technical issues associated with multi-hop communication to be solved, such as complex routing and channel assignment schemes.

In order to efficiently control the wireless multi-hop communication between each wireless port and the central port, the multi-hop control layer, which is inserted between the data link layer and the network layer, has been introduced for the multi-hop routing and channel allocation (see Fig.2). A route construction scheme based on the total transmit power minimization criterion [8], [9] is used to fix the route from each wireless port to the central port. In this paper, only the multi-hop uplink is considered. We assume that a user in a cell can only take relaying assistance from wireless ports in that cell. The signal transmitted from the mobile terminal is received by its nearest wireless port. Then, the received signal is relayed to the central port via the constructed route. The transmit power of a mobile terminal can be significantly reduced in comparison with present cellular systems.
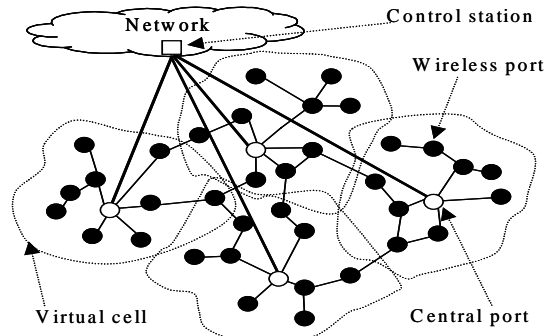

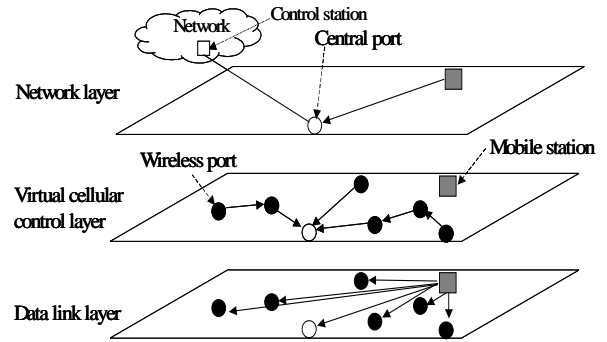**Fig. 1** Wireless multi-hop virtual cellular system.

Fig. 2 Layer structure.

3. Application of CS-DCA in the Uplink Multi-Hop communication

We will now address the issue of dynamic channel assignment to the incoming calls in the multi-hop VCN. The problem of dynamic channel assignment has been extensively considered in the context of cellular networks [2], [3]. However there are significant differences between the two networks. The multi-hop communication imposes additional complexity, as non-conflicting channels must be allocated to the wireless links along the source (MT) destination (CP) path.

As illustrated in Fig.3, consider the data transfer on a link, WP_T-WP_R, using channel f_1. For this link allocation to be successfully made, the following criteria need to be satisfied:

1) WP_T must not receive from any other WP using channel f_1. Otherwise the transmission from WP_T will interfere at WP_T.

2) WP_R must not be involved in any other call transmission in channel f_1. Or the transmission from WP_T will interfere at WP_R.
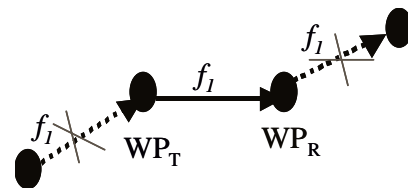

Fig.3 Interference model for an uplink multi-hop transmission.

We consider that the system bandwidth is divided into several frequency channels with different carrier frequencies. One of the available channels is allocated to a link between the MT and its nearest WP or between two adjacent wireless ports along a multi-hop route. Since DS-CDMA is applied, the same channel can be shared by different multi-hop links. In this case, a link (WP$_1$-WP$_2$) can serve two different calls in the same frequency channel, using different orthogonal spreading codes, if the wireless constraints are satisfied, resulting in an efficient usage of the limited frequency resource.

The route, between each wireless port and the central port, construction procedure based on total transmit power minimization criterion [9], [10], is carried out using the control channel having a carrier frequency different from the channels for multi-hop communications. After the whole route between the MT and the CP is decided, the CS-DCA [4], which was proposed for single link calls in the traditional cellular networks, is applied to assign frequency channels to all the uplinks along the MT-CP path. The single link assignment procedure is repeated in a sequence over the multi-hop path. If at any link of the multi-hop path there is no channel available, the call is blocked.

In CS-DCA, each receiver side wireless port is equipped with a channel priority table (as in [4]); priority function value and the number of times the channel was accessed are listed. Table 1 shows an example of a channel priority table. The channel priority function $P(i)$ is updated each time the channel is accessed to show the successful transmission probability on channel i. The WP receiver selects a channel among available ones using its channel priority table. The CS-DCA procedure for one link in the multi-hop communication is as follows.

Step1: For a link (WP$_T$- WP$_R$), if a channel f_0 is allocated to the same link in another call, WP$_R$ selects f_0 and measures the signal-to-noise plus interference power ratio (SINR). If the measured SINR meets the required quality, the selected channel is allocated and its priority function is increased. Otherwise, the priority function of that channel is decreased and the procedure goes to the next step.

Step2: The WP$_R$ selects the channel with the highest priority among the unchecked channels. If the channel is used for transmitting data in another call or is used by the WP$_T$ for reception, the WP$_R$ decreases the priority function of the selected channel and selects the next channel with highest priority function. Otherwise, the procedure goes to the next step.

Step3: The WP$_R$ measures the SINR of the selected channel. If the measured SINR meets the required value, the channel is allocated and its priority function is increased. Otherwise, the priority function of the selected channel is decreased and the procedure goes back to step2.

If the channel allocations for links over the multi-hop route from the MT to the CP are successful, the call is established. Otherwise, the call is blocked.

Table1 An example of channel priority table.

Channel index i	Channel priority value $P(i)$	Number of times the channel is accessed $N(i)$
0	0.8	5
1	0.6	8
⋮	⋮	⋮
C-1	0.1	20

4. Computer Simulation

A computer simulation was carried out to measure the blocking probabilities of both the multi-hop VCN and the present cellular network. A total of 19 virtual cells of hexagonal layout (the center virtual cell is the cell of interest) are considered. For a fair comparison the central port of each virtual cell is set in the middle of the cell. We assume that, the overall network traffic arrival follows a Poisson distribution with a mean arrival rate of λ; the holding time of each call is exponentially distributed with a mean of $\mu = 120$. The offered load G per cell is defined as

$$G = \lambda\mu \quad ,(1)$$

The burst arrival events are generated before the start of the simulation and are known a priori on the time scale. All these calls go through call admission procedure as it was described in Sect. .

The SINR is affected by distance dependent path loss, shadowing loss and fading. We assume L-path Rayleigh fading with uniform power delay profile. 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 [11].

A. SINR expression for computer simulation

In CS-DCA, the measurement of SINR is necessary. Below, we derive the SINR expression for the computer simulation.

The propagation channel can be modeled as the product of distance dependent path loss, log-normally distributed shadowing loss and multi-path fading. Assuming an L-path fading channel with uniform power delay profile, the received power P_{i-j}^r of the signal transmitted from the transmitter #i and received at the wireless port #j is given by

$$P_{i-j}^r = P_{i-j}^t \cdot r_{i-j}^{-\alpha} \cdot 10^{-\eta_{i-j}/10} \cdot \sum_{l=0}^{L-1} \left| \xi_{i-j}(l) \right|^2 \quad , (2)$$

where P_{i-j}^t is the transmit power of the transmitter #i, α is the path loss exponent and r_{i-j}, η_{i-j} and $\xi_{i-j}(l)$ are respectively the distance, log normally distributed shadowing loss with the standard deviation σ in dB and the l-th path's complex path gain between #i and #j. $\{\xi_{i-j}(l); i,j,l\}$ are characterized by time-invariant independent and identically distributed (i.i.d) complex

Gaussian variables with zero-mean and a variance of $1/L$. Signal-to-noise power ratio (SNR)-based ideal TPC is assumed. The transmit power P^t_{i-j} is determined as

$$\frac{P^t_{i-j}}{N} = \Lambda_{\text{target}} \cdot r^{\alpha}_{\text{i-j}} \cdot 10^{\frac{\eta_{i-j}}{10}} \left(\sum_{l=0}^{L-1} \left| \xi_{i-j}(l) \right|^2 \right)^{-1} \quad , (3)$$

where Λ_{target} is the target SNR and N is the noise power. Assuming ideal L-finger coherent Rake combining based on maximum ratio combining (MRC), the SINR after Rake combining at wireless port #i is given by

$$\lambda = \Lambda_{\text{target}} \sum_{l=0}^{L=1} \lambda_l \quad , (4)$$

where

$$\lambda_l = \frac{\left| \xi_{i-j}(l) \right|^2 \Big/ \sum_{l'=0}^{L-1} \left| \xi_{i-j}(l') \right|^2}{1 + \frac{\Lambda_{\text{target}}}{SF} \left\{ \begin{array}{l} (m+1) \cdot \left[1 - \left| \xi_{i-j}(l) \right|^2 \Big/ \sum_{l'=0}^{L-1} \left| \xi_{i-j}(l') \right|^2 \right] \\ + \sum_{\substack{k \\ (k,q(k)) \neq (i,j)}} \left(\frac{r_{k-j}}{r_{k-q(k)}} \right)^{-\alpha} 10^{-(\eta_{k-j} - \eta_{k-q(k)})/10} \\ \times \frac{\sum_{l'=0}^{L-1} \left| \xi_{k-j}(l') \right|^2}{\sum_{l'=0}^{L-1} \left| \xi_{k-q(k)}(l') \right|^2} \end{array} \right\}}$$

$$(5)$$

In Eq.5, SF is the spreading factor and m is the number of times the same link (#i, #j) is being used for different calls. #$q(k)$ is the index of the receiver WP of the interfering link (#k, #$q(k)$). The second term of the dominator is the own inter-path interference (IPI) and the third term is the interference from other transmitters in other links. Since orthogonal spreading code is assumed, the same path-interference is suppressed for the second term. The expression derived above is used for computing the SINR in the computer simulation.

B. Simulation results and discussions

First to show the advantage of multi-hop communication in the VCN, the average total transmit power of all the multi-hop links between an MT and the CP normalized by that of single-hop (MT-CP), as a function of the maximum number of allowable hops N, is plotted in Fig.4. With K=20 number of wireless ports in the virtual cell, α=3.5 and σ=6dB. It is clearly shown that the multi-hop communication can significantly reduce the total transmit power. It can also be seen that the normalized transmit power is almost the same for N>4,

therefore we can suggest that the maximum number of allowable hops can be limited to 4 (for similar conditions) in order to avoid unnecessary long time delay.
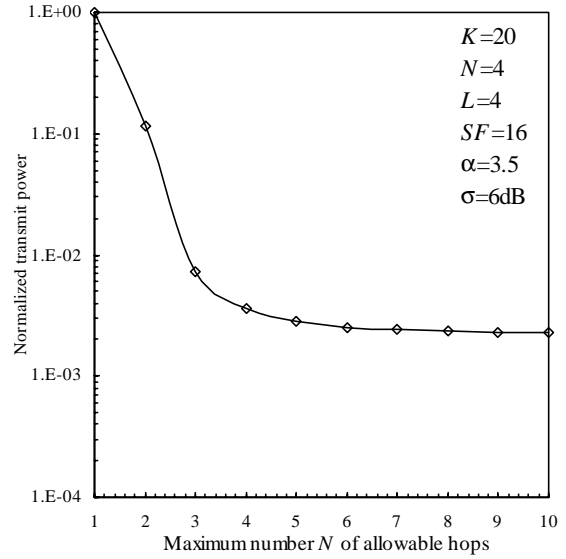

Fig.4 Normalized average transmit power per call.

We show in Fig.5 an example of the distribution of channels allocated by the CS-DCA (the number indicates the channel index) when the number C of available channels is C=4. The central port is located in the middle of the virtual cell. Other 19 wireless ports, each having omni-directional transmit/receive antenna, are randomly located. We can see that the same channel is reused for many links in the communications (e.g., channel#**1**), resulting in an efficient frequency usage.
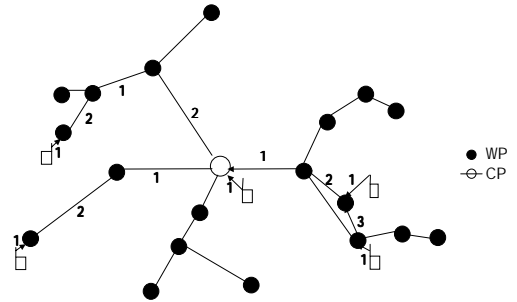

Fig.5 Some examples of multi-hop links channel allocations.

Next, the simulation results for the blocking probability in both multi-hop VCN and present DS-CDMA cellular network are presented and discussed. These results are evaluated as a function of the average offered cell load.

A comparison of blocking probabilities of multi-hop VCN and present cellular network is shown, with C as a parameter, in Fig.6 for N=4, α=3.5, σ=6dB, L=4 and SF=16. It is clearly seen that multi-hop provides less blocking probability. This is because with using the multi-hop communication, the transmit power of interfering links is decreased, resulting in reduced interference.
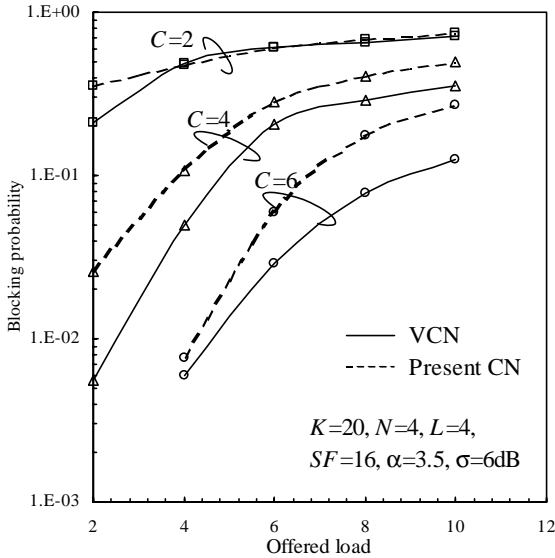
Fig.6 Blocking probabilities of the VCN and the present cellular network (CN) for different number C of available channels.

Fig.7 Impact of the number N of maximum allowable hops on the blocking probability in the VCN.

If frequency channels are few like in case of 2channels, then the impact of limited channel exhaustion results in almost equal blocking probability in the multi-hop VCN and the present cellular network. However, as more frequency channels are available, the blocking reduction from multihopping is larger as clear from the curves of C=4 and 6. The possible reason can be discussed below. In the multi-hop VCN, different channels should be allocated to adjacent links. As the offered load increases, the probability of different routes intersection increases. Therefore, the need for different channels for adjacent links increases. In the case of C=2, the limited channel exhaustion results in significant degradation of the blocking probability in the multi-hop VCN.

The impact of N on the blocking probability is shown in Fig.7 for C=6. We can see that as N increases, the blocking probability decreases. This is because as shown in Fig.2 as N increases, the transmit power decreases and results in the decreased interference.
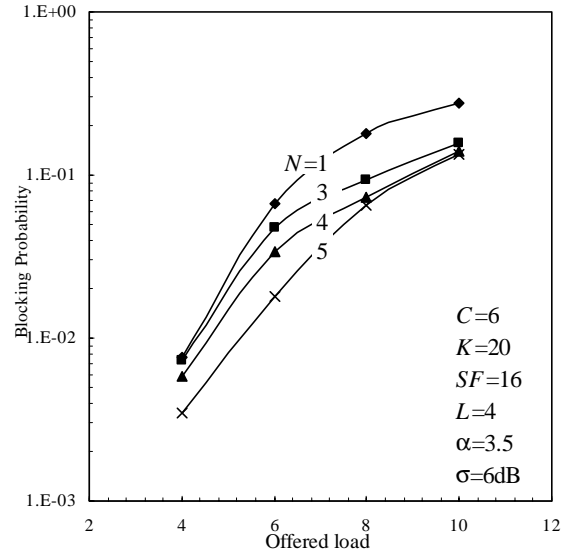
The impact of number K of wireless ports on the blocking probability is shown in Fig.8 for C=6, α=3.5, σ=6dB, L=4 and SF=16. We can see that as K increases, the blocking probability reduces. This is due to further decrease of the transmit power of the multi-hop links and hence less interference on the hops. As K increases, the probability to find route with small transmit power increases.
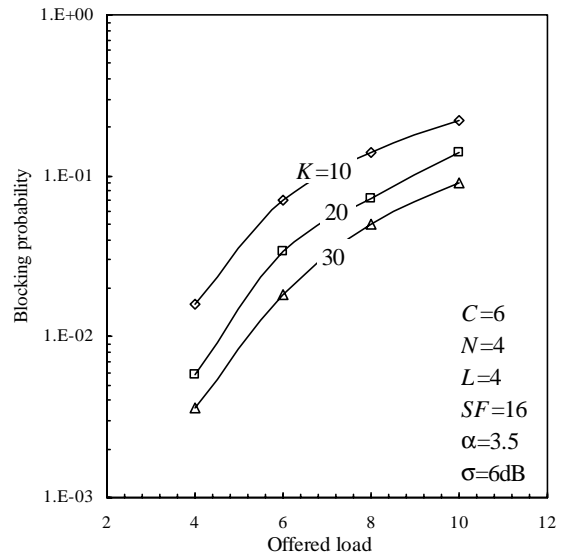

Fig.8 Impact of number K of wireless ports in the virtual cell on the blocking probability.

The impact of the number L of paths on the blocking probability is shown in Fig.9 for K=20, C=6, α=3.5, σ=6dB and SF=16. We can see that as L increases the blocking probability increases as well. A possible reason for this is about the increasing own-inter-path-interference (IPI) (The first term inside the brackets of the denominator of Eq.(5)).
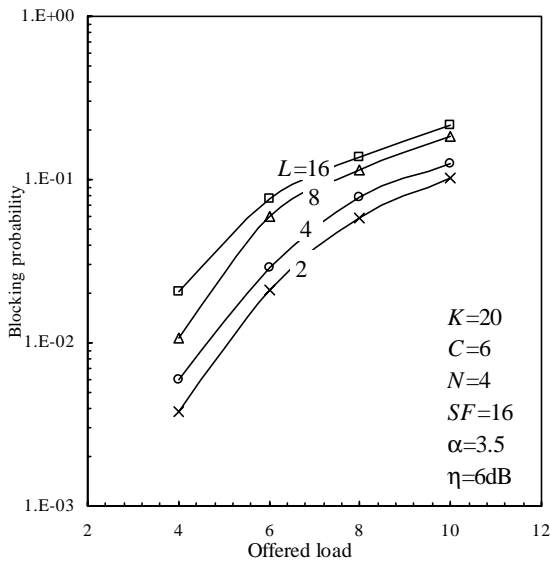
Fig.9 Impact of *L* on the blocking probability in the multi-hop VCN.

5. Conclusions

In this paper, an on-demand strategy style to assign channels to uplink multi-hop communications in DS-CDMA Virtual Cellular Network (VCN) was proposed. CS-DCA algorithm was used with some additional conditions to meet with the interference constraints of the multi-hop communication. The blocking probability was evaluated by computer simulation. Comparison between multi-hop VCN and present cellular network was given.

Due to decreased transmit power in the multi-hop links, the decreased interference leads to less blocking probability compared to present cellular network. Improving the blocking probability performance leads to an increase in the supportable load of the network for the given blocking probability.

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