Distributed Dynamic Channel Assignment for A Multi-hop Virtual Cellular System

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***Abstract*— There have been strong demands for higher speed data transmissions in mobile communications. To reduce the peak transmit power while increasing the data transmission rates, authors recently proposed a wireless multi-hop virtual cellular system. In a multi-hop virtual cellular system, an efficient channel allocation algorithm is necessary. In this paper, the channel segregation dynamic channel allocation (CS-DCA) scheme is applied. After all multi-hop routes over distributed wireless ports in a virtual cell are constructed, the CS-DCA is carried out to allocate the channels to multi-hop up and down links. Each wireless port is equipped with a channel priority table. The transmit wireless port of each link initiates the CS-DCA procedure and selects a channel among available ones using its channel priority table to check. In this paper, the DCA failure rate is evaluated by computer simulation. It is found that the failure rate is almost insensitive to the allowable number of hops.**

Keywords: virtual cellular system, multi-hop network, adhoc network, routing, dynamic channel allocation

I. INTRODUCTION

Recently, mobile communications services are shifting from voice conversations to data communications. There have been strong demands for higher speed data transmissions. However, there will be a serious problem; as data transmission rate becomes higher, the peak transmit power becomes larger. To reduce the peak transmit power while increasing the data transmission rates, we proposed a wireless multi-hop virtual cellular system as illustrated in Fig. 1 [1]. The multi-hop virtual cellular system consists of a central port, which is a gateway to the network, and many distributed wireless ports. A cluster of distributed wireless ports acts as one virtual base station. For the multi-hop uplink (mobile-to-central port), the signal transmitted from a mobile terminal is received by end wireless ports (defined as wireless ports which directly transmit/receive the signal to/from a mobile terminal) surrounding a mobile terminal. The signal transmitted from a mobile terminal and received at end wireless ports is relayed to the central wireless port. Since each end wireless port can act as a site diversity branch, the transmit power of a mobile terminal can be significantly reduced in comparison with present cellular systems [1]. On the other hand, for the multi-hop downlink (central port-to-mobile), the signal to a mobile terminal can be multicast from the central wireless port to the end wireless ports.

If all end wireless ports communicate directly with the central wireless port, the transmit powers of some end wireless ports may become very large due to pathloss, shadowing loss, and multipath fading. To avoid this, multi-hop wireless communication [2], [3] has been introduced to the virtual cellular system. In order to efficiently control the wireless multi-hop communication between the end wireless port and the central wireless port, the virtual cellular control layer that is inserted between the data link layer and the network layer has been introduced as illustrated in Fig. 2 [4], [5]. The virtual cellular control layer manages the multi-hop routing and channel allocation. A routing algorithm based on the total transmit power minimization criterion is presented in [4].

In the multi-hop virtual cellular systems, an efficient channel allocation algorithm is necessary. The channel allocation scheme is classified as the fixed channel allocation (FCA) and the dynamic channel allocation (DCA) [6]. Using FCA, predetermined fixed channels are allocated to each wireless port. FCA cannot adapt to changing traffic conditions and user distributions. On the other hand, using DCA, all channels are available at each wireless port and one of the available channels is allocated if the channel meets the required quality. DCA can be implemented either in a centralized or a distributed fashion [6]; the latter seems to be promising for the multi-hop virtual cellular systems.

In this paper, we apply the channel segregation DCA (CS-DCA) [7] for multi-hop communications in a virtual cellular system. The channel allocations for the multi-hop up and down links need to be simultaneously carried out. Sec. II presents a channel allocation procedure using CS-DCA for the multi-hop up and down links. The channel allocation successfully completes, if the allocation is successful for both up and down links, otherwise the channel allocation fails. In Sec. III, the channel allocation failure rate is evaluated by computer simulation. Sec. IV offers some conclusions.

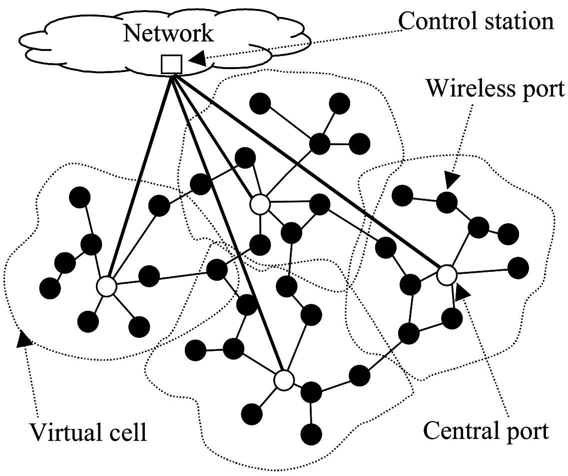

Fig. 1 Wireless multi-hop virtual cellular system.

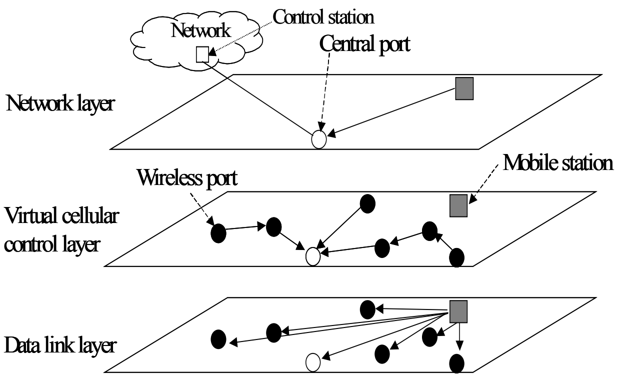

Fig. 2 Layer structure.

II. APPLICATION OF CS-DCA

Direct sequence code division multiple access (DS-CDMA) is considered for wireless multi-hop communication. The system bandwidth is divided into several frequency channels. One of the available frequency channels is allocated to a link between two adjacent wireless ports along a multi-hop route. Since DS-CDMA is applied, the same frequency channel can be shared by different multi-hop links. We have proposed a route construction scheme based on total transmit power minimization criterion [4], [5]. The route construction procedure is carried out using control frequency channel having different carrier frequency from the frequency channels for multi-hop communications. After all routes are constructed, frequency channels for multi-hop communications are assigned to the multi-hop up and down links. The transmit side on each link initiates the CS-DCA procedure. For the downlink, several multi-hop routes may branch from a relaying wireless port. In this case, the same frequency channel can be used for all the branching multi-hop downlink routes. Furthermore, the downlink frequency channel may be reused for the uplink transmission, resulting in an efficient usage of the limited frequency resource. In the CS-DCA, each wireless port is equipped with a channel priority table as in [7]. The transmit wireless port selects a frequency channel among available ones using its channel priority table. The transmit frequency channel is allocated first for the downlink and then for the uplink. The CS-DCA is carried out at each transmit wireless port according to the following steps.

Step 1 (downlink frequency channel allocation): wireless port of interest (#A in Fig.3) selects a frequency channel having the highest priority, among available frequency channels that are not in use for receiving and have not been tested for allocation, as the downlink transmit frequency channel. The immediate receiving wireless ports (#C and #D in Fig.3) are informed about the selected downlink frequency channel.

Step 2: wireless ports #C and #D measure the signal-to-interference plus noise power ratio (SINR) of the informed downlink frequency channel and report the measurement results to wireless port #A. If both SINRs reported from wireless ports #C and #D meet the quality requirement, the selected frequency channel is allocated as the downlink frequency channel; otherwise, the procedure goes back to Step 1.

Step 3 (uplink frequency channel allocation): wireless port #A selects the same frequency channel that is allocated for the downlink transmission and informs the uplink immediate receiving wireless port (#B in Fig.3) of the selected frequency channel.

Step 4: wireless port #B measures the SINR of the informed frequency channel and reports the measurement result to wireless port #A. If the measured SINR meets the quality requirement, that frequency channel is allocated as the uplink frequency channel and goes to Step 6, otherwise goes to Step 5.

Step 5: wireless port #A reselects a new frequency channel having the highest priority, among available frequency channels that are not in use for receiving and have not been tested for allocation, as the uplink transmit frequency channel. An immediate receiving side is informed about the selected uplink transmit frequency channel and the procedure goes back to Step 4.

Step 6: end of up and down link frequency channel allocation at the wireless port of interest.

The above procedure is repeated one port-by-one port. Frequency channel re-allocation among all wireless ports needs to be done periodically; but this depends on how fast the traffic distribution changes (this is not discussed in this paper).

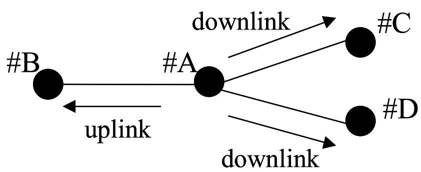

Fig. 3 Up and downlink branches.

III. COMPUTER SIMULATION

DS-CDMA with coherent QPSK data modulation and BPSK spreading is assumed. For a required bit error rate (BER) of 10^{-3}, the required SINR γ_{req} is set as -10 dB for a spreading factor *SF*=100. For simplicity, a total of 19 virtual cells of hexagonal layout (the center virtual cell is the cell of interest) are considered for simulation. *K*=20 wireless ports (including the central wireless port), each having omni directional transmit/receive antenna, are randomly located in each virtual cell. The received power $P_{r,j}(i)$ of the signal transmitted from the wireless port #*i* and received at wireless port #*j* is given by

$$P_{r,j}(i) = P_t(i) \cdot r_{i,j}^{-\alpha} \cdot 10^{-\eta_{i,j}/10} \cdot \left|\xi_{i,j}\right|^2 \qquad , (1)$$

where $P_t(i)$ is the transmit power of wireless port #*i*, α is the pathloss exponent and $r_{i,j}$, $\eta_{i,j}$, and $\xi_{i,j}$ are respectively the distance, the shadowing loss (in dB) and the complex fading gain between wireless ports #*i* and #*j*. $\{\xi_{i,j}\}$ are characterized by time-invariant independent zero-mean complex Gaussian variables with zero-mean and $E[\left|\xi_{i,j}\right|^2]=1$, where $E[*]$ denotes ensemble average operation. Signal-to-noise power ratio (SNR)-based ideal transmit power control (TPC) and interference limited condition are assumed. The received SINR γ at the wireless port #*j* is given by

$$\gamma = \frac{P_t(i) \cdot r_{i,j}^{-\alpha} \cdot 10^{-\eta_{i,j}/10} \cdot \left|\xi_{i,j}\right|^2}{\sum_k P_t(k) \cdot r_{k,j}^{-\alpha} \cdot 10^{-\eta_{k,j}/10} \cdot \left|\xi_{k,j}\right|^2} \qquad , (2)$$

Fig. 4 shows an example of the distribution of frequency channels allocated by the CS-DCA (the number indicates the frequency channel index). Frequency channel #5 is allocated to the downlink at central wireless port #A. It can be seen that the same frequency channel is reused for both uplink and downlink transmissions at different wireless ports (e.g., frequency channel #3 is used for both up and downlinks at wireless ports #B and #C), resulting in an efficient frequency usage.

If frequency channels are successfully allocated to all wireless ports, the channel allocation is successful; otherwise the channel allocation is considered to have failed. The received SINR γ is affected by pathloss exponent α and shadowing loss $\eta_{i,j}$ (see Eq.(2)). Therefore, the impact of these parameters to the DCA failure rate is evaluated. The control frequency channel used in the route construction is different from the frequency channels used in multi-hop communications. This may affect the DCA failure rate. Therefore, the impact of the fading correlation ρ between complex fading gains of the control frequency channel and multi-hop communication frequency channels on the DCA failure rate is also evaluated.

Fig. 5 plots the simulated DCA failure rate as a function of the number of available frequency channels with pathloss exponent α as a parameter for the shadowing loss standard deviation σ=7dB and ρ=0. To avoid large transmission delay, the maximum allowable number of hops is limited to *N*. For comparison, single-hop case (*N*=1) is also plotted. As α becomes larger, the DCA failure rate decreases. This is because the interference power from the interfering ports decreases as α becomes larger. It is found that the failure rate is almost insensitive to *N*. Possible reason for this is discussed below. As *N* increases, the average number of hops increases. This increases the failure rate due to the limited number of frequency channels. On the other hand, as *N* increases, the transmit power of each wireless port can be reduced due to shorter link distance between two adjacent ports, thereby reducing the interference power to other wireless ports. This contributes to decreasing the failure rate. As a consequence, the failure rate becomes almost insensitive to *N*.

Fig. 6 plots the DCA failure rate as a function of the number of available frequency channels with σ as a parameter for *N*=5, α=3.5, and ρ=0. The DCA failure rate is almost insensitive to σ. Possible reason for this is discussed below. As σ becomes larger, larger variations in the received signal powers at different ports may result. Hence, the route selection diversity effect, which is obtained by the route construction based on the total transmit power minimization criterion, contributes to decreasing the DCA failure rate. On the other hand, as σ increases, the probability of large interference power may increase. This contributes to increasing the DCA failure rate. As a consequence, the DCA failure rate is kept almost insensitive to σ. Fig. 6 plots the case of *N*=5. We also evaluated the DCA failure rates for various values of *N* to find that the DCA failure rate is almost insensitive to *N* irrespective of σ.

Fig. 7 plots the DCA failure rate as a function of the number of available frequency channels with the fading correlation ρ as a parameter for *N*=5, α=3.5 and σ=7dB. The DCA failure rate increases as ρ decreases. When ρ<0.4, the DCA failure rate is almost identical to that of ρ=0. We also evaluated the DCA failure rate for different values of *N* to find that the DCA failure rate is almost insensitive to *N* irrespective of ρ.

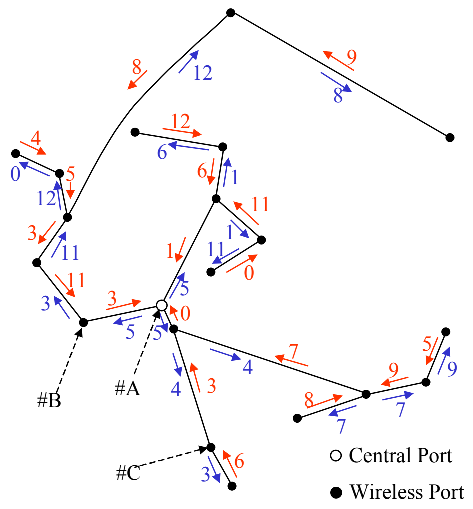

Fig.4 An example of CS-DCA result. Numbers indicate frequency channel index.

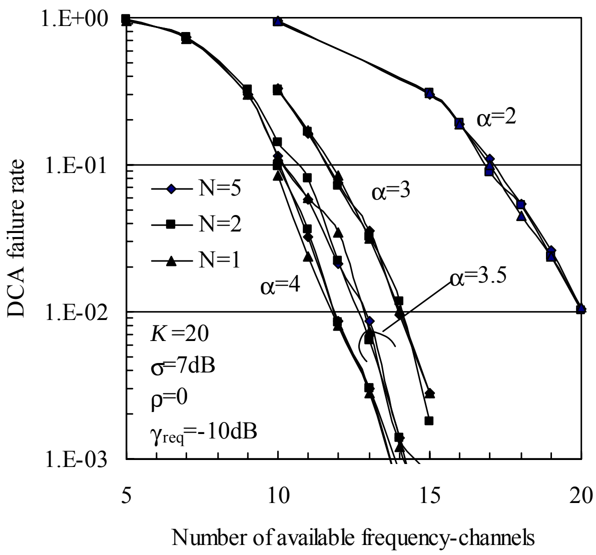

Fig.5 DCA failure rate as a function of the number of available frequency channels with α as a parameter for σ=7dB and ρ=0.

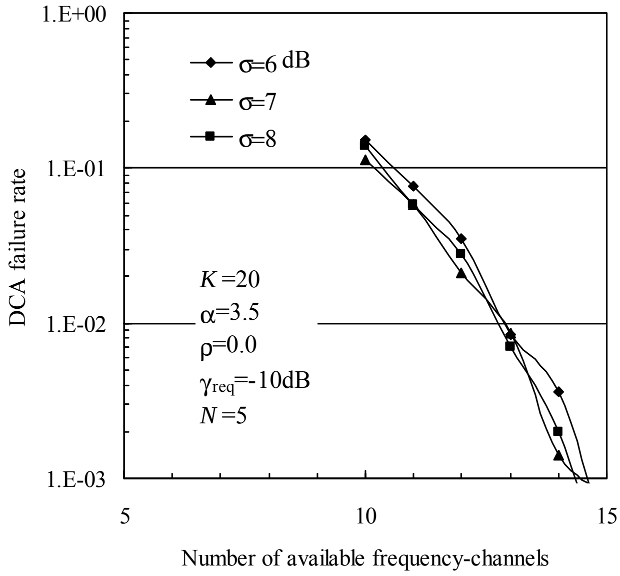

Fig.6 DCA failure rate as a function of the number of available frequency channels with σ as a parameter for N=5, α=3.5 and ρ=0.

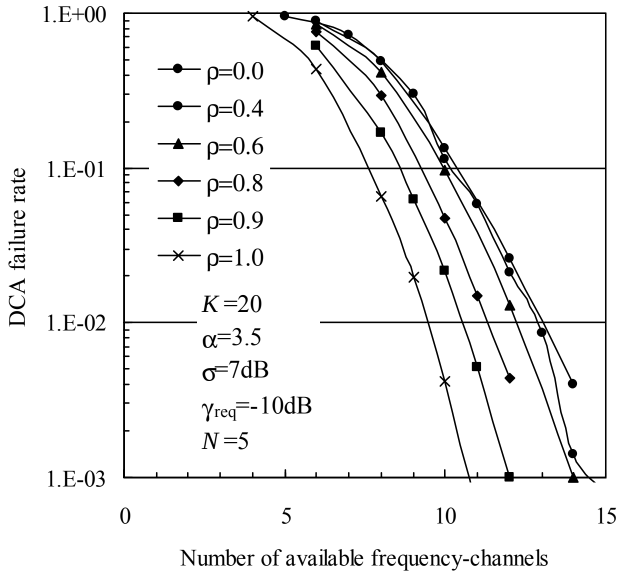

Fig.7 DCA failure rate as a function of the number of available frequency channels with ρ as a parameter for N=5, α=3.5 and σ=7dB.

IV. CONCLUSIONS

Distributed DCA is a promising channel allocation scheme for wireless multi-hop systems. In this paper, the CS-DCA algorithm was applied to a multi-hop DS-CDMA virtual cellular system and the DCA failure rate was evaluated by computer simulation. It was found that the failure rate is almost insensitive to the allowable number of hops irrespective of the values of the pathloss exponent, the shadowing loss standard deviation and the fading correlation. It was also found that the DCA failure rate decreases as the pathloss exponent or the fading correlation becomes larger, but it is almost insensitive to the shadowing loss standard deviation.

In this paper, omni directional antenna was assumed. An adaptive antenna array technique can be used to effectively reduce the interference to/from other ports and therefore, more efficient frequency usage is possible. This is left for an interesting future study.

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