Study of a Multi-hop Communication in a Virtual Cellular System

Eisuke KUDOH and Fumiyuki ADACHI

Dept. of Electrical and Communication Engineering, Graduate School of Engineering, Tohoku University

05 Aza-Aoba, Aramaki, Aoba-ku, Sendai, 980-8579 Japan

E-mail: kudoh@mobile.ecei.tohoku.ac.jp, adachi@ecei.tohoku.ac.jp

Abstract: A virtual cellular system, which was proposed recently to significantly reduce the transmit power of a mobile terminal while increasing frequency efficiency, consists of a central port and many distributed wireless ports. In this paper, wireless multi-hop communication is applied between central port and wireless ports and the cumulative distribution functions (cdfs) of the number of hops and the transmit power of each wireless port are evaluated when the maximum number N of allowable hops is limited. It is found that multi-hop communication can reduce the transmit power of wireless port considerably while avoiding unnecessary large time delay.

keywords: virtual cellular system, multi-hop network, adhoc network, routing, transmit power efficiency

1. Introduction

Major services provided by cellular mobile communications systems are shifting from voice conversations to data communications. There is a strong demand for higher speed data transmissions. However, there will be a serious problem; as data transmission rate becomes higher, the peak transmit power becomes larger [1], [2]. To decrease the peak transmit power while increasing the data transmission rate, we proposed a virtual cellular system to significantly reduce the transmit power of a mobile terminal while improving the frequency efficiency [3].

Fig. 1 illustrates the conceptual diagram of the virtual cellular system [3]. The virtual cellular system consists of a central port, which is a gateway to the network, and many distributed wireless ports. A mobile terminal communicates simultaneously with the distributed wireless ports. For the uplink, the signals transmitted from a mobile terminal and received at wireless ports need to be relayed to the central wireless port, while for the downlink, the signal to the mobile terminal can be multicast from the central wireless port to distributed wireless ports. Therefore, the routing algorithm is an important technical issue. Routing algorithms proposed for wireless multi-hop networks or adhoc networks can be applied [4]~[6].

In Ref.[4], a routing algorithm that minimizes the number of hops is presented. Decreasing the number of hops reduces the transmission time delay; however, the total transmit power may increase since a distant wireless port may be selected to relay. In Ref.[5] a routing algorithm using the link distance information is proposed. However, this algorithm does not necessarily choose the wireless ports that minimize the propagation path-loss due to the existence of shadowing. In the data relay of virtual cellular system, the frequency reuse is also applied to efficiently utilize the limited frequency bandwidth as in present cellular systems. The frequency reuse distance can be reduced by decreasing the total transmit power of wireless ports for data relay. In Ref.[6], a routing algorithm to minimize the total transmit power of wireless ports for data relay is proposed and the total transmit power is only evaluated for the case of the maximum number of allowable hops being limited to 2, a path-loss exponent of 3.5 and a shadowing loss standard deviation of 8dB.

In this paper, to utilize the frequency efficiently, we apply the routing algorithm which minimizes the total uplink transmit power for data relay among wireless ports in the virtual cell while limiting the number of hops. It was shown by computer simulation [7] that as the maximum number of allowable hops becomes larger the total transmit power can be reduced while limiting the number of hops under various parameters (i.e. distance dependent path-loss and shadowing loss.) However, as the maximum number of allowable hops becomes larger, the time delay of the multi-hop network becomes longer. Therefore, in this paper, we evaluate the cumulative distribution function (cdf) of the number of hops and the transmit power of each wireless port for various parameters, i.e., limited number of hops, path-loss exponent and standard deviation of shadowing loss, in the multi-hop virtual cellular network.

The reminder of this paper is organized as follows. Sect. 2 introduces a multi-hop system. Sect.3 evaluates cdfs of the number of hops and the transmit power of each wireless port by computer simulation. Sect.4 gives some conclusions.

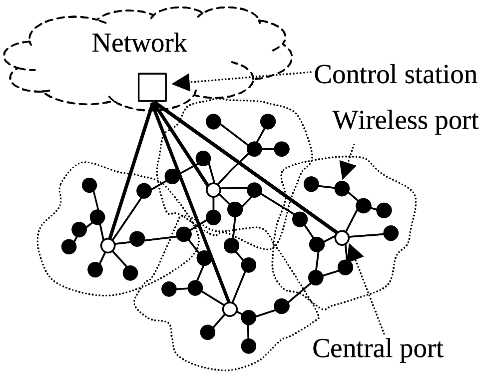


Fig. 1 Virtual cellular system.

2. Multi-hop System

If all wireless ports communicate with the central port directly, the transmit powers of some wireless ports may become very large due to path-loss, shadowing loss, and multipath fading. To avoid this, multi-hop wireless system is applied. In this paper, the virtual cell control layer that is inserted between the data link layer and the network layer is introduced as illustrated in Fig. 2 [4]. The signal transmitted from a mobile terminal is received by all wireless ports. Since each wireless port can act as a site diversity branch, the transmit power of a mobile terminal can be significantly reduced compared to the present cellular systems [3]. The virtual cell control layer manages the construction of multi-hop routes between each wireless port and the central port.

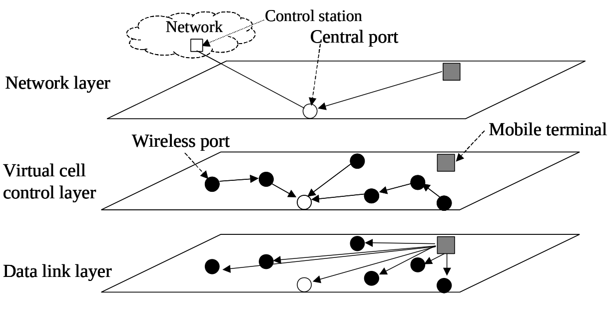


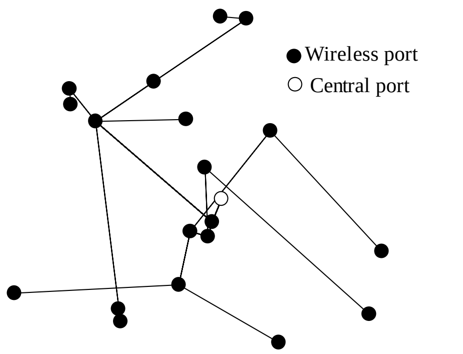
Fig. 2 Layer structure.

3. Computer Simulation

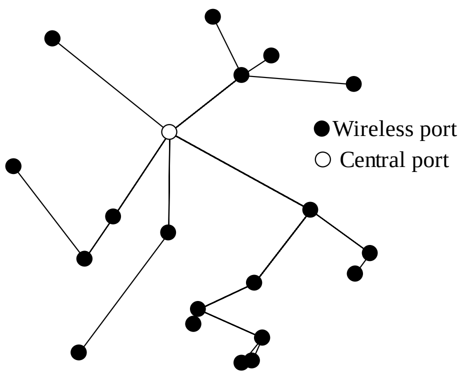
To reduce the interference power and increase the frequency efficiency, the routing algorithm based on the minimum total transmit power is considered [4]. Signal-to-noise power ratio (SNR)-based slow transmit power control is assumed. Wireless ports are randomly located in an entire virtual cell.

3.1. Constructed Multi-hop Routes

Fig. 3 shows some examples of constructed routes for K=20 and N=5, where K is the number of wireless ports and N is the maximum number of allowable hops, respectively [4]. The propagation path-loss exponent α of 3.5 and the log-normally distributed shadowing loss with standard deviation σ of 7dB are assumed. Fig. 4(a) shows that the central port needs to transmit/receive the uplink/downlink signals via only one wireless port. This suggests that the downlink transmit power of central port can be reduced considerably. Of course, this does not always happen. Sometimes, the central port needs to have multiple connections with surrounding wireless ports.



(a)



(b)

Fig.3 Some examples of constructed routes.

3.2. Cdf of Transmit Power

Fig.4 plots the cdf of wireless port transmit power normalized by the average transmit power for the single hop case (N=1) with the maximum number N of allowable hops as a parameter. It can be seen that multi-hop communication can reduce the transmit power of each wireless port considerably. When $N \geq 5$, at the probability of 80%, the transmit power can be smaller than that of the N=1 case by about -20dB. However, the cdf of normalized transmit power is almost identical for $N \geq 5$. This suggests that the maximum number of allowable hops can be limited to 5 in order to avoid unnecessary large time delay with allowing negligible increase of transmit power. In the following, we show that this can also be true irrespective of the values of the path-loss exponent α and the standard deviation σ of log-normally distributed shadowing loss.

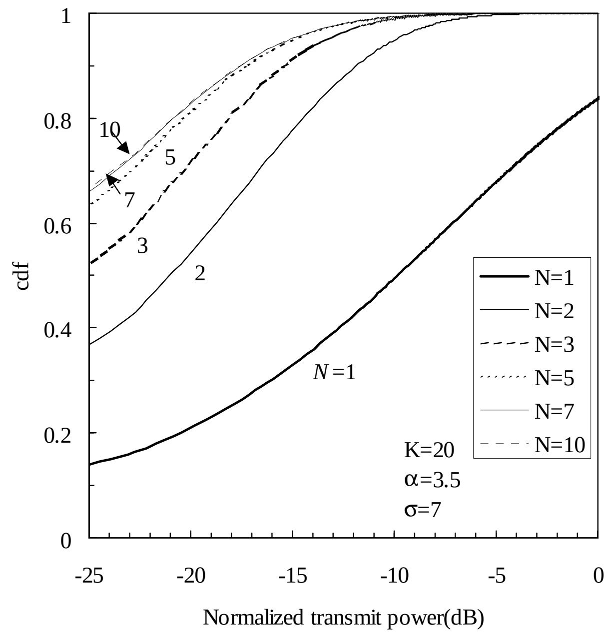


Fig. 4 Cdf of normalized transmit power of each wireless port with the maximum number *N* of allowable hops as a parameter.

Fig. 5 plots the cdf of normalized transmit power of each wireless port with α as a parameter for *K*=20 and σ=7dB. It can be seen from the figure that as α becomes larger, the medium value of normalized transmit power reduces. This is because multi-hop can shorten link distance between transmitting and receiving wireless ports significantly.

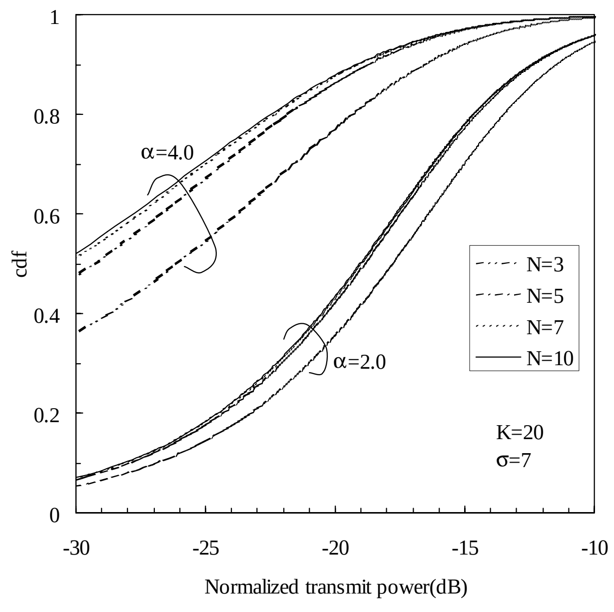


Fig. 5 Cdf of normalized transmit power of each wireless port with the propagation path-loss exponent α as a parameter.

Fig. 6 plots cdf of normalized transmit power of each wireless port as a function of the maximum number *N* of allowable hops with the shadowing loss standard deviation σ as a parameter for *K*=20 and α=3.5. As σ becomes larger, the medium value of normalized total transmit power reduces. This is because the route diversity effect increases as the variation in the propagation loss between wireless ports becomes larger.

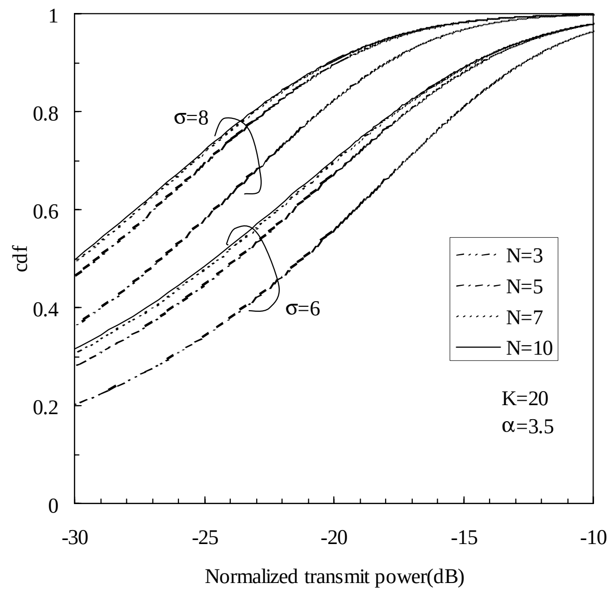


Fig. 6 Cdf of normalized transmit power of each wireless port with the standard deviation σ of shadowing loss as a parameter.

3.3. Cdf of the Number of Hops

Fig.7 plots the cdf of the number of hops with the maximum number *N* of allowable hops as a parameter for α=3.5 and σ=7dB. Fig.8 plots the cdf of the number of hops with the propagation path-loss exponent α as a parameter for *K*=20 and σ=7dB. Fig.9 plots the cdf of the number of hops with the standard deviation σ of log-normally distributed shadowing loss as a parameter for *K*=20 and α=3.5. If an infinite number of hops is allowed, about 20% of constructed routes require more than 5 hops. This suggests that about 20% of constructed routes with *N*=5 are not power minimum routes and hence, the transmit power may increase. However, it can be seen from Fig.4 that even if *N*=5 is needed, the increase in the transmit power is negligible irrespective of α and σ.

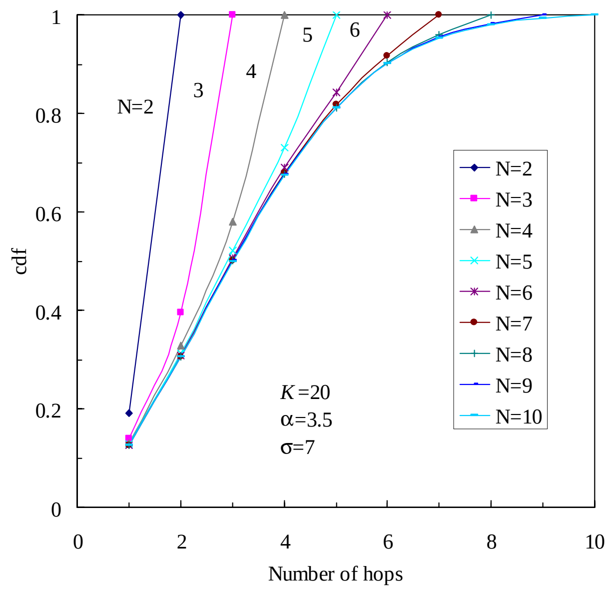


Fig.7 Cdf of number of hops with the maximum number *N* of allowable hops as a parameter.

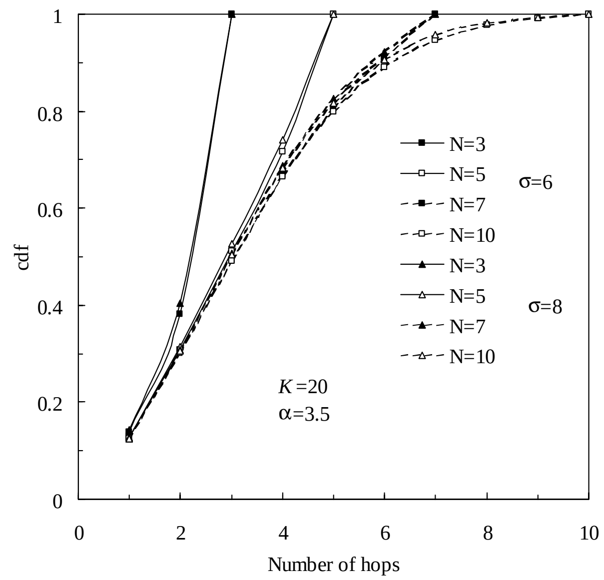


Fig.9 Cdf of the number of hops with the standard deviation σ of the log-normally distributed shadowing loss as a parameter.

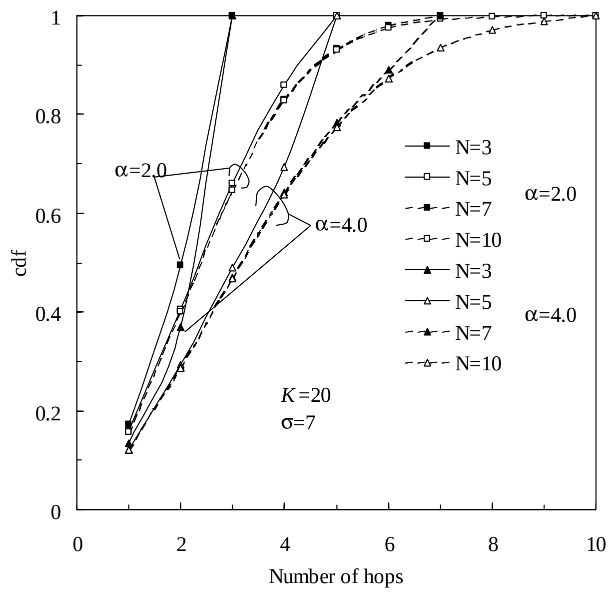


Fig.8 Cdf of the number of hops with the propagation path-loss exponent α as a parameter.

4. Conclusions

Multi-hop wireless communication was applied to the virtual cellular system. Applying the routing algorithm based on the minimum total uplink transmit power, the cdfs of the wireless port transmit power and the number of hops were evaluated by computer simulation. It is found that the cdf curves are almost identical, when the maximum number *N* of allowable hops is larger than 5, irrespective of the path-loss exponent α and shadowing loss standard deviation σ. It suggests that multi-hop communication can reduce the transmit power of wireless port considerably while avoiding unnecessary large time delay.

References

[1] F. Adachi, “Wireless past and future-evolving mobile communication systems”, IEICE Trans. Fundamentals, Vol. E84-A, No.1, pp.55-60, Jan. 2001.

[2] T. Otsu, Y. Aburakawa and Y. Yamao, “Multi-hop wireless link system for new generation mobile radio access networks”, IEICE Trans. Commun., Vol. E85-B, No.8, pp.1542-1551, Aug. 2002.

[3] E. Kudoh and F. Adachi, “Power and frequency efficient virtual cellular network”, Proc. IEEE VTC’2003 Spring, Cheju, Korea, pp.2485-2489, April 2003.

[4] C. E. Perkins and E. M. Royer, “Ad-hoc on-demand distance vector routing”, Proc. IEEE WMCSA’99, pp.90-100, Feb. 1999.

[5] T. Mukai, H. Murata and S. Yoshida, “Study on channel selection algorithm and number of established routes of multi-hop autonomous distributed radio network”, (in Japanese) IEICE Trans. Commun., Vol.J85-B, no.12, pp.2080-2086, Dec. 2002.

[6] A. Fujiwara, S. Takeda, H. Yoshino, T. Otsu and Y. Yamao, “Capacity improvement with a multi-hop access scheme in broadband CDMA cellular systems”, (in Japanese) IEICE Trans. Commun., Vol.J85-B, no.12, pp.2073-2079, Dec. 2002.

[7] E. Kudoh and F. Adachi, “Transmit power efficiency of a multi-hop virtual cellular system”, submitted to IEEE Vehicular Technology Conference 2003 fall.