Multi-hop Virtual Cellular Network

Eisuke KUDOH and Fumiyuki ADACHI
Dept. of Electrical and Communication Engineering, Graduate School of Engineering, Tohoku University
6-6-05 Aza-Aoba, Aramaki, Aoba-ku, Sendai, 980-8579 Japan
E-mail: kudoh@ecei.tohoku.ac.jp, adachi@ecei.tohoku.ac.jp

1. Introduction

The 3rd generation mobile communication systems, known as IMT-2000 systems, have data transmission capability of up to 2 Mbps [1]. Recently, high-speed downlink packet access (HSDPA) aiming at a maximum peak throughput of around 10 Mbps is under development for the enhancement of the IMT-2000 systems [2]. However, since information transferred over the Internet is becoming increasingly rich, even wireless transmission capability of the enhanced IMT-2000 will sooner or later become insufficient. There is a strong demand for peak rates of around 100Mbps ~ 1Gbps even in mobile communications systems to offer mobile users Internet-related broadband multimedia services. This is the task of the so called 4th generation (4G) mobile communications systems, which is expected to emerge around 2010 [3]. However, there will be an important problem to overcome; as the transmission rate becomes higher, the peak transmit power of a mobile terminal (MT) should be increased. Reducing the cell size is a simple way to avoid larger peak transmit powers while increasing the transmission rate [3], [4]. However, if the cell size becomes smaller, the control signal traffic for handover and location registration may increase. To avoid this problem, we recently proposed a wireless multi-hop virtual cellular network (VCN) [5], [6]. This article introduces the wireless multi-hop VCN. After presenting the VCN concept in Sect.2, Sect. 3 describes the multi-hop route construction algorithm and the multi-hop channel allocation using channel segregation dynamic channel allocation (CS-DCA) algorithm. The transmit power efficiency and the blocking probability are discussed in Sect.4.

2. Multi-hop VCN concept

Fig. 1 shows the multi-hop VCN. The wireless multi-hop VCN consists of a central port (CP), which is the gateway to the network, and many distributed wireless ports (WPs). WPs that directly communicate with the MT are called end WPs. For the VCN, WPs are stationary and the installation or removal of WPs is made whenever necessary; this is different from so-called wireless multi-hop network, in which each MT relays the signal to other MTs [4]. Signals received at (or transmitted from) the end WPs are relayed to (or from) the CP by means of wireless multi-hop technique. For mobility management, the MT location information updating is essential. To reduce the location information control message traffic, a distributed mobility management scheme is used, in which the CP supports the intra-VC mobility management and the control station in the core network supports the inter-VC mobility management [7]. The features of the multi-hop VCN are summarized below.

(a) The control signal traffic for handover and location registration to/from the network increases as the cell size becomes smaller. However, in the VCN, a group of distributed WPs acts as one virtual base station and hence, the control traffic will not increase (however, there exists control signal traffic within each VC for multi-hop route construction and maintenance).
(b) Since each end WP acts as a site diversity branch, the transmit power of each MT and the total transmit power of end WPs can be made significantly smaller than the present cellular network
(c) Reducing the transmit power contributes to the reduction in the interference power to other VCs, and thus the frequency efficiency improves significantly.
(d) Grouping of distributed WPs, to construct VC, may not necessarily be fixed but can be different for each user and the VC size for the uplink may not necessarily be the same as for the downlink.

3. Wireless multi-hop routing and channel allocation

For multi-hop VCN, the routing and the channel allocation among distributed WPs are important technical issues. In order to reduce the interference power, the multi-hop routing algorithm is based on the total transmit power minimization criteria [5]. Fig. 2 shows an example of routing message propagation. The route construct request message is sent periodically from all WPs (#A in Fig.2) to the CP via other WPs. If the relaying WP receives more-than-one route construction request messages, the relaying WP selects the route that has the minimum total required transmit power. The route notification message is sent back from the CP to each WP via other WPs along the total transmit power minimum route. In order to further reduce the transmit power, multi-hop MRC (MHMRC) diversity, as shown in Fig. 3, can be applied [8][9]. MT#0 transmits its signal, which is received by WP#1, but the same signal is received by WP#2. WP#1 relays its received signal to WP#2. Therefore, WP#2 receives the same signal twice; first from MT#0 and then from WP#1. These two signals can be combined based on the well-known MRC combining [10]. Since the same signals transmitted from previous ports have been received before the signal from the immediately previous port is received, the relay time of multi-hop MHMRC diversity is the same as that of the simple multi-hop relay.

In the wireless multi-hop VCN, 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) [11]. Using FCA, predetermined fixed channels are allocated to each WP. FCA cannot adapt to changing traffic conditions and user distributions. On the other hand, using DCA, all channels are available at each WP 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 [11]; the latter is promising for the multi-hop VCN. The CS-DCA [12] is applied to multi-hop links among WPs [6] and the user link between an MT and end WP [13]. After all routes are constructed, channels are assigned to the up/down links between any two adjacent WPs along each route. Fig.4 shows the flow chart of CS-DCA. The transmit side initiates the CS-DCA procedure. In the CS-DCA, each WP is equipped with a channel priority table. The CS-DCA is carried out at each transmit WP. The transmit WP selects a channel among available ones using its channel priority table.

4. Transmit power efficiency and blocking probability

The average transmit power of the user link (between MT and end WP) normalized by the transmit power of a present cellular network is plotted in Fig. 5 as a function of the number K of WPs per VC for the path loss exponent α=3.5. A hexagonal VC layout is assumed. Both MT and WP use two-branch antenna diversity reception (M=2). By increasing K, the average transmit power can be significantly reduced. When K=8, the MT transmit power (for the uplink) can be reduced, using MRC diversity combining, to less than 1/100 of that of the present cellular network. The total transmit power of end WPs (for the downlink) is smaller with site selection diversity transmission (SSDT) than with multiple transmit diversity (MTD). This is because with MTD, all WPs transmit the same signal to an MT, while only the best WP transmits with SSDT. However, even with MTD, when K=7, the total transmit power of end WPs can be reduced to 1/10 of that of the present cellular network.

An example of the distribution of frequency channels allocated by the CS-DCA (the number indicates the frequency channel index) is illustrated in Fig. 6. The same frequency channel is reused for both uplink and downlink transmissions at different WPs, resulting in an efficient frequency usage. 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. The blocking probabilities of the multi-hop VCN and the present cellular network are plotted with the number C of available channels as a parameter in Fig.7 for SF=16, J=4, α=3.5, σ=6dB and L=2 [13]. The performance difference between the two networks depends on C. In high traffic load, the multi-hop VCN is superior to the present cellular network.

5. Conclusions

A wireless multi-hop VCN concept that can avoid larger peak transmit powers while increasing the transmission rate was introduced. The wireless multi-hop VCN is a promising concept to offer mobile users Internet-related broadband multimedia services. However, before the realization of the multi-hop VCN, there are many technical issues related to packet scheduling, mobility management, etc.

References

[1] F. Adachi, M. Sawahashi and H. Suda, “Wideband DS-CDMA for next generation mobile communication systems”, IEEE Commun. Mag. vol.36, no.9, pp.55-69, Sept. 1998.

[2] 3GPP, TP25.848, “Physical layer aspects of UTRA high speed downlink packet access.”

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

[4] 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.

[5] E. Kudoh and F. Adachi, “Power and frequency efficient multi-hop virtual cellular concept”, IEICE Trans. Commun., vol. E88-B, no.4, pp.1613-1621, April 2005.

[6] E. Kudoh and F. Adachi, “Distributed dynamic channel assignment for a multi-hop DS-CDMA virtual cellular network”, IEICE Trans. Commun., vol. E88-B, no.6, pp.2525-2531, June 2005.

[7] E. Kudoh and F. Adachi, “Distributed Layered Mobility Management for Multi-hop Virtual Cellular Network”, IEICE Technical report, RCS2004-238, pp.13-18, Jan. 2005(in Japanese).
[8] I. Daou, E. Kudoh and F. Adachi, “Transmit Power Efficiency of Multi-Hop MRC Diversity for a DS-CDMA Virtual Cellular Network”, IEICE Trans. Commun., vol. E88-B, no.9, pp.2525-2531, Sept. 2005.
[9] I. Daou, E. Kudoh and F. Adachi, “Transmit Power Efficiency of Multi-Hop Hybrid Selection/MRC Diversity for a DS-CDMA Virtual Cellular Network”, Proc. IEEE VTC’2005 Fall, Sept. 2004.
[10] W. C. Jakes, *Microwave mobile communications*, John Wiley & Sons, 1974.
[11] I. Katzela and M. Naghshineh, “Channel assignment schemes for cellular mobile telecommunication systems: a comprehensive survey”, IEEE Personal Communications, pp.10-31, June 1996.
[12] Y. Furuya and Y. Akaiwa, “Channel segregation, a distributed adaptive channel allocation scheme for mobile communication systems”, IEICE Trans., vol.E74, no.6, pp.1531-1537, June 1991.
[13] L. Soundous, E. Kudoh and F. Adachi, “On Demand Channel Assignment for Multi-hop Virtual Cellular Network”, IEICE Technical report, RCS2004-376, pp.57-62, Mar. 2005.

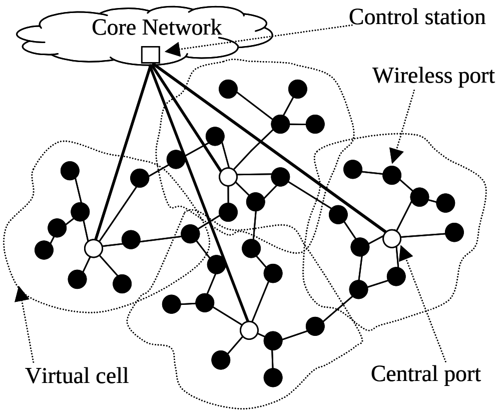
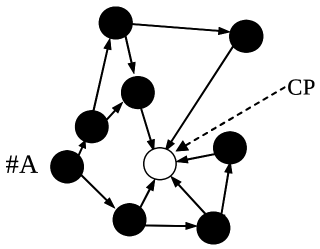
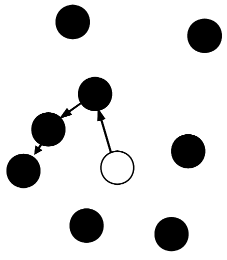


Fig. 1 VCN.



(a) Propagation of route construct request message



(b) Propagation of route notification message

Fig.2 Example of routing message propagation.

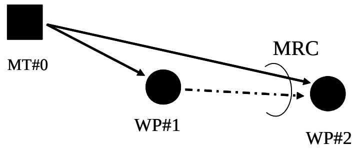


Fig.3 MHMRC diversity.

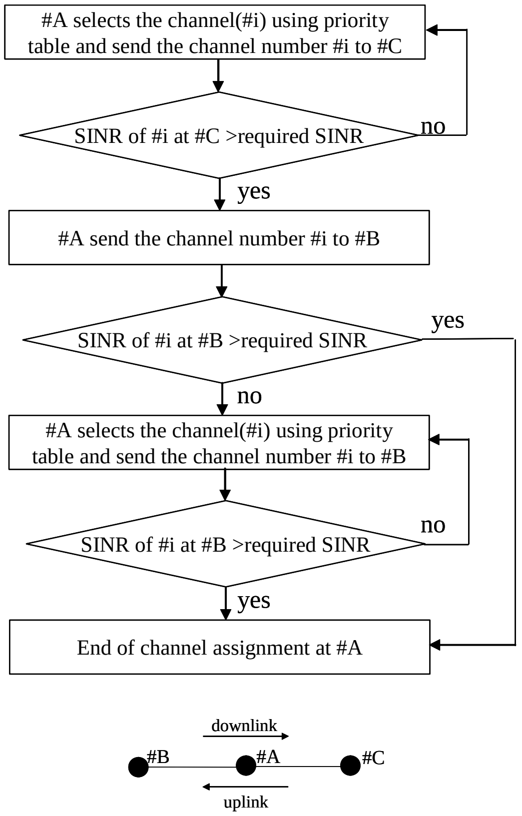


Fig.4 Flow chart of CS-DCA.

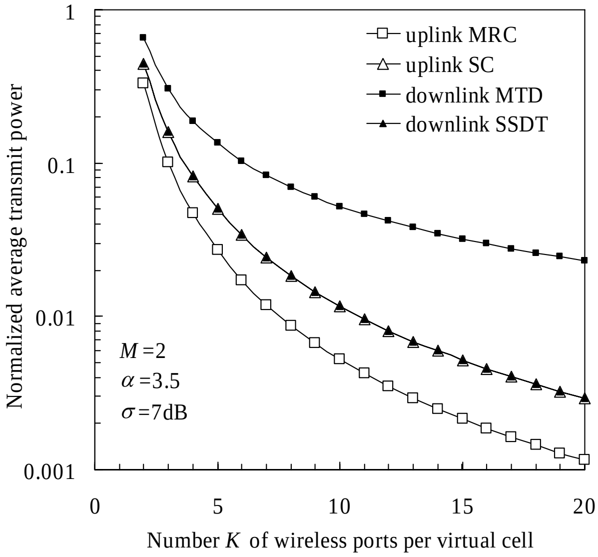


Fig. 5 Normalized average transmit power per VC.

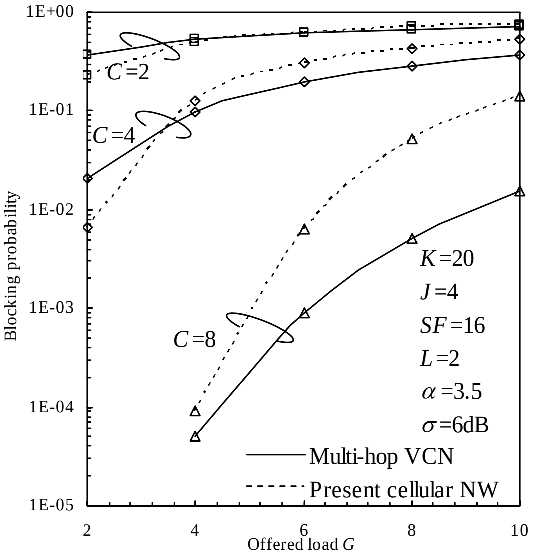


Fig.7 Blocking probability.

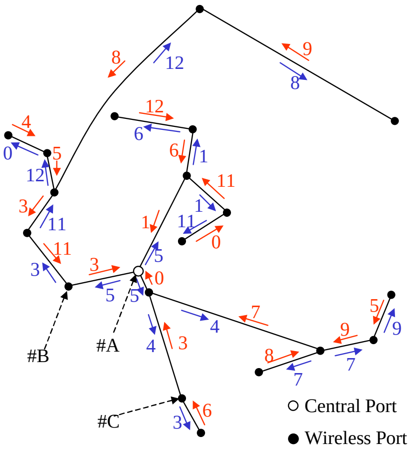


Fig.6 An example of CS-DCA result.