社団法人 電子情報通信学会
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信学技報
TECHNICAL REPORT OF IEICE

マルチホップバーチャルセルラネットワークにおける経路再構築アルゴリズム

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あらまし　高速無線ネットワークを実現するためにバーチャルセルラネットワーク(VCN)が提案されている．移動端末から送信された信号は，分散配置された無線ポートで受信され，コアネットワークへのゲートウェイとなる中央無線ポートへとマルチホップ通信によって転送される．無線ポート間のマルチホップ通信ネットワークを構築するためには経路構築方法が重要となってくる.筆者らは総送信電力を最小とする経路構築方法を示してきた．しかしながら，伝搬環境の変化やトラフィックの分布の変動につれて適切なネットワークトポロジ得るため，新しいポートを増設したりポートを撤去することが必要となる.この場合にはマルチホップ経路を再構築する必要がある.本論文では､制限経路再構築アルゴリズムを提案し,総送信電力の増加とホップ数増加の分布を計算機シミュレーションにより明らかにしている．

キーワード　バーチャルセルラネットワーク，ポート増設/ポート撤去、経路構築の時間/メッセージ数

Modified Rerouting Algorithm for a Multi-hop Virtual Cellular Network

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Abstract In the multi-hop virtual cellular network (VCN), many wireless ports are distributed in each VC and the transmitted signal from/to a mobile user is relayed by the multi-hop technique to/from a central port which acts as a gateway to the network. According to the long term change of propagation environment and traffic distribution, addition and removal of wireless ports are necessary in order to get the adequate network topology. Hence, the route reconstruction is an important technical issue. In this paper, we propose a modified rerouting algorithm for port addition and removal, then we analyze theoretically the time and number of messages for route reconstruction, and evaluate the transmit power efficiency by computer simulation.

Keyword *Virtual cellular network, Port addition/removal, Routing time/number of messages.*

1. Introduction

The mobile communication systems services are shifting from voice conversation to data conversation through the internet. However, as the data transmission rate becomes higher, the peak transmit power becomes larger. To decrease the peak transmit power, a multi-hop virtual cellular network (VCN) was proposed [1] [2]. In VCN, as shown in Fig 1, each virtual cell (VC) has a central port, which is a gateway to the network, and many distributed wireless ports. A group of the wireless ports works as a virtual base station. If all the wireless ports communicate directly with the central port, some wireless ports may need significantly large transmit powers due to path-loss, shadowing loss and multi-path fading. To avoid this, wireless multi-hop technique is used.

For uplink (downlink) data transmissions, many wireless ports can be used to relay the signal transmitted from a mobile terminal (the central port) to the central port (a mobile terminal). The routing algorithm is an important technical issue. Routing algorithms proposed for wireless multi-hop network or adhoc network [3]-[6] can be applied to VCN. To decrease the interference power and increase the frequency efficiency, a routing algorithm that minimizes the total uplink transmit power while limiting the number of hops was introduced in [7].

According to the long term change of the propagation environment and the traffic distribution, addition and removal of wireless ports are necessary in order to get the adequate network topology. In this case, rerouting is necessary to construct new routes from mobile terminal to the central port. In [8], a table-driven routing algorithm for link/port failure was proposed. This rerouting algorithm can be applied for port removal; however, new algorithm is necessary for port addition. In this paper, we propose a modified rerouting algorithm applied for port addition and removal. Since the transmit power of the reconstructed route by this rerouting algorithm may not necessarily be the minimum transmit power, we compare the transmit power of the modified rerouting with that of the complete power minimized one. We analyze theoretically the time and number of messages for route reconstruction, and evaluate the transmit power efficiency by computer simulation.

This paper is organized as follows. In Sect. 2 we present the modified minimum transmit power rerouting algorithm for port addition and removal, and analyze theoretically the time and number of messages for route reconstruction. In Sect. 3, the transmit power for both cases of port addition and removal is evaluated by computer simulation. Sect. 4 gives some conclusions.

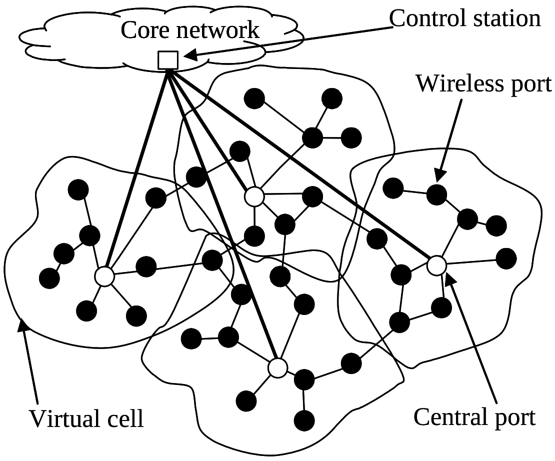

Fig.1 Virtual cellular network.

2. Modified Routing Algorithm

For the complete power minimized rerouting algorithm, to decrease the interference power and increase the frequency efficiency, a routing algorithm that minimizes the total uplink transmit power while limiting the number of hops was introduced in [7]. After a port addition or removal, the rerouting performs the same operation as the original routing. In order to reduce the number of messages for rerouting after a port addition and removal, we propose a modified routing algorithm. After a port installation or removal, the modified rerouting uses the original routing information. It should be noted that the newly added wireless ports only work as end-ports and do not contribute in any other route as a relaying port.

A. Port addition

For the modified routing, Fig. 2 shows an example of the route construction process in a VCN with four wireless ports (K=4) and the allowable maximum number of hops being four (N=4). Before a new port #3 addition, routes from each end-port to the central port are constructed. The route reconstruction algorithm is as follows:

Step 1: The newly installed wireless port (#3) sends the RREQ.

Step 2: The wireless ports (#2, #1, #0) that received the RREQ, sends the Route REPly (RREP) including the information of its total transmit power until the central port.

Step 3: The newly installed port receives the RREPs from the other wireless ports, computes its minimum transmit power and send the route notification message to its immediate previous port (#1).

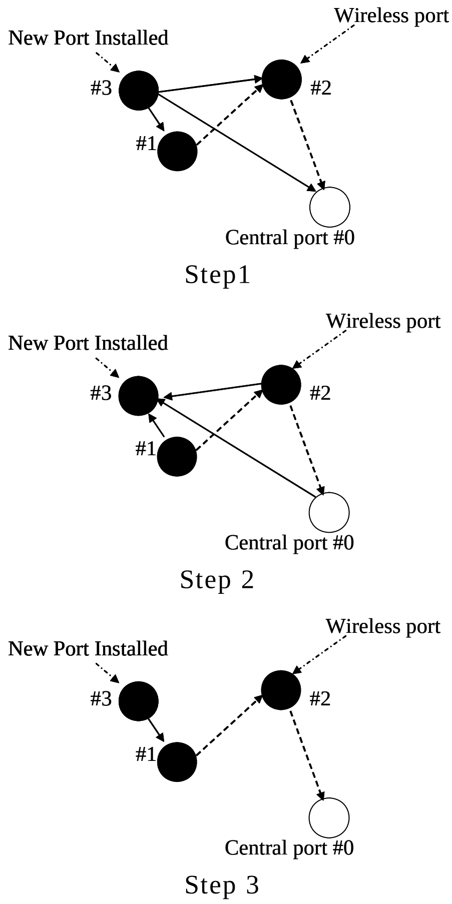

Fig. 2 Example of route construction message flow for the adaptive rerouting.

In the modified routing, since the newly added port only works as an end-port and does not contribute in any other route as a relaying port, the reconstructed route after port addition is not necessarily the minimum total transmit power route for the modified routing. However, using the modified routing, the route construction time and messages may be less than the complete algorithm.

To discuss the decrease in the routing time and number of messages, we compare this modified routing to the complete power minimized rerouting algorithm.

For the complete routing, first the newly added wireless port sends its RREQ and the route construction operation restarts. Since the route construction starts from the newly added port until the central port and each wireless port broadcasts its RREQ, the total number N_{msg} of routing messages in the worst case is given by

$$N_{msg}=1+ (K-2)(N-1)+N(K-1) , \quad (1)$$

where the first term is the RREQ message sent from the newly added wireless port, the second term is the number of RREQ messages sent by the wireless ports during the route construction operation and the last term is the number of route notification messages. Since the messages from different ports may be received simultaneously, the routing time $T_{routing}$ in the best case is given by

$$\begin{aligned} T_{routing} &= 1 + (N-1) + N \\ &= 2N \times \text{Packet's length.} \end{aligned} \quad (2)$$

However, for the modified routing the newly added port broadcasts its RREQ, then, receives the RREP from several wireless ports before sending the route notification message to its immediately previous port. Therefore, the number of routing messages in the worst case is given by

$$N_{msg}=1+ (K-1) + 1= K+1 \quad , \quad (3)$$

where the first term is the RREQ message sent from the newly added wireless port, the second term is the number of RREP messages sent by the wireless ports to the new installed port and the last term is the route notification message. Since the messages from different ports are received simultaneously, the routing time $T_{routing}$ in the best case is given by

$$T_{routing} = 3 \times \text{Packet's length.} \quad (4)$$

B. Port removal

For the complete power minimized rerouting algorithm, after a port removal, the routing restarts again to construct the minimum transmit power routes from each wireless port to the central port. However, for the modified routing, the rerouting is considered to be the same as in the case of a port failure in [8].

To compare the performance between the modified and complete routing in the case of port removal, we discuss the routing time and number of messages.

In the complete routing, the error route notification messages need to be sent from the source to the central port, before starting the route construction again. Therefore, the number N_{msg} of routing messages in the worst case is given by

$$N_{msg}=N+(K-2)(N-1)+N(K-1) \quad , \quad (5)$$

where the first term is the number of route error notification messages, the second term is the number of RREQ messages sent by the wireless ports during the route construction operation and the last term is the number of route notification messages. The routing time $T_{routing}$ for the conventional routing of a port removal is given by

$$T_{routing} = 3N \times \text{Packet's length.} \quad (6)$$

In the modified routing, the number of messages during the rerouting operation is the same as the port failure case. Therefore, N_{msg} in the worst case is given by

$$N_{msg}=N(K-1). \quad (7)$$

The rerouting time for the adaptive rerouting of a port removal is given by

$$T_{routing} = N \times \text{Packet's length.} \quad (8)$$

Fig. 3 shows the maximum number of messages for the modified and complete routing for both port addition and removal as a function of N for K=50. It is seen that the adaptive routing reduces significantly the number of messages during the route construction compared to the ideal algorithm for both port removal and addition cases.

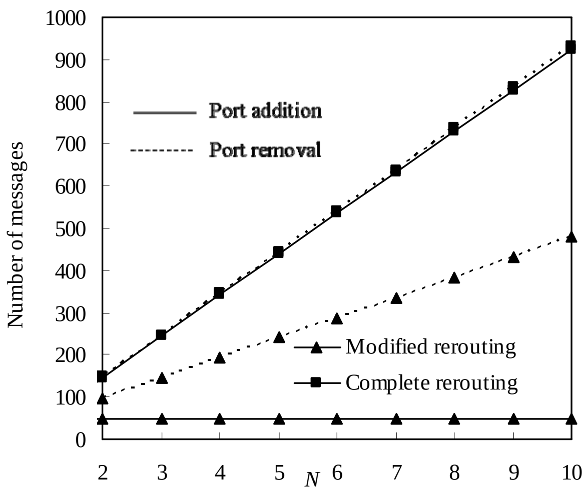

Fig. 3 Number of routing messages.

Fig. 4 shows the routing time for the modified and complete routing for both port addition and removal as a function of *N* for *K*=50. It is seen that the modified routing reduces the routing time compared to the complete algorithm for both port removal and addition cases.

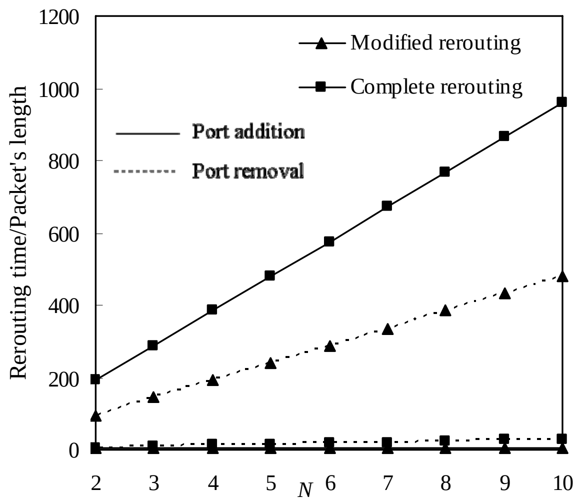

Fig. 4 Rerouting time.

3. Computer Simulation

Since the reconstructed route after port addition or removal is not necessarily the minimum total transmit power route for the modified routing, we compute the total transmit power using the modified and the complete routing for both port addition and removal cases.

Signal-to-noise power ratio (SNR)-based transmit power control (TPC) is assumed. Wireless ports are randomly located in an entire virtual cell. The total average transmit power along the route from the source wireless port to the central port is evaluated by computer simulation. In order to limit the relay time, the maximum number of hops is limited to *N*.

A. Power efficiency

Fig. 5 plots the total transmit power, in the case of port addition, along the route normalized by that of single-hop case as a function of *N* for the modified and the complete rerouting algorithms. It is assumed that the path-loss exponent α=3.5, the shadowing standard deviation σ=7dB and *K*=50. It is seen that the transmit power rise for the modified rerouting from the complete one is almost negligible. This suggests that although the newly added port does not contribute as a relaying port in the modified rerouting while it does in the complete one, this does not affect greatly the total transmit power.

Fig. 6 plots the total transmit power, in the case of port removal, along the route normalized by that of single-hop case as a function of *N* for α=3.5, σ=7dB and *K*=50, for both of the modified and the complete rerouting algorithms. It is seen that although the reconstructed route after the port removal may not be necessarily the minimum total transmit power route, the transmit power rise for the modified routing from complete one is almost negligible.

B. Relay time

To evaluate the increase in the relay time after the route reconstruction, we measure the cumulative distribution of the number of hops after a port addition and removal for both the modified and complete rerouting algorithms.

Fig 7 plots the cumulative distributions of the number of hops after a port addition with *N* as a parameter for α=3.5, σ=7dB, and *K*=50 for both the modified and complete rerouting. It is seen that the number of hops for the modified algorithm is almost the same as that of the complete one. As a conclusion, the modified algorithm does not increase the number of hops in the multi-hop route after a port addition.

Fig 8 plots the cumulative distributions of the number of hops after a port removal with *N* as a parameter for α=3.5, σ=7dB, and *K*=50 for both the modified and complete rerouting. It is seen that the number of hops in the multi-hop routes increases by 5% for the modified routing compared to the complete one. In order to explain more about the increase in the number of hops using the modified rerouting compared to the complete one, Fig 9 shows an example of reconstructed routes after the modified and the complete algorithms. It is seen that the number of hops increases for the modified rerouting.

Fig 10 plots the probability of having different reconstructed routes for both modified and complete rerouting with *N* as a parameter for α=3.5, σ=7dB, and *K*=50 for port addition and removal cases. It is seen that the probability of having different reconstructed routes is much larger for port removal compared to the port addition, and it is around 23% for port removal and 7% for port addition when *N*=10. This result explains the increased number of hops for port removal of Fig. 8.

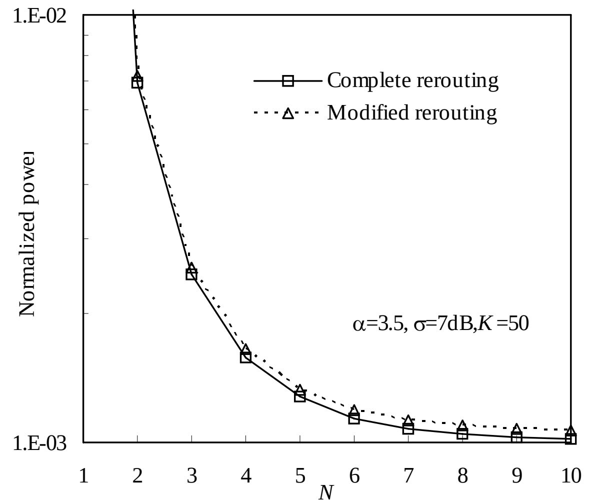

Fig 5 Total transmit power after port addition for both modified and complete rerouting algorithms.

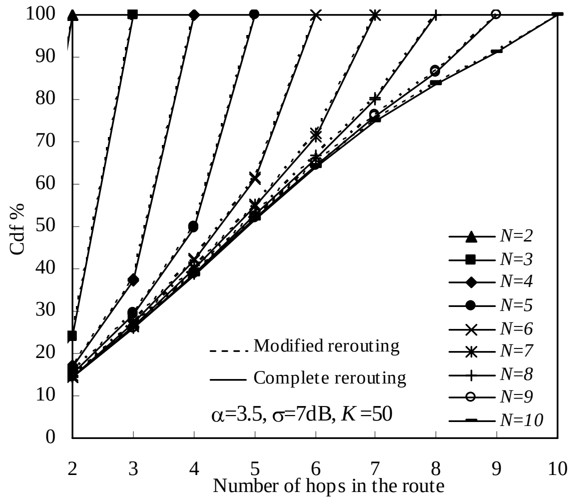

Fig. 7 Cdf of the number of hops in the route after a port addition with *N* as a parameter.

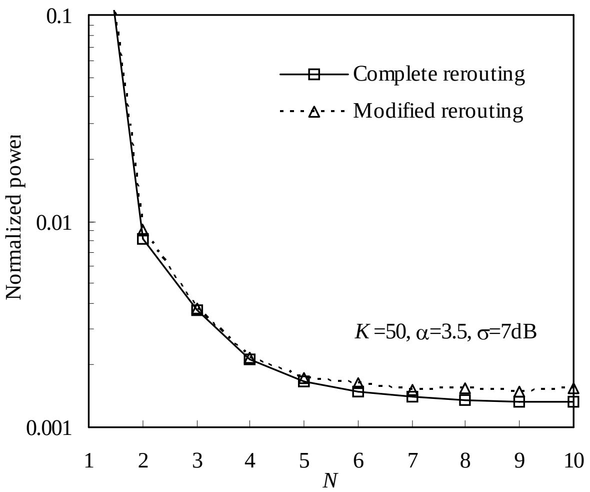

Fig.6 Total transmit power after port removal for modified and complete rerouting algorithms.

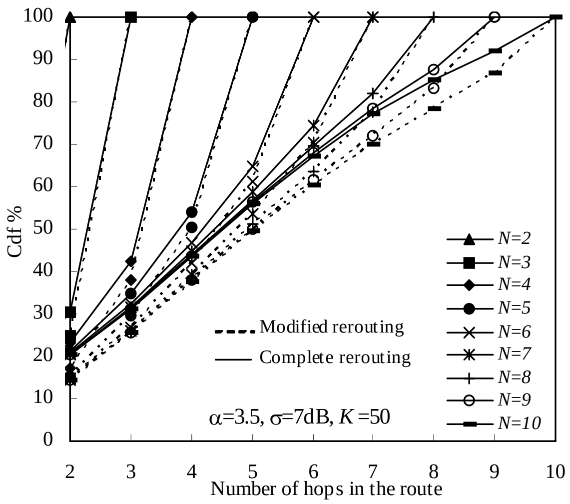

Fig. 8 Cdf of the number of hops in the route after a port removal with *N* as a parameter.

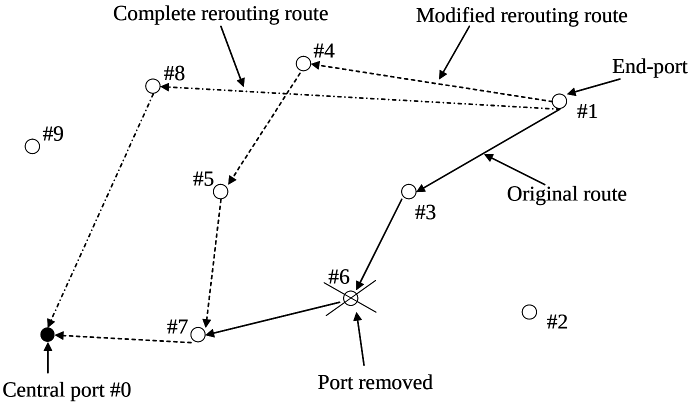

Fig 9 Example of reconstructed routes after port removal

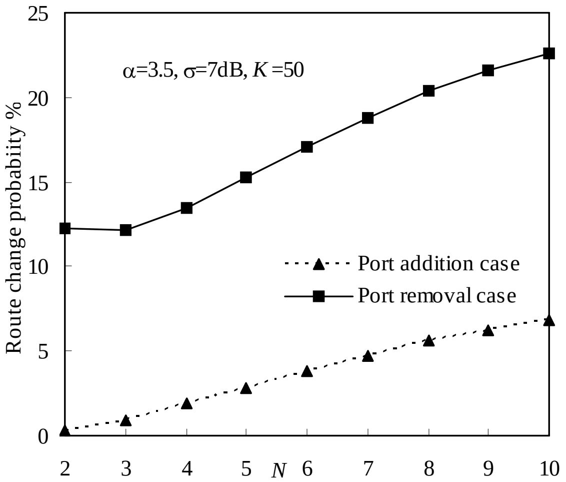

Fig 10 Probability of having different reconstructed routes using modified and complete rerouting algorithms.

4. Conclusions

In this paper, we proposed a modified rerouting for port addition and removal in a VCN and we compared it with the complete power minimized rerouting algorithm. For the complete routing, the route reconstruction operation restarts in any port addition or removal; therefore, the constructed routes are always the minimum transmit power routes. However, the routing time and number of messages are in the same order as the original routing. On the other hand, in the modified routing, the information stored during the original routing are used in order to reduce the routing time and number of messages. However, the constructed routes may not be necessarily the minimum transmit power routes. The routing time and the maximum number of messages were discussed. It was found that the modified routing reduces significantly the routing time and the maximum number of messages for the port addition and the port removal. The total transmit power for the complete and modified routing were evaluated by computer simulation for both port addition and removal cases. It was found that the total transmit power for the modified routing is almost the same as the complete one. It was shown that the number of hops in the route after a port addition is the same using either the modified or the complete algorithms; however, after a port removal, the number of hops in the route increases by 5% when using the modified routing.

References

[1] E. Kudoh and F. Adachi, ”Study of Multi-hop communication in a virtual cellular system”, Proc. WPMC’2003, pp. 261-265, Yokosuka, Japan, Oct. 2003.

[2] E. Kudoh and F. Adachi, ”Power and frequency efficient virtual cellular network”, Proc. IEEE VTC’2003 Spring, Cheju, Korea, April 2003.

[3] E. M. Royer and C. K. Toh. “A review of current routing protocols for adhoc mobile wireless networks”, IEEE Personal Commun., pp.46-55, April 1999.

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

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

[6] A. Fujiwara, S. Takeda, H. Yoshino, T. Otsu and Y. Yamao, “Capacity improvement with a multihop access scheme in broadband CDMA cellular system”, (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 multihop virtual cellular system”, Proc. IEEE VTC’2003 Fall, Orlando, Florida, USA, Oct. 2003.

[8] I. Daou, E. Kudoh and F. Adachi, "Adaptive route reconstruction algorithm for multi-hop virtual cellular network," Technical report, RCS2004-377, pp.63-68, March 2005.