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マルチホップバーチャルセルラネットワークにおける適応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､このマルチホップ経路に経路障害が発生した場合には経路を再構築する必要がある.本論文では､テーブル駆動型適応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，テーブル駆動型ルーティングプロトコール，経路障害

Adaptive Route Reconstruction Algorithm for Multi-hop Virtual Cellular Network

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Abstract　In the multi-hop virtual cellular network (VCN), the route construction is an important technical issue. However, because of the malfunction of some ports or some interference obstacles in a link between wireless ports, some link or port failure may occur. In this paper, we propose a table-driven route reconstruction algorithm based on the minimum transmit power criterion in order to reconstruct rapidly the multi-hop route when a link or port failure occurs. The transmit power rise and the distribution of the increased number of hops in the case of a link failure are evaluated by computer simulation.

Keyword　*Virtual cellular network, Table-driven routing protocol, Link/port failure.*

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 wireless ports distributed in VC. 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 to select the relaying ports to the central port. Routing algorithms proposed for wireless multi-hop network or adhoc network [3]-[6] can be applied to VCN. To increase the frequency efficiency, a routing algorithm that minimizes the total uplink transmit power while limiting the number of hops was introduced in [7]. Because of the malfunction of some ports or some interference obstacles in a link between wireless ports, link or port failure may occur. In this case, it is necessary to reconstruct rapidly a new multi-hop route and continue the data transmission. In this paper, we discuss the case of link or port failure, and propose a table-driven routing algorithm based on the minimum transmit power criterion robust in the route failure to reconstruct rapidly a new multi-hop route. The table-driven algorithm requires each port to maintain routing table that stores routing information, which always should be updated by sending messages periodically from each port [3].

This paper is organized as follows. Sect. 2 presents the table-driven minimum transmit power routing algorithm and the route reconstruction algorithm. In Sect. 3, the transmit power rise due to the failure and the distribution of increased number of hops are evaluated by computer simulation. Sect. 4 gives some conclusions.

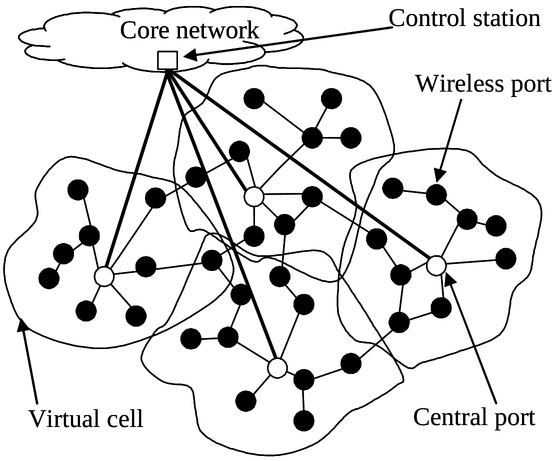

Fig.1 Virtual cellular network.

2. Table-Driven Minimum Transmit Power Routing Algorithm

During the route construction operation in the algorithm proposed in [7], the wireless ports only need to store the information about their previous port along the route. However, as a link or a port failure occurs along the route, the route reconstruction process should start from the source wireless port again. Therefore, the time spent during the route reconstruction is expected to be as long as the route construction time. In order to reduce the route reconstruction time, a routing table is used to store not only the information in the Route construct REQuests (RREQ) of the previous port, but also the RREQ of a certain number of candidates of previous wireless ports. As the number of candidates becomes larger, the routing table in each wireless port becomes larger too. If the information of only one previous port is stored in the routing table, this port may be the failed port and the route reconstruction algorithm may fail. Therefore, to reduce the memory size in each wireless port, we assume that each wireless port only stores in its routing table the information of two different candidates of previous port. The source wireless port RREQ is denoted by RREQ_s and the RREQ from the other wireless ports as RREQ_r.

A. Route construction

Fig. 2 presents the route construction algorithm flow chart, where n is the number of hops, N is the allowable maximum number of hops, $\#k(n)$ is the wireless port index that receives the RREQ_r after n hops, and $\#k(0)$ represents the source wireless port. $P_{t,req}(k(n\text{-}1),k(n))$ is the required transmit power of the wireless port $\#k(n\text{-}1)$ and is computed using the following equation:

$$P_{t,req}(k(n-1),k(n)) = P_{req} + P_t(k(n-1)) - P_r(k(n)) \quad \text{in dB,} \qquad (1)$$

where P_{req} is the required received signal power, $P_t(k(n\text{-}1))$ is the RREQ_r transmit power of the wireless port $\#k(n\text{-}1)$, and $P_r(k(n))$ is the received signal power at the wireless port $\#k(n)$. The source RREQ_s includes the source ID, its transmit power $P_t(k(0))$, and the number of hops=0. Whereas RREQ_r of the wireless port $\#k(n)$ includes the source ID, its ID, its transmit power $P_t(k(n))$, the number of hops n, and the total transmit power $P(k(n))$ given by

$$P(k(n)) = \sum_{i=0}^{n-1} P_{t,req}(k(i-1),k(i)) \quad . \qquad (2)$$

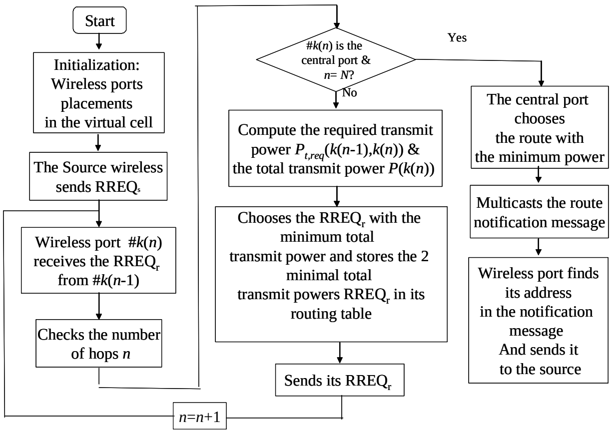

Fig.2 Route construction algorithm flow chart.

In order to explain the route construction operation, Fig. 3 shows an example of the route construction process in a VCN with 7 wireless ports and N=4. Route construction algorithm is as follows:

Step 1: The source wireless port #1 = $\#k(0)$ sends the RREQ_s.

Step 2: The wireless port $\#k(n)$ receives the RREQ_r, computes the total transmit power, compares it with the two total transmit powers stored in its routing table. If it is smaller than the stored powers, the wireless port updates its routing table by storing the information of the received RREQ_r, and sends its own RREQ_r in the cell. Therefore after the route construction, each wireless port has in its table the two minimal total transmit powers reaching it from two different wireless ports.

Step 3: The central port chooses the RREQ_r with the minimum total transmit power, and sends the route notification message to its immediately previous port.

Step 4: The source wireless port receives the notification message.

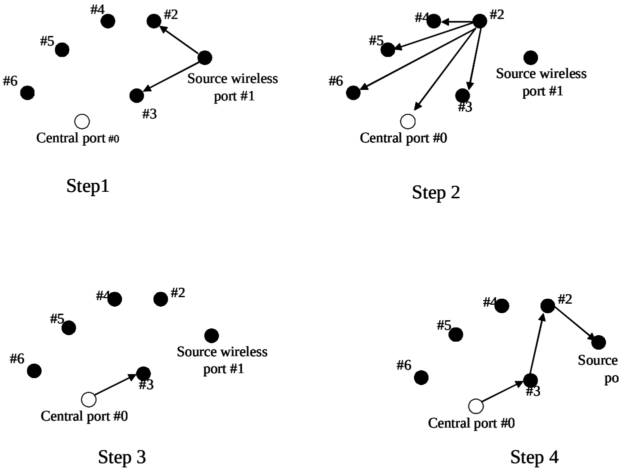

Fig. 3 Example of route construction message flow.

After the route is constructed, each port keeps to update its routing table in any case of link or port failure along the constructed route. Table 1 shows an example of the routing table of the port #4; port #4 stores the information of the two RREQ_r of the previous ports with the minimal total transmit power and the second minimal transmit power among all the wireless ports, then computes its minimum total transmit power.

Table 1 An example of routing table of port #4.

Source ID	Port sending RREQ ID	Previous port transmit power	Number of hops	Total transmit power
#1	#2	$P_t(2)$	2	$P(2)+P_t(2)$
	#1	$P_t(1)$	1	$P(1)+P_t(1)$
Port #4 total transmit power is $P(4)=P(2)+P_t(2)$ and its immediately previous port is port #2.				

B. Route reconstruction

If a wireless port along the route does not receive any signals from its previous port, it deletes its previous port information from its routing table; then selects a new previous port and sends a route reconstruction message to its new previous wireless port. The reconstruction message includes also the failed wireless port ID. The new previous port receives the route reconstruction message and checks its routing table. If its minimum transmit power previous port is not the failed port, then the new previous port sends the route reconstruction message to it. Else the new previous port sends it to its second minimum transmit power previous port; which will repeat the same procedure until the route reconstruction message reaches the source wireless port.

Using the above mentioned route reconstruction algorithm, the wireless ports don't need to proceed to the route reconstruction by broadcasting the RREQ. But the previous wireless ports need only to relay the new route reconstruction message until the source wireless port.

Fig. 4 shows an example of the route reconstruction process in a VCN with 7 wireless ports and N=4. Route reconstruction algorithm is as follows:

Step 1: A failure between ports #2 and #3 occurs in the constructed route.

Step 2: The wireless port #3 sends a new route reconstruction message to its other previous port #4 including the failed wireless port ID #2.

Step 3: Since the candidate port of previous port of port # 4 for the minimum transmit power route is the failed port #2. Port #4 relays the route reconstruction message to its other candidate port of previous port #1 for the second minimum transmit power route.

Step 4: The source wireless port receives the route reconstruction message and sends the route notification message to the central port.

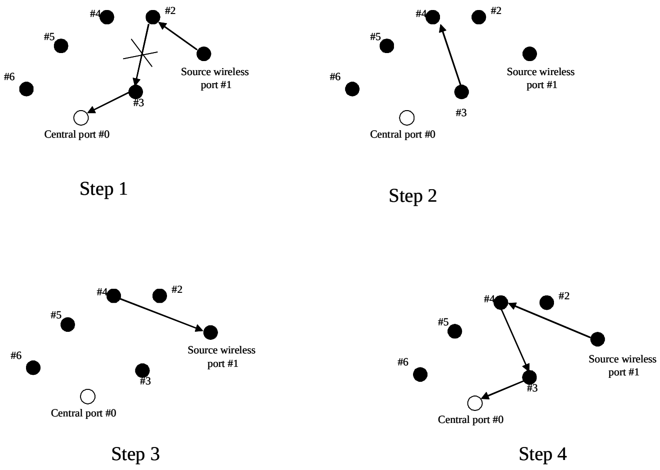

Fig. 4 Example of route reconstruction message flow.

Since the wireless ports only choose one new previous port between the two candidates of previous ports stored in their routing table to reconstruct rapidly the route, the reconstructed route after the failure may not be necessarily the minimum transmit power route. However, using this proposed route reconstruction algorithm, only a few messages from the wireless port that detects a failure to the source wireless port need to be sent for the route reconstruction.

To discuss more the decrease in the number of messages, we compare this proposed algorithm to the conventional algorithm which performs the same operation as the route construction.

For the conventional algorithm, first the wireless port that detects a failure sends the route error message to the source wireless port. Then the source wireless port sends the $\mathrm{RREQ_s}$ and the route construction operation restarts. Here since the route construction starts from the source wireless port until the central port and each wireless port sends its $\mathrm{RREQ_r}$, the number of messages using the route construction operation is in the order of the number K of wireless ports in a virtual cell multiplied by the number N of maximum allowable hops. The number N_{msg} of messages in the worst case is given by

$$N_{msg}=N+1+(K-2)\times(N-1)+N\ , \qquad (3)$$

where the first term is the number of route error notification messages to the source, the second term is the $\mathrm{RREQ_s}$ from the source wireless port, the 3rd term is the number of $\mathrm{RREQ_r}$ sent by the wireless ports during the route construction operation broadcast and the last term is the number of route notification messages.

However for the proposed algorithm, since the route reconstruction message is relayed along the route from the wireless port until the source wireless port, as the failure occurs closer to the source wireless port, the less becomes the number N_{msg} of messages. The worst case of reconstruction operation is when the central port detects the failure from its immediately previous port; in this case, the number of messages for the reconstruction operation is equal to N, but it is independent from K, i.e., $N_{msg}=N$. Fig. 5 shows the worst case number of hops for both the proposed and conventional reconstruction algorithms as a function of N for K=50. It is seen that the proposed algorithm reduces significantly the number of messages during the route reconstruction compared to the conventional algorithm.

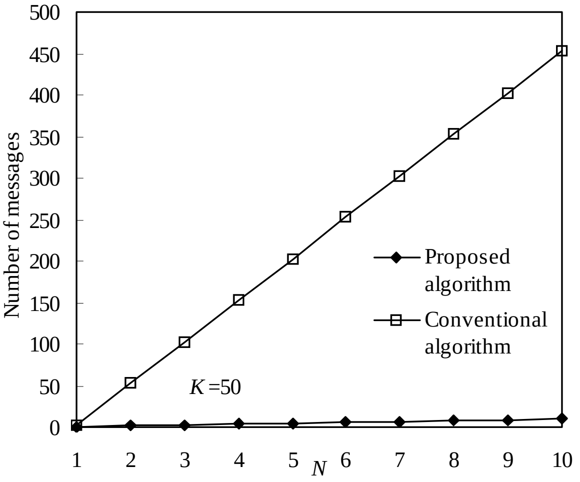

Fig. 5 Number of messages during the route reconstruction.

Since the reconstructed route after the failure is not necessarily the minimum total transmit power route, we compare the total transmit power rise after the failure for both the proposed algorithm and the conventional one.

3. Computer Simulation

Signal-to-noise power ratio (SNR)-based slow transmit power control is assumed. Wireless ports are randomly located in an entire virtual cell.

Fig. 6 shows an example of constructed and reconstructed routes, from a source wireless port to a central port, for K (the number of wireless ports)=50 and N=5. The distance-dependent path-loss exponent α of 3.5 and the log-normally distributed shadowing loss with standard deviation σ of 7dB are assumed. As expected only the ports near the link failure has changed.

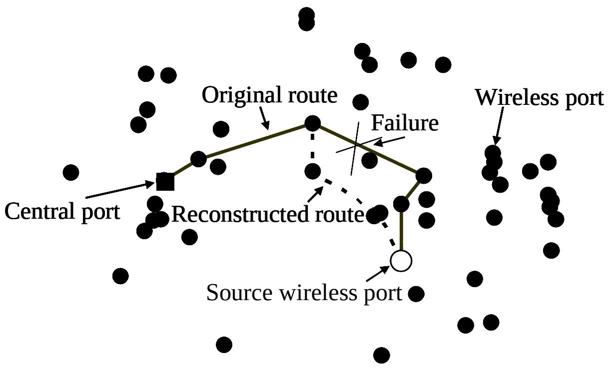

Fig. 6 Example of constructed and reconstructed routes in the case of a link failure.

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.

Fig. 7 plots the total transmit power along the route normalized by that of single-hop case as a function of N for α=3.5, and σ=7dB, for both of the proposed and the conventional algorithms. It is seen that although the reconstructed route after the failure may not be necessarily the minimum total transmit power route, the transmit power rise for the proposed algorithm is almost the same as that of the conventional one which provides the minimum total transmit power after the failure. Thereby the transmit power of the proposed algorithm is almost the same as the minimum transmit power of the failure.

Since the number K of wireless ports in each VC is an important design parameter, we evaluate the impact of K on the transmit power rise. Fig. 8 plots the total transmit power along the route normalized by that of single-hop case as a function of N with K as a parameter for α=3.5, and σ=7dB. It is clearly seen that the total transmit power increases after the failure for all the values of K. This is because the reconstructed route has a larger total transmit power than the original route, since the reconstructed route is not the minimum total transmit power route. It is also seen in Fig. 8 that the total transmit power rise becomes larger as K decreases. This is because as K decreases, the possibility of choosing smaller transmit power routes decreases; therefore, the transmit power difference between the original route and that of the reconstructed route increases.

To evaluate the increase in the relay time after the route reconstruction, we compute the cumulative distribution of the number of hops before and after a failure. Fig 9 plots the cumulative distributions of the number of hops before and after a link failure with N as a parameter for α=3.5, σ=7dB, and K=50. When N=5, the number of hops at the probability of 80% is almost the same for both the cases of before and after the failure. However, when N=10, at 80% probability, the number of hops only increases by one hop after the failure.

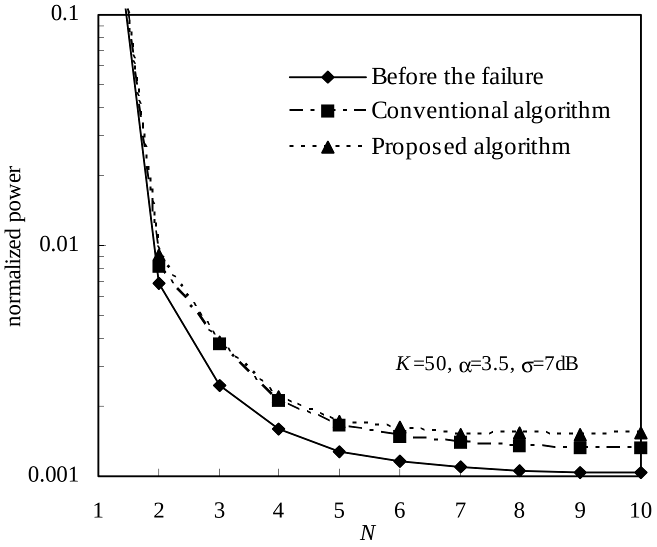

Fig.7 Transmit power efficiency for the proposed and the conventional algorithm.

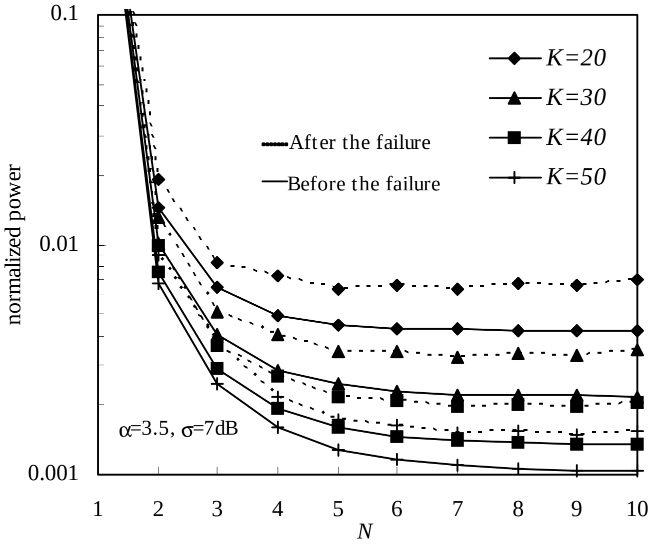

Fig.8 Impact of K in the transmit power.

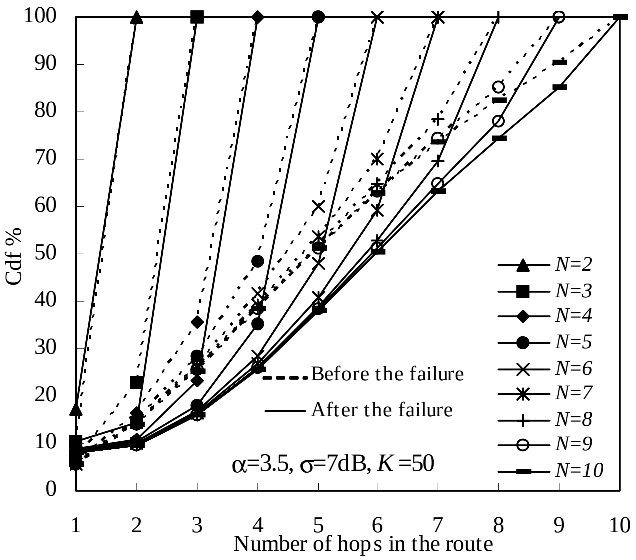

Fig. 9 Cdf of the number of hops in the route before and after a failure with *N* as a parameter.

4. Conclusions

In this paper, a table-driven route reconstruction algorithm was presented in the multi-hop VCN to combat the route failure. By using a routing table with the information of two candidates of previous ports for the minimum and the second minimum transmit power, a multi-hop route can be reconstructed after the failure. The number of messages during the route reconstruction operation using the proposed algorithm is significantly smaller than the number of messages using the conventional route construction algorithm. The total transmit power rise due to the failure depends on the number *K* of wireless ports in the virtual cell. However, the total transmit power rise is almost the same as that of the conventional one. It was shown that the number of hops increases by less than one hop for *N*=10 at the probability of 80%.

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