

DS-CDMA バーチャルセルラネットワークにおけるマルチホップ MRC ダイバーシチの送信電力効率

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あらまし 超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。本論文では、このマルチホップ通信にマルチホップ最大比合成 (MHMRC) ダイバーシチを適用したときの送信電力効率を計算機シミュレーションにより明らかにする。

キーワード バーチャルセルラネットワーク, マルチホップ MRC ダイバーシチ, 送信電力制御, 無線マルチホップ

Transmit Power Efficiency of Multi-Hop MRC Diversity for a DS-CDMA Virtual Cellular Network

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Abstract In virtual cellular network (VCN), proposed for high-speed packet mobile communications, the signal transmitted from a mobile terminal is received by wireless ports distributed in each virtual cell and relayed to the central port that acts as a gateway to the core network. In this paper, multi-hop maximal ratio combining (MHMRC) diversity is presented for the VCN to reduce the transmit power while achieving the required communication QoS. The transmit power efficiency is evaluated by computer simulation for a DS-CDMA VCN.

Keyword *Virtual cellular network, Multi-hop MRC diversity, transmit power control, wireless multi-hop.*

1. Introduction

The mobile communication systems services are shifting from voice conversation to data transmission 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) that can significantly reduce the transmit power was proposed [1]. In VCN, as shown in Fig 1 [2], each virtual cell (VC) has a central port, which is a gateway to the network, and many wireless ports distributed in VC. The 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 intermediate ports till 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 [7].

While relaying the data through the constructed multi-hop route, each wireless port receives not only from its immediately previous port along the route, but may also receive from multiple previous ports

that have transmitted the same signal to their next ports. The concurrent received signals transmitted from multiple previous ports can be combined to reduce the transmit power while achieving the required QoS [8]. In [8], multi-hop maximal ratio combining (MHMRC) is used without transmit power control (TPC) and a single frequency channel is considered. However, in order to accommodate many mobile terminals, multiple frequency channels may be necessary. In this letter, we apply the MHMRC for VCN in multiple frequency channels with TPC. Furthermore, the carrier frequencies used for the control channel for route construction and the data communication channel may be different. Since the fading correlation between the control and the data transmission channels may not be 1, the route which minimizes the total transmit power in the control channel may not minimize the total transmit power in the data transmission channel. In order to improve transmit power efficiency degradation caused by the carrier frequency difference between the control and the data communication channels, we propose the route modification algorithm.

This letter is organized as follows. Sect. 2 presents the MHMRC diversity concept, and the transmit power analysis for DS-CDMA VCN. In Sect. 3, the power efficiency of MHMRC is evaluated by computer simulation for various parameters i.e., path-loss exponent, shadowing, fading correlation and number of wireless ports. Sect. 4 gives some conclusions.

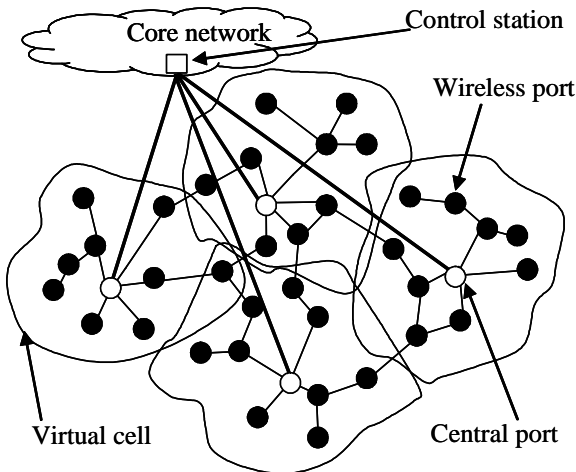


Fig.1 Virtual cellular concept.

2. Multi-Hop MRC

With multi-hop connection along the minimum transmit power route, the transmit power of each wireless port can be significantly reduced; however the introduction of multi-hop diversity may further reduce the transmit power. In multi-hop connection as illustrated in Fig. 2 (a), each wireless port relays the signal to its next port. But, the same signal may be received by multiple ports along the route.

Fig. 2 (b), explains the concept of MHMRC. A mobile terminal transmits its signal, which is received by port #1, but the same signal is received by ports #2, #3 and #4. Port #1 relays its received signal to port #2. Therefore, port #2 receives the same signal twice; first from port #0 and then from port #1. Therefore, port #2 can combine them before relaying the signal to port #3, which can combine the 3 received signals before relaying the signal to port #4. Port #4 can, thus, receive the same signal four times to combine. For diversity combining, well known MRC combining [9] can be used. Using MHMRC relay, the port transmit power can be reduced. Since the same signals transmitted from previous ports have been received before the signal from the immediately previous port is received, the delay time of multi-hop MHMRC is the same as that of the simple multi-hop relay.

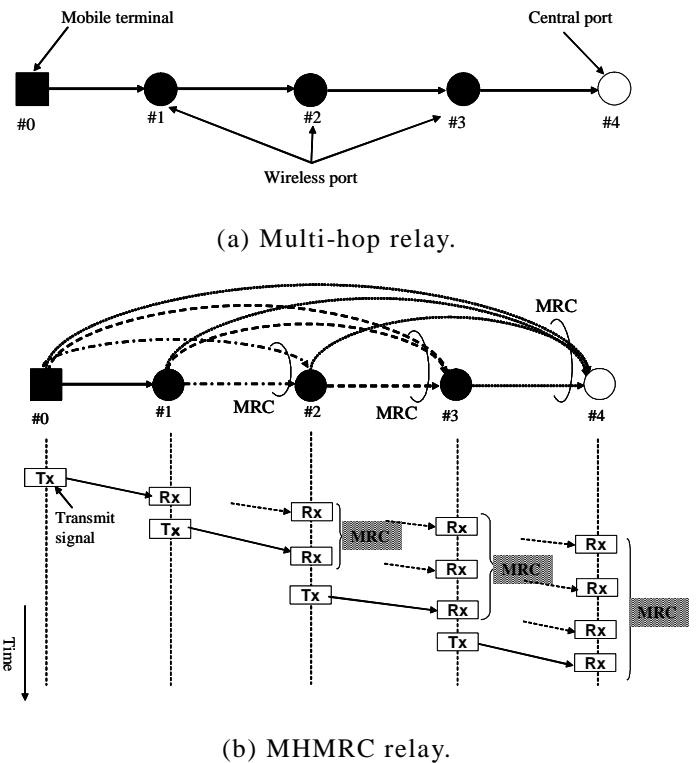


Fig.2 Multi-hop diversity relay.

In order to evaluate the transmit power reduction, the numerical expressions of transmit power is derived below. We assume the ideal transmit power control (TPC) based on the signal-to-noise power ratio (SNR) measurement and the ideal rake combining. We assume an L -path Rayleigh fading channel. For a multi-hop relay without diversity, the transmit power $P_i(i)$ from port # i is given by

$$P_i(i) = \frac{P_{req}}{d_{i,j}^{-\alpha} 10^{-\frac{\eta_{i,j}}{10} \sum_{l=0}^{L-1} |\xi_{i,j}(l)|^2}} \quad , (1)$$

where P_{req} is the required received signal power, α is the path-loss exponent and $d_{i,j}$, $\eta_{i,j}$ and $\xi_{i,j}$ are respectively the distance, the shadowing loss (in dB) and the l -th path complex path gain between wireless ports $\#i$ and $\#j$. Assuming the uniform power delay profile of the multi-path channel, $\{\xi_{i,j}\}$ are independent complex Gaussian variables with zero-mean and $E\left[|\xi_{i,j}|^2\right]=1/L$, where $E[*]$ denotes the ensemble average operation.

To determine the total transmit power along the MHMRC route, we consider an n -hop connection from the mobile terminal to the central port; port $\#i=0$ is the mobile terminal and port $\#i=n$ is the central port, whereas port $\#i=1\sim n-1$ the intermediate port. The received power $P_r(1)$ of from the mobile terminal $\#i=0$ is given by

$$P_r(1) = P_t(0) d_{0,1}^{-\alpha} 10^{-\frac{\eta_{0,1}}{10}} \sum_{l=0}^{L-1} |\xi_{0,1}(l)|^2 \quad .(2)$$

Therefore, the mobile terminal transmit power $P_t(0)$ is expressed as

$$P_t(0) = \frac{P_{req}}{d_{0,1}^{-\alpha} 10^{-\frac{\eta_{0,1}}{10}} \sum_{l=0}^{L-1} |\xi_{0,1}(l)|^2} \quad .(3)$$

For ports $\#i=2\sim n-1$, the received power $P_r(i)$ at port $\#i$ is the sum of all the received powers from all the previous ports and is given by

$$\begin{aligned} P_r(i) &= \sum_{j=0}^{i-1} P_t(j) d_{j,i}^{-\alpha} 10^{-\frac{\eta_{j,i}}{10}} \sum_{l=0}^{L-1} |\xi_{j,i}(l)|^2 \\ &= \sum_{j=0}^{i-2} P_t(j) d_{j,i}^{-\alpha} 10^{-\frac{\eta_{j,i}}{10}} \sum_{l=0}^{L-1} |\xi_{j,i}(l)|^2 \\ &\quad + P_t(i-1) d_{i-1,i}^{-\alpha} 10^{-\frac{\eta_{i-1,i}}{10}} \sum_{l=0}^{L-1} |\xi_{i-1,i}(l)|^2 \end{aligned} \quad .(4)$$

The total transmit power P_{Total} is given by the sum of the transmit powers along the route:

$$P_{Total} = \sum_{i=0}^{n-1} P_t(i) \quad .(5)$$

Since $P_r(i) = P_{req}$ with TPC, the transmit power $P_t(i-1)$ of the port $\#(i-1)$ is given by

$$P_t(i-1) = \frac{P_{req} - \sum_{j=0}^{i-2} P_t(j) d_{j,i}^{-\alpha} 10^{-\frac{\eta_{j,i}}{10}} \sum_{l=0}^{L-1} |\xi_{j,i}(l)|^2}{d_{i-1,i}^{-\alpha} 10^{-\frac{\eta_{i-1,i}}{10}} \sum_{l=0}^{L-1} |\xi_{i-1,i}(l)|^2} \quad .(6)$$

If the received power $P_r(i)$ at the port $\#i$ from the other previous ports, $\#1\sim\#(i-1)$, is larger than the required received power P_{req} , i.e., $P_r(i) \geq P_{req}$, the port $\#(i-1)$ can be removed from the constructed route, i.e., $P_t(i-1)=0$; the transmit power $P_t(i-2)$ of the port $\#(i-2)$ becomes

$$P_t(i-2) = \frac{P_{req} - \sum_{j=0}^{i-3} P_t(j) d_{j,i}^{-\alpha} 10^{-\frac{\eta_{j,i}}{10}} \sum_{l=0}^{L-1} |\xi_{j,i}(l)|^2}{d_{i-2,i}^{-\alpha} 10^{-\frac{\eta_{i-2,i}}{10}} \sum_{l=0}^{L-1} |\xi_{i-2,i}(l)|^2} \quad .(7)$$

Using this route modification algorithm, the number of hops decreases and consequently, the delay time also decreases.

3. Computer Simulation

Mobile terminals and wireless ports are randomly located in each VC. The total average transmit power along the route from a mobile terminal 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 . We evaluate the impact of the radio propagation parameters (path-loss exponent α , the shadowing standard deviation σ and also the fading correlation ρ between the control channel and data communication channel). The number K of wireless ports in each VC is also an important design parameter.

Fig. 3 plots the total transmit power along the route normalized by that of single-hop case as a function of N with ρ as a parameter for $\alpha=3.5$, $\sigma=7$ dB, $L=2$ and $K=50$. It is clearly seen that the MHMRC decreases the total transmit power for all ρ values. The power reduction by MHMRC is larger when ρ becomes smaller. For $\rho \geq 0.5$, the MHMRC diversity gain gets smaller, and becomes very small when $\rho=1$. This is because, when $\rho=1$, the route construction channel and the data communication channel experience the same fading, and hence the data communication route is also the minimum transmit power route. The fading correlation property between the control channel and the data communication channel may be given by [8]

$$\rho = \frac{1}{L} \frac{\sin\left(\frac{2\sqrt{3}\pi L}{\sqrt{L^2-1}} \Delta f \tau_{rms}\right)}{\sin\left(\frac{2\sqrt{3}\pi}{\sqrt{L^2-1}} \Delta f \tau_{rms}\right)} \exp\left(j2\sqrt{3}\pi \sqrt{\frac{L-1}{L+1}} \Delta f \tau_{rms}\right) \quad (8)$$

where Δf is the carrier frequency separation between the two channels and τ_{rms} is the rms delay spread of the fading channel. When $L=2$ and $\Delta f \cdot \tau_{rms} = 0.165$, the frequency separation is $\Delta f = 165\text{kHz}$ for $\rho=0.5$.

To evaluate the MHMRC power reduction, we computed the MHMRC diversity gain as a function of N . The diversity gain is defined as the ratio of the average total transmit powers with and without MHMRC diversity. Fig. 4 plots the MHMRC diversity gain (in dB) as a function of N with ρ as a parameter for $K=50$, $\alpha=3.5$, $\sigma=7\text{dB}$, and $L=2$. It is seen from this figure that as ρ decreases, the diversity gain increases; it is about 3.7dB when $\rho=0$.

Fig. 5 plots the MHMRC diversity gain as a function of N with α as a parameter for $K=50$, $\sigma=7\text{dB}$, $L=2$ and $\rho=0$. It is seen that as α decreases, the diversity gain increases. A reason for this is discussed below. Comparing Eq. (1) and Eq. (6), we can see that the MHMRC diversity gain depends on the second term of the numerator of Eq. (6), i.e.,

$\sum_{j=0}^{i-2} P_t(j) d_{j,i}^{-\alpha} 10^{-\frac{\eta_{j,i}}{10}} \sum_{l=0}^L |\xi_{j,i}(l)|^2$, which increases as α decreases, and consequently, the transmit power reduces, thereby increases the diversity gain as α decreases.

Fig. 6 plots the MHMRC diversity gain as a function of N with σ as a parameter for $K=50$, $\alpha=3.5$, $L=2$ and $\rho=0$. As σ increases, the diversity gain decreases. This can be explained by the fact that as σ increases the route selection diversity effect increases [7]; therefore, the port transmit power without MHMRC can be reduced; hence, the second term of the numerator of Eq. (6) decreases also, thereby decreases the diversity gain as σ increases.

Fig. 7 plots the MHMRC diversity gain as a function of N with K as a parameter for $\alpha=3.5$, $\sigma=7\text{dB}$, $L=2$ and $\rho=0$. As K increases the MHMRC gain decreases. This is because as K increases, the possibility of choosing smaller transmit powers route increases; therefore, the port transmit power without MHMRC diversity can be reduced; hence, the second term of the numerator of Eq. (6) decreases also, thereby the decreases diversity gain as K increases.

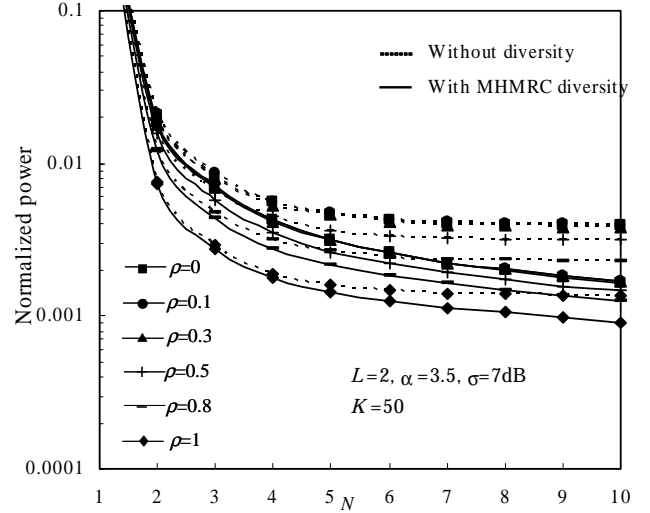


Fig. 3 Impact of ρ on the transmit power.

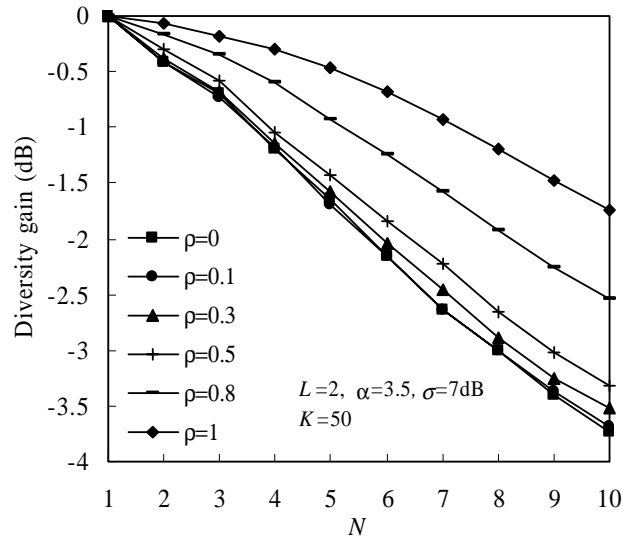


Fig. 4 Impact of ρ on the diversity gain.

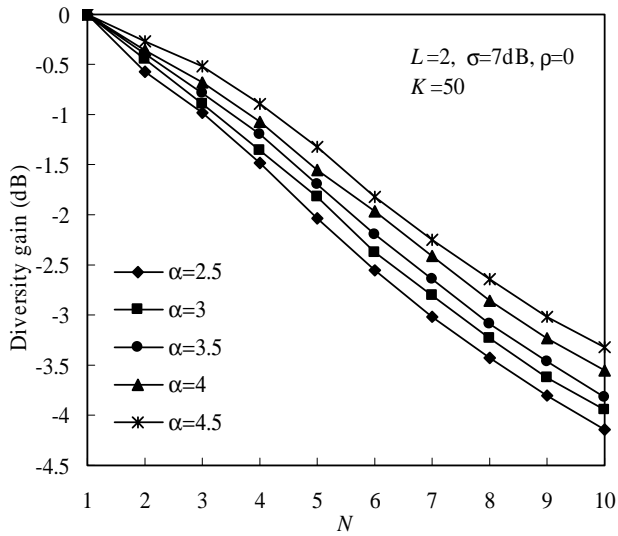


Fig. 5 Impact of α on the diversity gain.

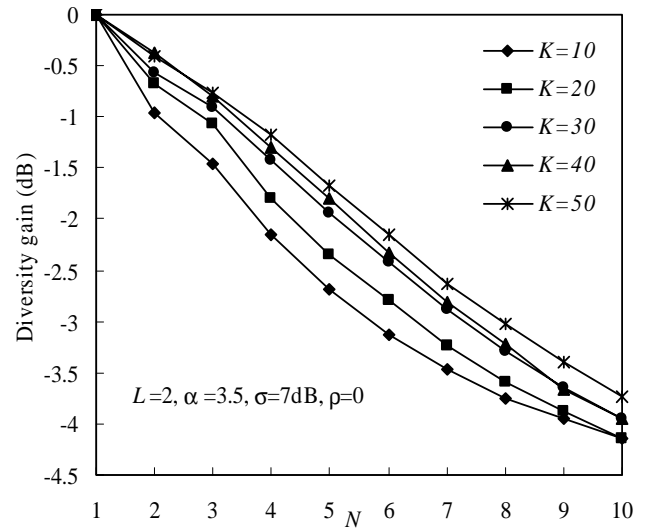


Fig. 7 Impact of K on the diversity gain.

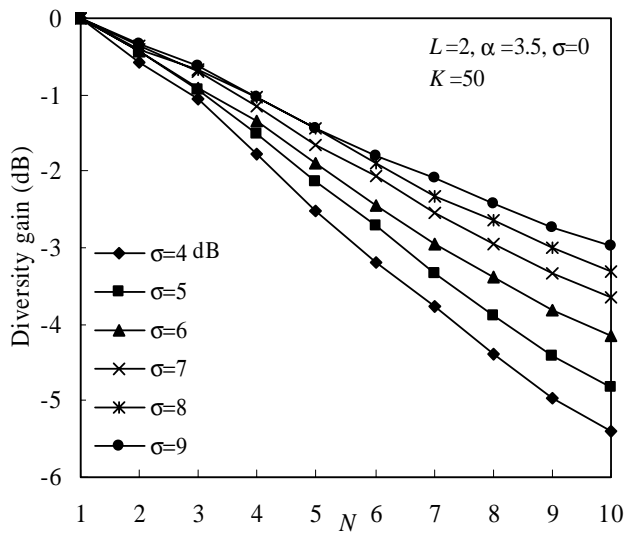


Fig. 6 Impact of σ on the diversity gain.

4. Conclusions

In this paper, MHMRC diversity was introduced to reduce the route total transmit power in the multi-hop VCN and a route modification algorithm was presented. The power reduction effect of MHMRC diversity was evaluated by computer simulation. The MHMRC diversity gain in the route total transmit power depends on the propagation conditions as the path loss exponent α , shadowing loss standard deviation σ and fading correlation ρ , as well as on the number K of wireless ports in each virtual cell. It was found that as α decreases, the diversity gain increases and that as σ and K increase, the MHMRC diversity gain decreases. Since the introduction of MHMRC diversity can remove some of wireless ports along the constructed route, the multi-hop delay time can be shortened as well as reducing the total transmit power along the route. The reduction in the number of wireless ports along a route will be evaluated in the future work.

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