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

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***Abstract*—In a multi-hop virtual cellular network (VCN) proposed for high data rate mobile communications, the signal transmitted from a mobile terminal is received by the multiple wireless ports distributed in a virtual cell and relayed to the central port that acts as a gateway to the core network. Multi-hop maximal ratio combining (MHMRC) can be used to reduce the total transmit power of the wireless ports along a route by combining the signals received from all the previous ports. However, the received signals from far previous ports may be very weak and not effective in diversity combining. In order to reduce the number of signals to be combined, we apply the hybrid selection/MRC (H-S/MRC) diversity technique. We evaluate by computer simulation the power efficiency of the multi-hop H-S/MRC and compare it with that of MHMRC.**

Keywords- Multi-hop diversity, Transmit power control, Wireless multi-hop.

I. INTRODUCTION

The mobile communication systems services are shifting from voice conversations to data communications through the internet. As the data transmission rate becomes higher, the peak transmit power increases. To decrease the peak transmit power, a multi-hop virtual cellular network (VCN) was recently proposed [1]. In the multi-hop 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 each 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.

Unlike the so-called wireless ad-hoc network [2]-[5], each stationary wireless port relays the signal to the next port. 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). Routing algorithm is an important technical issue. Various routing algorithms have been proposed for wireless multi-hop network or ad-hoc network [2]-[5]. They can be applied to the VCN. To increase the frequency efficiency of the VCN, a power-efficient routing algorithm that minimizes the total uplink transmit power while limiting the number of hops was introduced [6].

While relaying the data along a constructed multi-hop route, each wireless port along the constructed multi-hop route receives not only from its immediately previous port, but also may 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 diversity-combined [7]. By applying TPC with multi-hop maximal ratio combining (MHMRC) diversity, the transmit power can be decreased. However, the received signals from far previous ports may be very weak and not effective in diversity combining.

In this paper, in order to reduce the number of signals for diversity combining, we borrow the idea of the hybrid selection/MRC (H-S/MRC) diversity technique [8] and introduce the multi-hop H-S/MRC to the multi-hop VCN. For multi-hop route construction, a control channel is used and its carrier frequency may be different from those of data channels for data relaying. Since the fading correlation between the control channel and the data channels may not be 1, the multi-hop route which minimizes the total transmit power determined by using the control channel may not minimize the total transmit power of the data communications. In order to minimize the transmit power penalty due to the fading correlation, we apply the route modification algorithm [7].

The rest of the paper is organized as follows. Sect. II presents the multi-hop H-S/MRC diversity and the transmit power analysis. In Sect. III, the power efficiency of multi-hop H-S/MRC is evaluated by computer simulation. Sect. IV gives some conclusions.

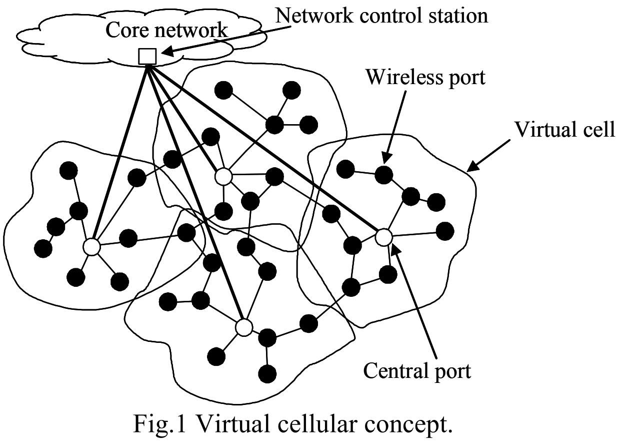

Fig.1 Virtual cellular concept.

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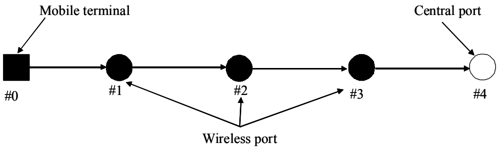
II. MULTI-HOP H- S/MRC DIVERSITY

With multi-hop relay 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 relay 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.

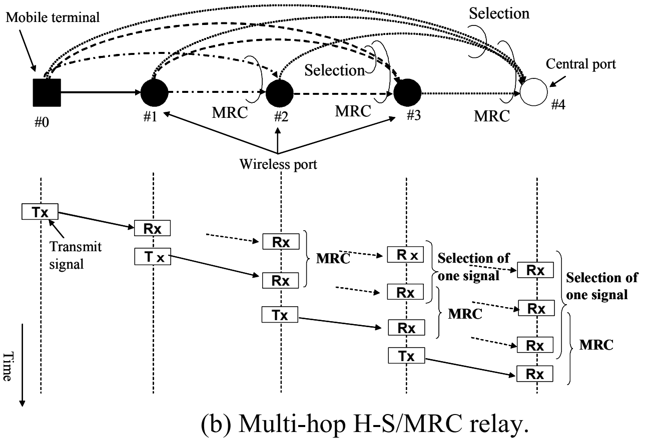
A. *Principle of multi-hop H-S/MRC diversity*

Fig. 2 (b) explains the concept of multi-hop H-S/MRC with *J* selected received signals. We assume that the received signal from the immediately previous port is always selected in multi-hop H-S/MRC. We consider an *N*-hop relay from the mobile terminal to the central port; port #*n*=0 is the mobile terminal and port #*n*=*N* is the central port, whereas ports #*n*=1~(*N*-1) are intermediate ports. Port #*n* receives not only the signal transmitted from the port #(*n*-1), but also the same signal from ports #0, #1,…, #(*n*-2). Therefore, the (*J*-1) strongest received signals are selected among the received signals from ports #0, #1,…, #(*n*-2), and are MRC-combined together with the one received from immediately previous port #(*n*-1).

MHMRC diversity is a special case of multi-hop H-S/MRC with *J* equal to the number of the previous ports. During the relaying process, a wireless port may also receive the signals transmitted from its next ports. However, those signals from the next ports will be received after having sent the signal and therefore, can not contribute to multi-hop diversity combining. The transmit power with multi-hop H-S/MRC is discussed below.



(a) Multi-hop relay.



(b) Multi-hop H-S/MRC relay.

Fig. 2 Multi-hop H-S/MRC diversity relay for *J*=2.

B. *Total transmit power*

We assume the ideal TPC based on the signal-to-noise power ratio (SNR) measurement and the ideal rake combining. We assume an *L*-path fading channel. The received signal power $P_r(1)$ of port #*n*=1 from the mobile terminal #*n*=0 is expressed as

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

where $P_t(0)$ is the mobile terminal transmit power, α is the path-loss exponent and $d_{n,m}$, $\eta_{n,m}$ and $\xi_{n,m}(l)$ are respectively the distance, the log-normally distributed shadowing loss (in dB) with the standard deviation of σ and the *l*-th path complex path gain between wireless ports #*n* and #*m*. Therefore, the mobile terminal transmit power $P_t(0)$ with ideal TPC is given by

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

where P_{req} is the required received signal power.

For ports #*n*=2~*N*, the received signal power $P_r(n)$ at port #*n* is the sum of the received powers from the selected previous wireless ports and is given by

$$P_r(n)=\sum_{j=0}^{J-1}P_t(s_j)d_{s_j,n}^{-\alpha}10^{-\frac{\eta_{s_j,n}}{10}}\sum_{l=0}^{L-1}\left|\xi_{s_j,n}(l)\right|^2\quad, \qquad (3)$$

where s_j is the selected wireless port index and $(s_0, s_1, \dots, s_{J-1}) \in (0,1,2,\dots, n-1)$. The received signal from the immediately previous wireless port is always selected, i.e., $s_{J-1}=n-1$. Since $P_r(n)=P_{req}$ with TPC and assuming that the port #*n* has received more than *J* signals, the transmit power $P_t(n-1)$ of the port #(*n*-1) is given by

$$P_t(n-1)=\frac{P_{req}-\sum_{j=0}^{J-2}P_t(s_j)d_{s_j,n}^{-\alpha}10^{-\frac{\eta_{s_j,n}}{10}}\sum_{l=0}^{L-1}\left|\xi_{s_j,n}(l)\right|^2}{d_{n-1,n}^{-\alpha}10^{-\frac{\eta_{n-1,n}}{10}}\sum_{l=0}^{L-1}\left|\xi_{n-1,n}(l)\right|^2}\ . \qquad (4)$$

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

$$P_{total}=\sum_{n=0}^{N-1}P_t(n)\quad . \qquad (5)$$

C. *Route modification algorithm*

If the sum of the received signal powers at the port #*n* from the ports $\#s_0 \sim \#s_{J-2}$, except from the immediately previous port #(*n*-1), is larger than the required received power, the immediately previous port #(*n*-1) can be removed from the constructed route; the port #*n* re-selects the (*J*-1) strongest received signals from the previous ports excluding the port #(*n*-1). This is called the route modification algorithm [7]. The transmit power $P_t(n-2)$ of the port #(*n*-2) is given by Eq. (4)

with replacing (n-1) by (n-2). This route modification algorithm decreases the number of hops and consequently, the relay time.

III. COMPUTER SIMULATION

Mobile terminals and wireless ports are randomly located in each VC. The average total 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_{max}. We discuss the impacts of the number J of selected received signals, the radio propagation parameters (path-loss exponent α, the shadowing standard deviation σ, the number L of propagation paths and also the fading correlation ρ between the control channel and data channels) and the number K of wireless ports per VC.

A. Normalized transmit power of multi-hop H-S/MRC

The normalized average transmit power P_{norm} is defined as the average total transmit power along the route with the multi-hop H-S/MRC diversity normalized by that of the single-hop case, i.e., $P_{norm}= E[P_{total}]/E[P_{single\text{-}hop}]$, where P_{total} and $P_{single\text{-}hop}$ are given by Eq. (5) and Eq. (2), respectively. P_{norm} becomes

$$P_{norm} = \frac{E[P_{total}]}{E[P_{single\text{-}hop}]} = \frac{E\left[\sum_{n=0}^{N-1}\left(\frac{1-\sum_{j=0}^{J-1}\frac{P_t(s_j)}{P_{req}}d_{s_j,n+1}^{-\alpha}10^{-\frac{\eta_{s_j,n+1}}{10}}\sum_{l=0}^{L-1}\left|\xi_{s_j,n+1}(l)\right|^2}{d_{n,n+1}^{-\alpha}10^{-\frac{\eta_{n,n+1}}{10}}\sum_{l=0}^{L-1}\left|\xi_{n,n+1}(l)\right|^2}\right)\right]}{E\left[\frac{1}{d_{0,N}^{-\alpha}10^{-\frac{\eta_{0,N}}{10}}\sum_{l=0}^{L-1}\left|\xi_{0,N}(l)\right|^2}\right]} \qquad .(6)$$

The transmit power $P_t(s_j)$ is given by Eq. (2) for port #s_j=0 and by Eq. (4) for ports #$s_j \in$ (1,2,…, n-1) with replacing #(n-1) by s_j. $P_t(s_j)$ is obtained recursively from Eq. (6). Since $P_t(0) \propto P_{req}$, it can be easily understood that $P_t(s_j)/P_{req}$ is not a function of P_{req}. As a consequence, P_{norm} does not depend on P_{req}.

Fig. 3 plots the normalized average transmit power as a function of the maximum number N_{max} of allowable hops with J as a parameter for α=3.5, σ=7dB, L=2, and K=50. J=1 is the case of no diversity. MHMRC diversity is a special case of multi-hop H-S/MRC with J=10. It is seen that as J increases, the total transmit power decreases, and J=10 (MHMRC) gives the minimum power. However, with J=5, the power increase from the case of MHMRC is only 20% for ρ=0 and 10% for ρ=1 when N_{max}=10. If 20% of the power increase is allowed, the number J of selected received signals for multi-hop H-S/MRC can be limited to 5.

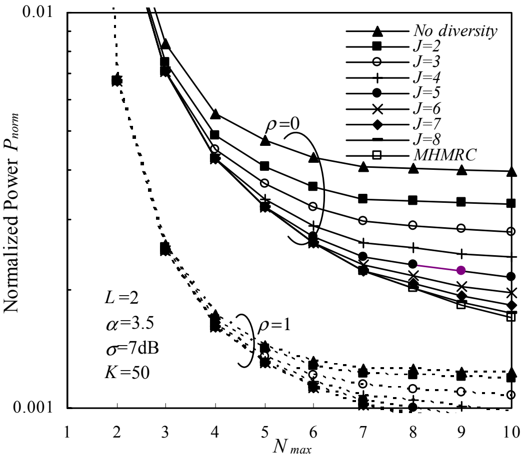


Fig.3 Effect of H-S/MRC on the normalized average transmit power along the route.

B. Impacts of various propagation parameters

Fig. 4 plots the normalized average transmit power as a function of N_{max} with ρ as a parameter. We assume J=5, K=50, α=3.5, σ=7dB, L=2 and ρ=0, otherwise stated. It is seen that the transmit power decreases as ρ increases for both MHMRC and multi-hop H-S/MRC. Multi-hop H-S/MRC requires slightly larger transmit power than MHMRC; this is because the number of signals to be combined is limited to J. The power penalty of multi-hop H-S/MRC is more significant for larger values of N_{max}. This is because, as N_{max} increases, the number of received signals that are not selected in H-S/MRC increases, and consequently, the sum of unselected received signal powers increases also; resulting in the increased transmit power penalty.

Figs. 5 and 6 plot the normalized average transmit power as a function of N_{max} with α and σ as a parameter, respectively. It is seen that the transmit power decreases as α and σ increase for both MHMRC and H-S/MRC. Fig. 7 plots the normalized transmit power as a function of N_{max} with L as a parameter. The transmit power almost does not depend on L. However, multi-hop H-S/MRC requires slightly larger transmit power than MHMRC. The power penalty of multi-hop H-S/MRC is insensitive to the values of α, σ and L, but it is more significant for larger values of N_{max}. The power penalty is around 20% for N_{max}=10.

C. Impact of K

Fig. 8 plots the normalized average transmit power as a function of N_{max} with K as a parameter. The transmit power decreases as K increases for both MHMRC and H-S/MRC. The power penalty of multi-hop H-S/MRC is insensitive to the values of K, but it is more significant for larger values of N_{max}. The power penalty is around 20% for N_{max}=10.

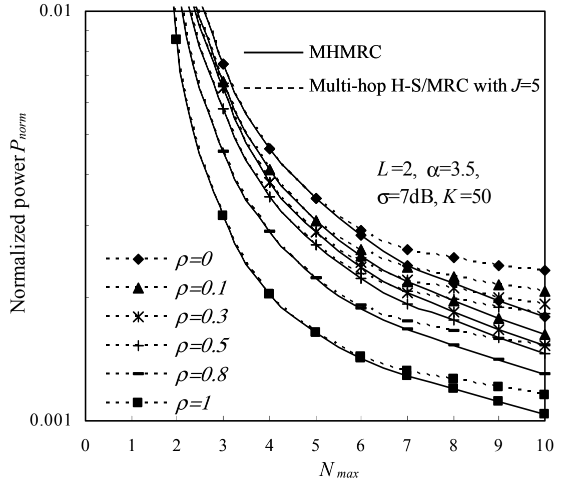


Fig.4 Impact of ρ .

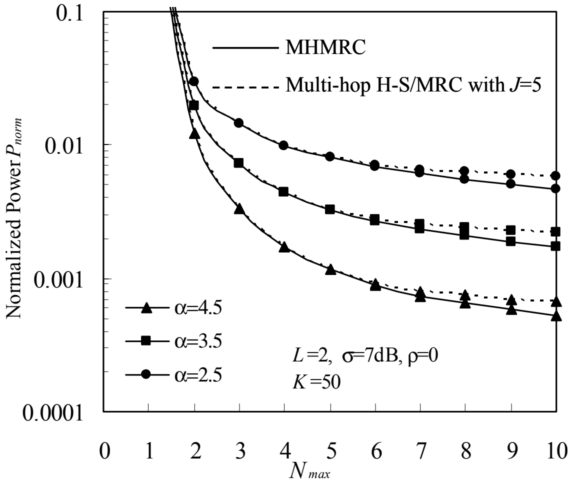


Fig. 5 Impact of α.

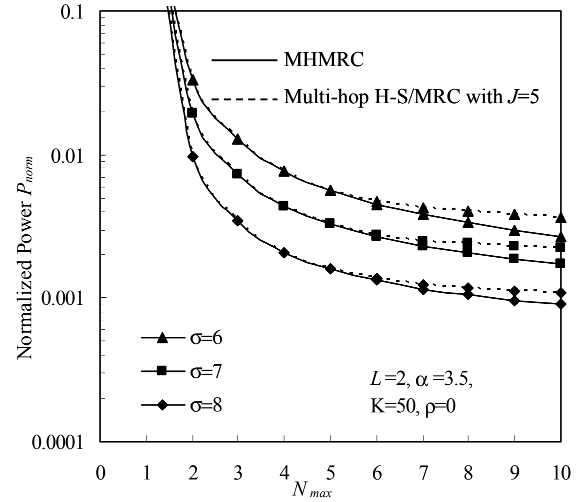


Fig. 6 Impact of σ.

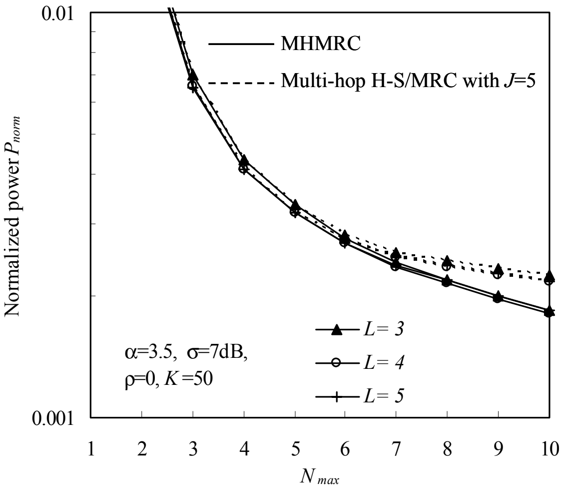


Fig. 7 Impact of L.

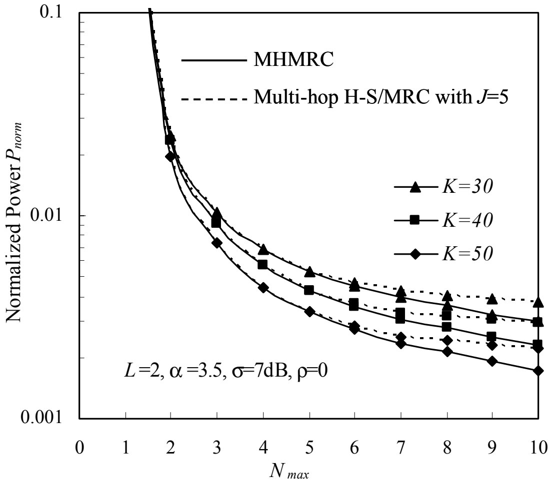


Fig. 8 Impact of K.

IV. CONCLUSIONS

The multi-hop MRC diversity can be used to reduce the total transmit power of wireless ports along a route in the multi-hop VCN; but the received signals from far previous ports in each wireless port along the route may be very weak and not effective in diversity combining. In this paper, the multi-hop H-S/MRC diversity was introduced to limit the number of signals to be combined. The power efficiency of multi-hop H-S/MRC was evaluated by computer simulation. The impact of the number J of selected received signals on the transmit power was discussed. It was shown that as J decreases, the transmit power increases, but the power penalty of multi-hop H-S/MRC compared to MHMRC is only 10% (20%) for ρ=1 (0) when J=5 and N_{max}=10. The transmit power penalty is more significant for larger values of N_{max}, however, it is insensitive to the values of α, σ, L and K.

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