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THROUGHPUT ANALYSIS OF ARQ IN MULTI-ROUTE PARALLEL TRANSMISSION IN OFDMA 2-HOP VIRTUAL CELLULAR NETWORK

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ABSTRACT

A 2-hop Virtual Cellular Network (VCN) is a promising network architecture for extending the coverage of a base station without increasing the transmit power in high speed data transmissions. In this paper an efficient method of multiple route construction and subcarrier allocation for parallel packet transmission in OFDMA 2-hop VCN, in order to increase the system throughput, is proposed. Moreover, to further improve the throughput performance, the uneven packet distribution protocol, in which more packets are sent through routes with better channel conditions, is proposed for ARQ in multi-route parallel transmission. The throughput performance of the proposed methods is evaluated by computer simulation. It is shown that the throughput performance of multi-route parallel transmission in 2-hop network greatly outperforms the performance of single-hop network for lower transmit power. It is also shown that the uneven packet transmission protocol further improves throughput performance at high transmission rate and low transmit power.

I. INTRODUCTION

There is an ongoing demand of high speed packet transmission that supports high data rate multimedia applications with varying Quality of Service (QoS) in the next generation mobile communication (4G) systems [1], [2]. However, with the conventional network architecture, for a very high transmission rate, prohibitively large transmit power is required for same range of communication. In order to keep the transmit power same as the current cellular system, the current network architecture should be changed. One example of a new network architecture is the multi-hop Virtual Cellular Network (VCN) [3], [4]. In the multi-hop VCN, a central port (CP) which is a gateway to the core network, communicates with a mobile terminal (MT) directly or indirectly via wireless ports (WPs) distributed inside the cell. A 2-hop VCN is the simplest case of the multi-hop VCN where the CP connects with MT directly or via one WP using 2 hops only. A link between a CP and an MT is called the direct-link, a link between a CP and a WP is called the WP-link and a link between a WP and an MT is called the user-link.

Orthogonal Frequency Division Multiple Access (OFDMA) in which the total bandwidth is divided into orthogonal subcarriers, is robust to frequency selective fading and provides flexibility for dynamic resource allocation [5]. In [6] it was shown that the channel capacity of OFDMA overcomes that of DS-CDMA in 2-hop VCN. Therefore, this paper focuses on parallel transmission in OFDMA 2-hop VCN. Parallel communication is a method of sending several data signals simultaneously over a communication link comprised of several channels in parallel at one time [7]. In OFDMA transmission, the orthogonal property makes the parallel transmission of plural streams of data possible. Instead of using all the orthogonal subcarriers, according to the rate of transmission required by an MT, only the subcarriers with high received signal-to-noise power ratio (SNR) can be allocated to the direct, WP and user-links.

Routing, channel allocation and packet transmission protocol are interesting research topics to realize the parallel transmission in OFDMA 2-hop VCN. In [6], subcarrier allocation is done to a single fixed route only. In this paper, a new routing and allocation scheme that further increases the system throughput by achieving greater route and frequency diversity gain has been studied. In this scheme, instead of allocating a channel to a single route fixed beforehand, routing and subcarrier allocation are done hand in hand to make multiple routes taking advantage of better channel conditions in multiple routes. Since there are more candidates of subcarriers to choose from in multiple routes than in single route, improvement in system throughput can be expected.

In multi-route parallel packet transmission, the qualities of channels in the multiple routes are different. Therefore, the probability of that the packet gets error in each route is different. When there are multiple routes, it is important to think how to distribute the packets among the routes efficiently to increase the system throughput. In this paper, we propose 2 kinds of packet distribution protocols. First an even distribution protocol, in which the packets to be sent are equally distributed in the multiple routes. This is the simplest method of packet distribution which does not consider channel quality of each multiple route. In this protocol the transmission delay occurred in transmitting the packets allocated to the route with bad channel condition increases and as a result the total transmission delay increases and the system throughput decreases. Next we propose an uneven distribution protocol, with a flow control that considers the channel quality of each multiple route. In this protocol more packets are sent through routes with better channel conditions in order to decrease the transmission delay and increase the system throughput.

The main objective of this paper is to do the throughput analysis of proposed multi-route channel allocation scheme and packet transmission protocols in the 2-hop transmission and make a comparison with the conventional single-hop transmission by computer simulation. The rest of the paper is organized as follows. Proposed routing and subcarrier allocation scheme is described in Sect. II. In Sect. III packet distribution protocol for ARQ is explained. In Sect. IV, throughputs of proposed multi-route allocation scheme and packet distribution protocols are evaluated by computer simulation. Sect. V concludes the paper.

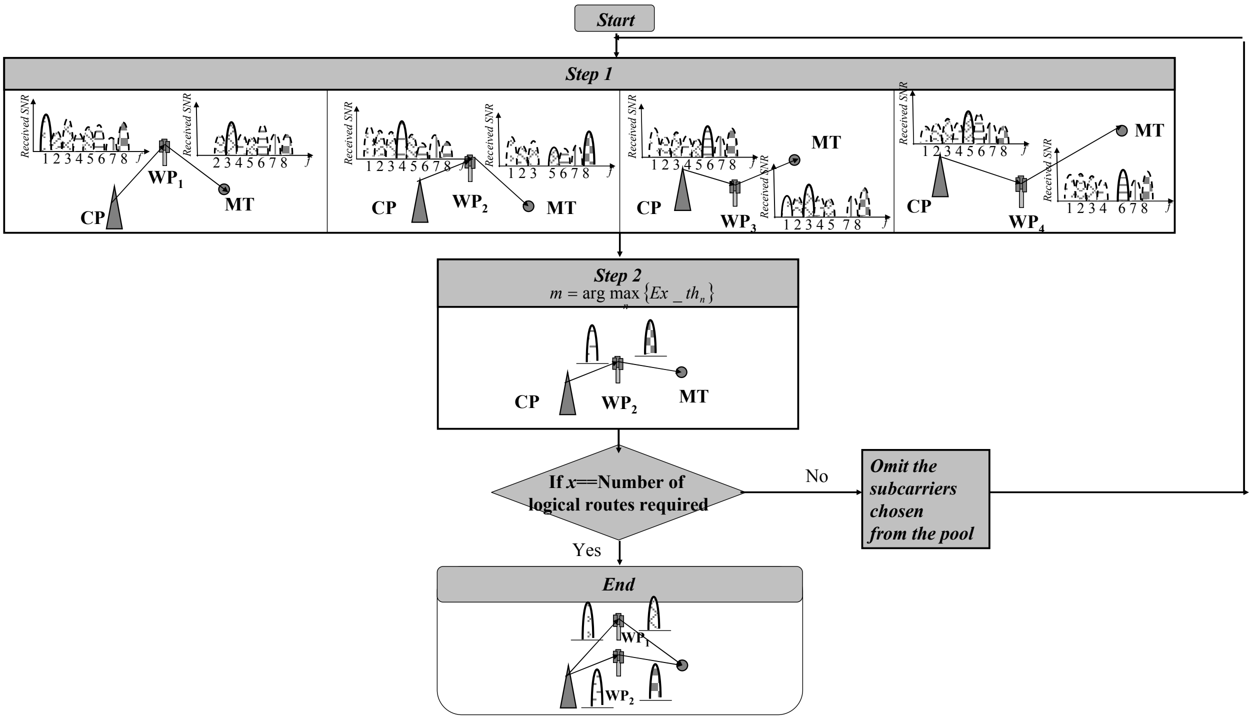

Figure 1: Selected multi-route (s.m.r) allocation.

II. MULTI-ROUTE SUBCARRIER ALLOCATION FOR PARALLEL TRANSMISSION

In this section, we introduce a new selected multi route allocation scheme for parallel transmission of packets in OFDMA 2-hop VCN that further increases the system throughput by achieving greater route and frequency diversity gain. In the selected multi route allocation, instead of allocating a channel to a single route fixed beforehand [6], routing and subcarrier allocation are done simultaneously to make multiple routes taking advantage of better channel conditions in multiple routes. Since there are more candidates of subcarriers to choose from in multiple routes than in single route, improvement in system throughput can be expected. Hereafter, the multiple routes constructed with the subcarriers allocated to the routes are called the logical routes. A logical route x is defined as a set of WP chosen WP_x, subcarrier allocated to the WP-link $C_{x,WP\text{-}link}$ and subcarrier allocated to the user-link $C_{x,user\text{-}link}$ given by

$\{x: WP_x, C_{x,WP\text{-}link}, C_{x,user\text{-}link}\}$

The s.m. r allocation is carried out in the following steps:

Step 1) For each WP n inside the cell, subcarrier with highest SNR $C_{n,WP\text{-}link}$ is chosen from the pool of N_c subcarriers for the WP-link, and subcarrier with highest SNR $C_{n,user\text{-}link}$ is chosen for the user link from the pool of N_c -1 subcarriers emitting the subcarrier that has been already chosen for the WP-link. Then the expected throughput Ex_th_n of nth WP is calculated, given by

$$Ex\_th_n = \{1-p(\gamma_{n,WP\text{-}link},N)\}\{1-p(\gamma_{n,user\text{-}link},N)\}, \quad (1)$$

where $p(\gamma_{n,WP\text{-}link},N)$is the packet error rate (PER) of the WP-link of nth WP, and $p(\gamma_{n,user\text{-}link},N)$ is the PER of the user-link of nth WP, $\gamma_{n,WP\text{-}link}$ is the received SNR of the WP-link of nth WP when a packet is sent through subcarrier $C_{n,WP\text{-}link}$, and $\gamma_{n,user\text{-}link}$ is the received SNR of the user-link of n^{th} WP when a packet is sent through subcarrier $C_{n,user\text{-}lin}$, N is the packet size. The expected throughput is defined as the throughput that can be expected when a packet is sent from CP to an MT via a WP using subcarriers that have been chosen as mentioned above.

Step 2) Expected throughputs of all the WPs are compared and the mth WP with the highest expected throughput is selected.

$$m = \arg\max_n \{Ex\_th_n\} \quad (2)$$

The subcarriers chosen for the WP-link and user-link of the mth WP are omitted from the pool of subcarriers and steps 1 and 2 are repeated until all the logical routes demanded by an MT are constructed.

Fig. 1 illustrates selected multi-route allocation when number of available subcarriers N_c =8 and number of logical routes required N_x =2.

III. PACKET DISTRIBUTION PROTOCOL FOR ARQ

When there are multiple parallel logical routes, it is important to think of a protocol to distribute the packets in those logical routes and retransmit them when error occurs in order to increase the system throughput. In this section two types of proposed packet distribution protocols for ARQ are explained. In both the protocols, downlink transmission is considered. In the single-hop transmission, a CP directly sends the packets to an MT. In 2-hop transmission at first a CP sends packets to a WP. Then the WP sends the correctly received packets to an MT in the next time slot. The buffer size of the WP is considered to be unlimited. The WP sends the packet with the lowest sequence number in the buffer whenever the subcarrier is free for transmission. Different packets are simultaneously sent through different logical routes allocated for the MT in parallel. Whenever error occurs, the transmitter selectively retransmits the packet to the receiver.

A. Even distribution Protocol

This is the simplest method of packet distribution. In this protocol, CP equally divides the packets to be sent and sends them through the parallel logical routes allocated for an MT. For example, if a transmitter has to send *No_pac* packets to an MT to which N_x parallel logical routes are allocated, *No_pac*/ N_x packets are sent through each logical route.

The Fig. 2 is the illustrative diagram that explains even distribution protocol in 2-hop transmission. In this figure parallel transmission through 2 logical routes is considered. The CP has to send 6 packets to the MT. The cross shows where the packet error occurs. When packet error occurs the receiver sends NACK to the transmitter. Then the transmitter selectively resends the error packet. Since the logical route 1 is constructed before logical route 2, the channel condition in logical route 1 is better than that in logical route 2. Therefore, more time slots are required to send the equal number of packets in logical route 2. From Fig. 2 we can see that in logical route 1, 6 time slots are required to send 3 packets whereas in logical route 2, 8 time slots are required. Since we are considering the parallel transmission 8 time slots are taken to send 6 packets.

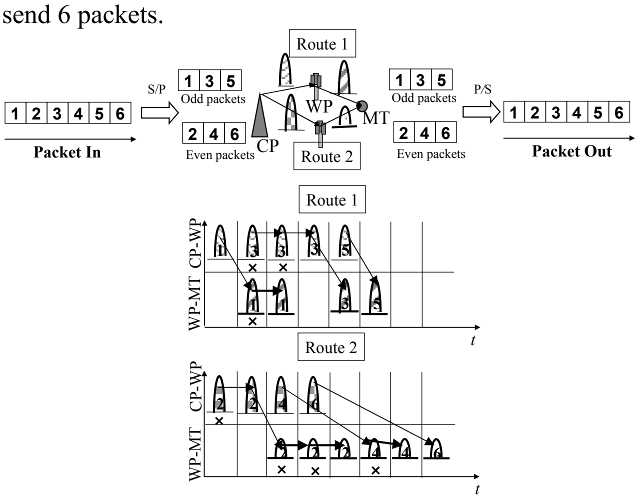

Figure 2: Even distribution protocol.

B. Uneven distribution Protocol

The channel condition of each logical route is different. In even distribution protocol the total packets are sent evenly though all the logical routes without considering the channel condition of each route. By doing this, the transmission delay in the route with bad channel condition increases and as a result the total transmission delay increases and the system throughput decreases.

Here, we introduce a packet distribution protocol with simplest method of flow control. In the flow control, we consider the difference in channel quality of each logical route. The logical routes are arranged in descending order according to their channel quality, and more packets are sent through routes with better channel conditions. By sending more packets through the logical route with better channel condition, throughput improvement can be expected by decreasing the transmission delay when packet error occurs.

In the single-hop transmission, the packet in queue to be sent is transmitted through the best available logical route. However, in the 2-hop transmission, by simply sending the packet in the queue through the best subcarrier in the WP-link, the throughput performance cannot be expected to be improved if the subcarrier available in the user-link is not good. When the subcarrier in the user-link is not good, the packets get accumulated in the WP's buffer, but fail to reach the MT. Therefore in the case of 2-hop transmission, the channel conditions in both WP-link and user-link of a logical route should be considered. We propose to send the packets through each logical route proportional to the expected throughput of that logical route. The number of packets n_x sent through logical route x is given by

$$n_x = \left\lfloor \left(\frac{\{1-p(\gamma_{x,WP-link},N)\}\{1-p(\gamma_{x,mobile-link},N)\}}{\sum_{x=2}^{N_x}\{1-p(\gamma_{x,WP-link},N)\}\{1-p(\gamma_{x,mobile-link},N)\}} \times No\_pac \right) + 0.5 \right\rfloor , \quad (3)$$

$$n_1 = No\_pac - \sum_{2}^{N_x} n_x , \quad (4)$$

where $\lfloor x \rfloor$ denotes the largest integer smaller than or equal to x, $\{1\text{-}p(\gamma_{x,WP-link},N)\}\{1\text{-}p(\gamma_{x,user-link},N)\}$ is the expected throughput of the logical route x, $p(\gamma_{x,WP-link},N)$ is the PER of the WP-link of the logical route x, $p(\gamma_{x,user-link},N)$ is the PER of the user-link of the logical route x, $\gamma_{x,WP-link}$ and $\gamma_{x,user-link}$ are the received SNRs at the WP-link and user-link when the packet is sent through the channels allocated for route x, N_x is the total number of logical routes, N is the packet size, and *No_pac* is the total number of packets to be sent. The CP checks the number of packets to be transmitted to each logical route.

The Figure 3 is the illustrative diagram that explains uneven distribution protocol in the 2-hop transmission. CP sends 4 packets through logical route 1 with better channel conditions and 2 packets through logical route 2, unlike in even distribution protocol in which 3 packets are sent through each route. By efficiently utilizing channel in logical route 1, we can see that 6 packets can be sent in 7 time slots unlike 8 times slots taken in even distribution protocol.

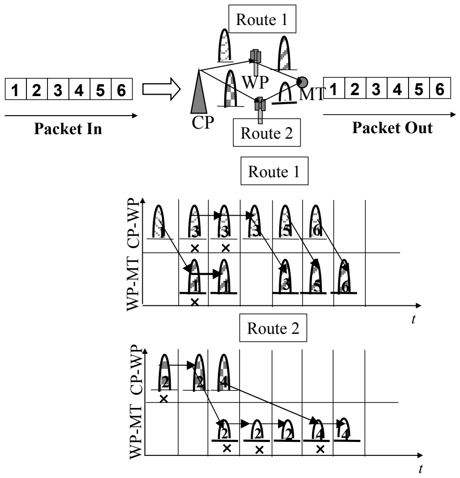

Figure 3: Uneven distribution protocol.

IV. COMPUTER SIMULATION

Monte-Carlo simulation was conducted to evaluate the throughput in a single user environment to compare the multi-route 2-hop transmission and the single-hop transmission. Moreover, the throughput performances of the even and uneven distribution protocols are also compared. The propagation channel is modeled as the product of distance dependent path loss, log-normally distributed shadowing loss and 16-path multi-path fading with uniform delay profiles. The received SNR in the WP-link or the user-link of logical route x $\gamma_{x,WP/user-link}$ is given by

$$\gamma_{x,WP/user-link} = \frac{P_t}{P_0}\left(\frac{r_{CP-n/n-MT}}{r_0}\right)^{-\alpha} 10^{-\frac{\eta_{CP-n/n-MT}}{10}} \cdot \left|H_{CP-n/n-MT}(C_{x,WP-link/user-link})\right|^2, \quad (5)$$

where P_t is the transmit power, r_{CP-n} is the distance between CP and WP chosen for that logical route x, r_{n-MT} is the distance between WP chosen for that logical route x and MT, α is the path loss exponent, η_{CP-n} is the shadowing loss parameter for the WP-link, η_{n-MT} is the shadowing loss parameter for the user-link, $H_{CP-n}(C_{x,WP-link})$ is the fading loss of WP-link using subcarrier $C_{x,WP-link}$ chosen for the WP-link of logical route x and $H_{n-MT}(C_{x,user-link})$ is the fading loss of user-link using subcarrier $C_{x,user-link}$ chosen for the user-link of logical route x.

The transmit power is normalized such that the received SNR at the cell edge is 0 dB.

$$P_0 = N_p / r_0^{-\alpha}, \quad (8)$$

where N_p is the noise power per transmitter per subcarrier, and r_0 is the cell radius.

The throughput is defined as the sum of the total number of correct packets received by an MT through all the parallel routes divided by the total time taken. The total time is the longest time taken in the worst logical route to complete the packet transmission allocated to that logical route. We assumed that ACK/NACK duration and transmission delay are negligibly shorter than the data packet duration. A circular cell of normalized radius r_0 with CP in its center is considered. An MT is generated at the cell edge (r_0,0) and 4 WPs are generated in between CP and MT at (r_0/2,0). It is assumed that the fading doesn't change in *No_pac* packets transmission. Then routing and subcarrier allocation is done as mentioned in Section II. Finally, packets transmitted from to the CP to the MT through the allocated subcarriers as mentioned in Section III.

The packet error model is described below:

The packet error rate of a packet $p(\gamma_{x,WP/user-link}, N)$ is given by

$$p(\gamma_{x,WP/user-link}, N) = 1 - \left(1 - p_b(\gamma_{x,WP/user-link})\right)^N, \quad (6)$$

where N is the total number of bits in a packet, $p_b(\gamma_{x,WP/user-link})$ is the bit error rate for QPSK modulation given by[8],

$$p_b(\gamma_{x,WP/user-link}) = \frac{1}{2} erfc\sqrt{\gamma_{x,WP/user-link}}, \quad (7)$$

where $\gamma_{x,WP/user-link}$ is the received SNR in the WP-link or the user-link of logical route x. When packet error occurs, the receiver uses selective repeat ARQ protocol and asks the transmitter to resend the error packet.

In computer simulation the maximum number of times that a transmitter can resend the packet to the receiver *Max_trans* is limited. If the receiver cannot correctly receive the packet even after retransmitting *Max_trans* times, it is considered that the packet is lost.

The simulation condition is summarized in Table 1.The total transmit power per subcarrier per transmitter is considered to be constant.

Table 1: Simulation Condition

Normalized transmit power per subcarrier per transmitter P_t/P_0	-6,-3,0,4,7 ,10,20,30,40(dB)
Path loss exponent (α)	3.5
Standard deviation of shadowing loss (σ)	7
Total number of subcarriers (N_c)	32
No. of subcarriers used to construct logical routes (N_{cx})	4,10,20
Packet size in bit (N)	512
Modulation	QPSK
No of packet transmitted (*No_pac*)	500
Maximum number of packet re-transmission (Max_trans)	4

A. Impact of number of subcarriers N_{cx} per user for the parallel transmission

Fig. 4 shows the impact of the number of subcarriers used per user for the parallel transmission on system throughput. When N_{Cx} subcarriers are used per user for the parallel transmission, in single-hop transmission N_{Cx} parallel transmissions are possible. However in 2-hop transmission only N_{Cx}/2 logical routes for the parallel transmissions are possible. As the transmission rate required by an MT increases, the number of subcarriers used to construct the logical routes for parallel transmission of packets increases as well. In the figure below the x-axis shows the number of subcarriers used which is proportional to the rate of transmission and y-axis shows the throughput. We can see that the throughput of 2-hop transmission greatly outperforms that of single-hop transmission at higher transmission rate. We can also see that the throughput performance the uneven distribution protocol, in which more packets are sent through routes with better channel conditions, outperforms the throughput performance of even distribution protocol at higher transmission rate when the number of subcarriers used for parallel transmission increases. In uneven distribution protocol, by sending more packets in routes with better channel conditions, the transmission delay when packet error occurs in routes with worse channel condition be reduced and this increases the throughput.

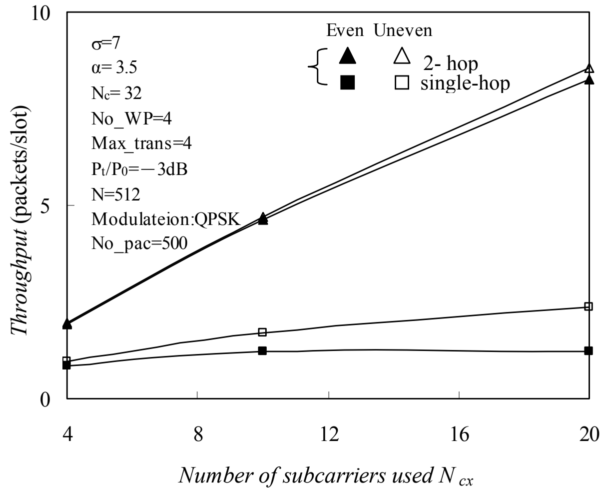

Figure 4: Impact of number of subcarriers N_{cx} per user.

B. *Impact of transmit power*

Fig. 5 shows the impact of normalized transmit power on system throughput. Focusing on the left hand side of the graph we can see that at low transmit powers the throughput of 2-hop transmission greatly outperforms that of single-hop transmission. We can also see that the throughput performance of the uneven distribution protocol, in which more packets are sent through routes with better channel conditions, outperforms the throughput performance of even distribution protocol. However when the power sufficiently increases the throughput performance of single-hop overcomes the performance of 2-hop transmission. This is because in 2-hop transmission N_{cx} parallel transmissions are possible when N_{cx} subcarriers are available, however in 2-hop transmission only $N_{cx}/2$ parallel transmissions are possible to send the same number of packets. However, in the real system there is a limitation to increasing the transmit power. Also when the power is sufficiently high, the channel conditions in all the multiple routes are good. Therefore, the packets are sent evenly in uneven distribution protocol as well. Therefore, the throughput performance of uneven distribution protocol is similar to that of even distribution protocol at sufficiently high transmit powers.

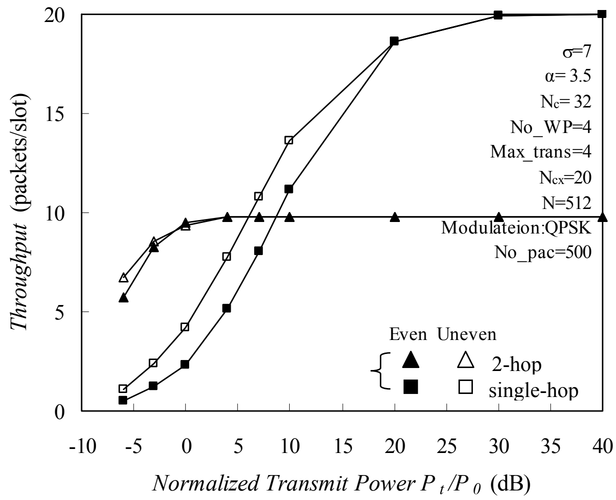

Figure 5: Impact of normalized transmit power.

IV. Conclusion

It is shown that the throughput performance of the parallel transmission in multi-route OFDMA 2-hop VCN greatly outperforms the performance of single-hop network when the transmit power is low and transmission rate is high. Moreover, even by introducing simple flow control throughput performance can be improved. Especially at high transmission rate that requires higher number of parallel transmission through multiple routes with different channel condition, uneven distribution protocol increases the throughput performance than the even distribution protocol using lower transmit power.

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