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マルチルート並列中継伝送 2-ホップ OFDMA バーチャルセルラネットワークにおける ARQ 法のスループット解析

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あらまし 送信電力の増加を抑制しながら，基地局のカバーエリアを拡大する方法としてマルチホップネットワークが注目されている．筆者らは，超高速無線通信を実現するために，マルチホップバーチャルセルラネットワーク(マルチホップ VCN)を提案している．本論文では，周波数ダイバーシチ効果のみならずルートダイバーシチ効果が見込まれる，経路とサブキャリアの同時割当を行うマルチルート並列中継伝送 2-ホップ OFDMA バーチャルセルラ・ネットワークを提案する．さらに，シングルホップの場合，経路構築後にサブキャリア割当を行う場合と比較し，良好なスループット特性が得られることを計算機シミュレーションにより示す．さらに，複数の経路に対して期待されるスループットに比例して送信パケット数を配分する方法を提案し，等分に配分する場合とスループット特性を比較する．

キーワード バーチャルセルラネットワーク，2 ホップネットワーク，スループット、*OFDMA, ARQ*，並列中継伝送.

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 routing with subcarrier allocation for multi-route parallel packet transmission in OFDMA 2-hop VCN, in order to increase the expected throughput, has been studied. Moreover, throughput performance of uneven packet transmission protocol in which more packets are sent through routes with better channel conditions is evaluated by computer simulation. It is shown that better throughput performance can be achieved in the multi-route parallel packet transmission than in the conventional single-route parallel packet transmission and that uneven packet transmission protocol further improves throughput performance at higher transmission rates.

Keywords: *virtual cellular network, 2-hop network, throughput, OFDMA, ARQ, parallel transmission..*

1. Introduction

There is an increasing demand of high speed packet data services in the next generation mobile communication system. 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) [1], [2]. 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.

Routing, channel allocation and packet transmission protocol are interesting research topics to realize the 2-hop VCN. In [3], a routing based on total transmit power required and adaptive subcarrier allocation has been studied. In [3], 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 route and frequency diversity gain to greater extent has been studied. In the new 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.

When there are multiple routes, it is also important to think of a protocol to distribute the packets in those multiple routes and retransmit them when error occurs. In this paper, we propose 2 kinds of distribution protocols: an even distribution protocol, in which the packets to be sent are equally distributed in the multiple routes and an uneven distribution protocol, in which more packets are sent through routes with better channel conditions in order to decrease the transmission delay and therefore 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 and single route allocation by computer simulation. In this paper Orthogonal Frequency Division Multiple Access (OFDMA), in which the total channel is divided into orthogonal subcarriers robust to frequency selective fading is considered. 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) are allocated to the direct, WP and user-links.

The rest of the paper is organized as follows. Routing and subcarrier allocation schemes are described in Sect. 2. In Sect. 3 packet transmission protocol is explained. In Sect. 4, throughputs of proposed multi-route allocation scheme and packet transmission protocols are evaluated by computer simulation. Finally the paper is concluded in Sect. 5.

2. Routing and Subcarrier allocation

In this section route construction and channel allocation for the parallel transmission of the packets is explained.

In the single-hop transmission, according to the rate of transmission required by an MT, *Nx* best subcarriers are allocated to the direct link from the pool of *Nc* subcarriers. Best subcarriers are the ones with the highest received SNR. The received SNR γ_k of a k^{th} subcarrier is given by[4][5]

$$\gamma_k = \frac{P_t r_{CP-MT}^{-\alpha} 10^{-\frac{\eta_{CP-MT}}{10}} \left|H_{CP-MT}(k)\right|^2}{N} \qquad (1)$$

where N is the noise power, P_t is the transmit power, $r_{CP\text{-}MT}$ is the normalized distance between a CP and an MT, α is the path loss exponent, $\eta_{CP\text{-}MT}$ is the shadowing loss between a CP and an MT, $H_{CP\text{-}MT}(k)$ is the complex fading gain of the k^{th} subcarrier between a CP and an MT. Fig. 2 shows an example of subcarrier allocation when Nc=8 and Nx=2. Subcarriers 1 and 3 with highest and second highest received SNR are chosen.

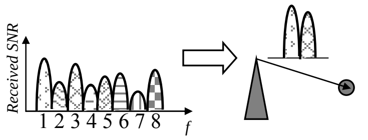


Fig. 1: Subcarrier allocation in single-hop transmission

Hereafter in the single-hop transmission, we will be calling the subcarriers allocated to an MT as the parallel logical routes constructed. In the case of 2-hop transmission, a set of subcarriers allocated to the WP-link and the user-link will be considered as one logical route and the total set will be considered as the parallel logical routes.

In 2-hop transmission route construction and channel allocation are done by two methods explained below:

Selected single route (s.s.r) allocation

In selected single route transmission, as explained in [3] at first a CP chooses a WP#*m* that requires the least amount of transmit power to send a packet to an MT:

$$m = \arg\min_n \left\{ \frac{P_{\text{target}}}{r_{CP-n}^{-\alpha} 10^{-\frac{\eta_{CP-n}}{10}} \sum_{k=0}^{N_c-1} \left|H_{CP-n}(k)\right|^2} + \frac{P_{\text{target}}}{r_{n-MT}^{-\alpha} 10^{-\frac{\eta_{n-MT}}{10}} \sum_{k=0}^{N_c-1} \left|H_{n-MT}(k)\right|^2} \right\} \qquad (2)$$

where n in the index of WP, P_{target} is the required received power, $r_{CP\text{-}n}$ is the normalized distance between a CP and n^{th} WP, $r_{n\text{-}MT}$ is the normalized distance between n^{th} WP and an MT, α is the path loss exponent, $\eta_{CP\text{-}n}$ is the shadowing loss between a CP and n^{th} WP, $\eta_{n\text{-}MT}$ is the shadowing loss between n^{th} WP and an MT, $H_{CP\text{-}n}(k)$ is the complex fading gain between a CP and n^{th} WP, and $H_{n\text{-}MT}(k)$ is the complex fading gain between n^{th} WP and an MT.

After the route is selected, subcarriers are allocated to WP-link and user-link subsequently. If *Nx* is the number of logical routes required by an MT, at first the subcarrier with highest SNR is chosen out of *Nc* subcarriers for the WP-link. Next the subcarrier with highest SNR is chosen out of *Nc*-1 subcarriers for the user-link. The same procedure is repeated until *Nx* logical routes are allocated in each link. Since the packets are transmitted in WP-link and user-link simultaneously, same subcarrier cannot be chosen in WP-link and user-link to avoid strong interference.

Fig. 3 illustrates routing and subcarrier allocation in selected single route transmission when *Nc*=8 and *Nx*=2. First subcarrier#1 is chosen for the WP-link from 8 subcarriers and then subcarrier#8 is chosen from pool of 7 subcarriers that does not include subcarrier#1. Next subcarriers 1 and 8 are omitted from the pool of subcarriers and similar procedure is repeated to form second logical route. Subcarrier#1 and #8 make the first logical route and subcarrier#3 and #6 make the second logical route.

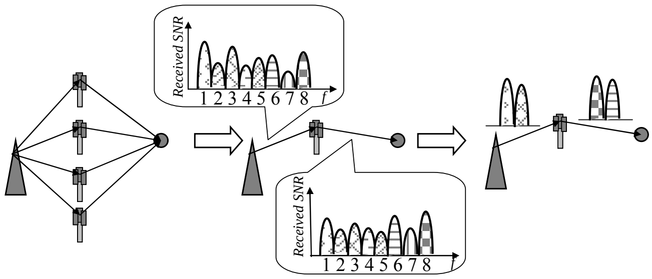


Fig. 2: Subcarrier allocation in selected single route

Proposed allocation scheme: Selected Multi-route (s.m.r) allocation

In selected multi-route transmission instead of doing the routing in advance, multiple route selection and channel allocation are done hand in hand in order to achieve better frequency and route diversity gain in the following steps:.

1) For each WP, subcarrier for the WP-link with highest SNR is chosen from the pool of Nc subcarrier, and subcarrier for the user-link with highest SNR is chosen from the pool of Nc-1 subcarrier. Then the expected throughput Ex_th_n of the n^{th} WP is calculated given by

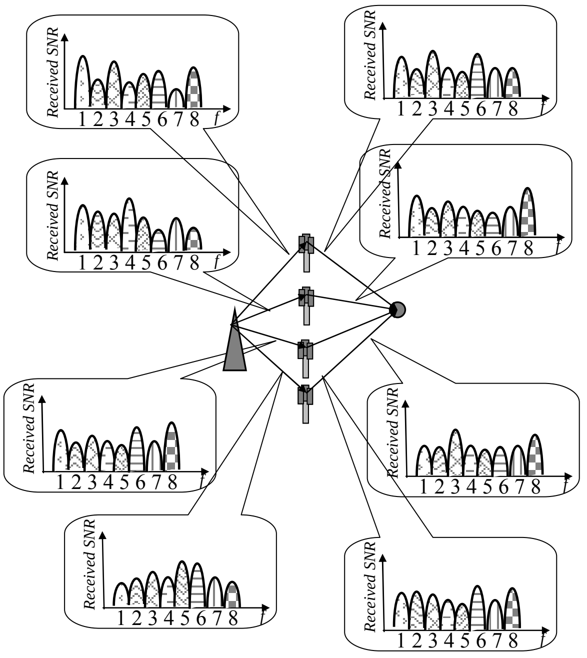
   $$Ex\_th_n=\{1-p(\gamma_{n,WP\text{-}link},N)\}\{1-p(\gamma_{n,user\text{-}link},N)\}, \quad (3)$$

   where $p(\gamma_{n,WP\text{-}link},N)$is the packet error rate of the WP-link of WP n, and $p(\gamma_{n,user\text{-}link},N)$ is the packet error rate of the user-link of WP n.

2) Next expected throughputs of all the WPs are compared and the WP#m with the highest expected throughput is selected.

   $$m=\arg\max_{n}\{Ex\_th_n\} \quad . \quad (4)$$

   The subcarriers chosen for the WP-link and user-link of the WP#m are omitted from the pool of subcarriers and the same procedure is repeated until all the logical routes demanded by an MT are constructed. Fig. 4 illustrates selected multi-route allocation when Nc=8 and Nx=2.



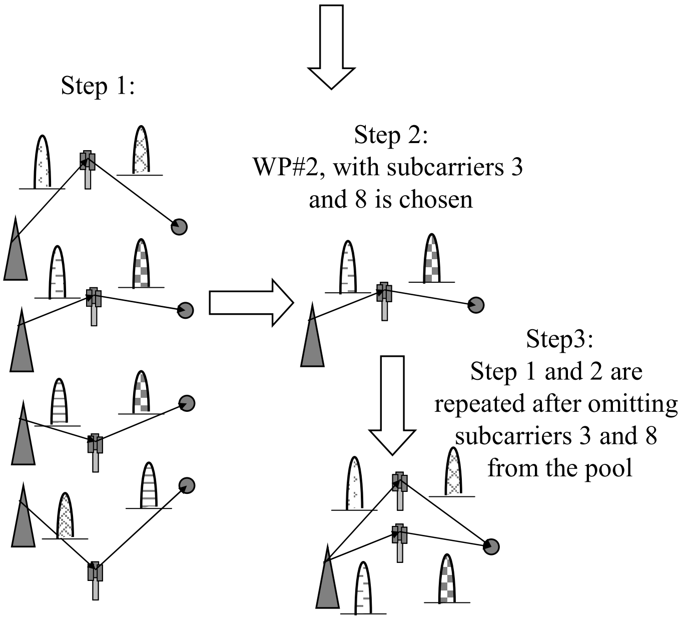


Fig. 3: Selected multi-route allocation

3. Packet Transmission Protocol

When there are multiple parallel logical routes, it is also important to think of a protocol to distribute the packets in those routes and retransmit them when error occurs. In this section two types of proposed packet transmission protocols 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. 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.

Even distribution protocol

In even distribution 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 *Nx* parallel logical routes are allocated, *No_pac*/*Nx* packets are sent through each logical route.

Uneven distribution protocol

The channel condition of each logical route is different. 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. Therefore we propose the uneven distribution protocol. The uneven distribution protocol is different for the single-hop transmission and 2-hop transmission.

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

$$n_x = \left\lfloor \frac{\{1-p(\gamma_{x,WP-link},N)\}\{1-p(\gamma_{x,mobile-link},N)\}}{\sum_{2}^{N_x}\{1-p(\gamma_{x,WP-link},N)\}\{1-p(\gamma_{x,mobile-link},N)\}} \times No\_pac \right\rfloor ,(5)$$

$$n_1 = No\_pac - \sum_{2}^{N_x} n_x ,(6)$$

Where $\lfloor x \rfloor$ denotes the largest integer smaller than or equal to x, $\{1\text{-}p(\gamma_{x,WP\text{-}link},N)\}\{1\text{-}p(\gamma_{x,user\text{-}link},N)\}$ is the expected throughput of the logical route x, $p(\gamma_{x,WP\text{-}link},N)$ is the packet error rate of the WP-link of the logical route x, $p(\gamma_{x,user\text{-}link},N)$ is the packet error rate of the user-link of the logical route x, $\gamma_{x,WP\text{-}link}$ and $\gamma_{x,user\text{-}link}$ are the received SNRs at the WP-link and user-link when the packet is sent through the channels allocated for route x, Nx 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 WP.

The Figures 4, 5, 6 and 7 show the illustrative diagrams that explain even distribution protocol and uneven distribution protocol in the single-hop transmission and the 2-hop transmission. In the figures parallel transmission is considered through 2 logical routes. The cross shows where the packet error occurs.

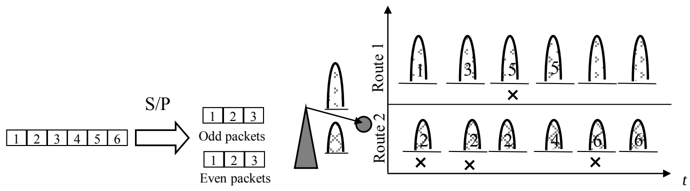


Fig. 4: Even distribution protocol in the single-hop transmission

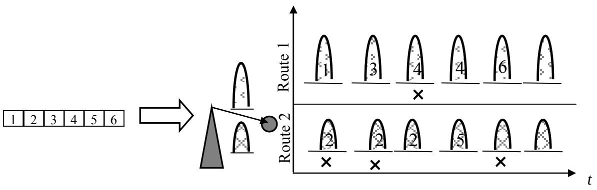


Fig. 5: Uneven distribution protocol in the single-hop transmission

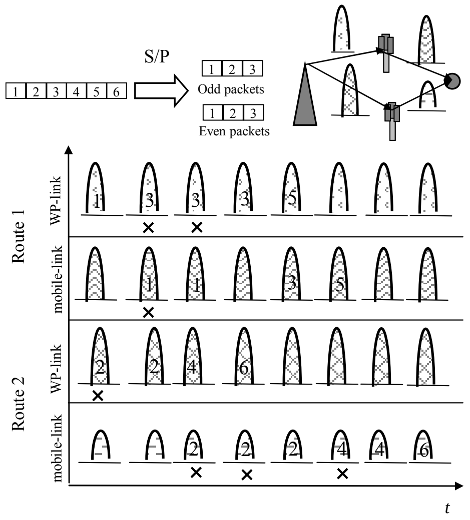


Fig. 6: Even distribution protocol in the2-hop transmission

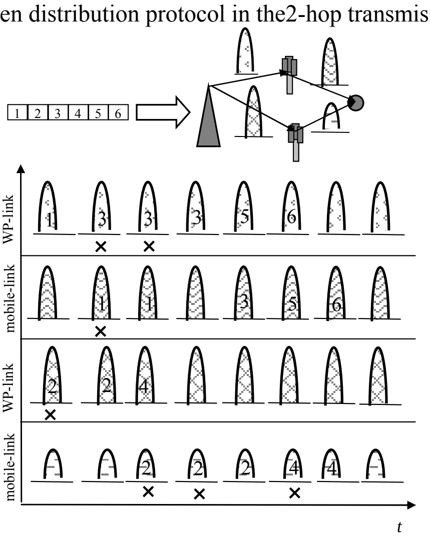


Fig. 7: Uneven distribution protocol in the2-hop transmission

4. Computer Simulation Results

Monte-Carlo simulation was conducted to evaluate the throughput in a single user environment to compare the selected single route, the selected multi-route and the single-hop transmissions. Moreover, the throughput performances of the even and uneven distribution protocols are also compared. 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. 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 2. Finally, packets transmitted from to the CP to the MT through the allocated subcarriers as mentioned in Section 3.

The packet error model is described below:

The packet error rate of a packet

$p(\gamma_{x,WP/user-link}, N)$ is given by

$$p(\gamma_{x,WP/user-link}, N) = 1 - (1 - p_b(\gamma_{x,WP/user-link}))^N \quad ,(7)$$

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[6],

$$p_b(\gamma_{x,WP/user-link}) = \frac{1}{2} erfc\sqrt{\gamma_{x,WP/user-link}} \quad ,(8)$$

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_tran* times, it is considered to be an error packet.

The simulation parameters are summarized in Table 1.The total transmit power is equally divided among the total logical routes allocated to an MT.

Table 1: Simulation Conditions

Total normalized transmit power ($\Sigma P_t/P_0$)	2,4,8,10 (dB)
Path loss exponent (α)	3.5
Standard deviation of shadowing loss (σ)	7
Total number of subcarriers (N_c)	32
No. of logical routes (Nx)	2,4,8,10
Packet size in bit (N)	512
Modulation	QPSK
No of packet transmitted (*No_pac*)	50,200,400,500
Maximum number of packet re-transmission (Max_trans)	4

A. *Impact of the number of logical routes*

Fig. 8 shows the impact of the number of logical routes. As the transmission rate required by an MT increases, the number of logical routes allocated to the MT for parallel transmission of packets increases as well. In the figure below the x-axis shows the no of logical routes which is proportional to the rate of transmission and y-axis shows the throughput. From Fig. 3 we can see that selected multi-route allocation (s.m.r) allocation shows better throughput performance than conventional selected single route (s.s.r) allocation, at higher transmission rate in which more subcarriers are needed for transmission than lower rates. This is because in s.m.r by choosing subcarriers from more number of candidates in multiple routes greater degree of route and frequency diversity gain can be achieved. It is also seen that the throughput of 2-hop transmission greatly outperforms that of single-hop transmission at higher transmission rate.

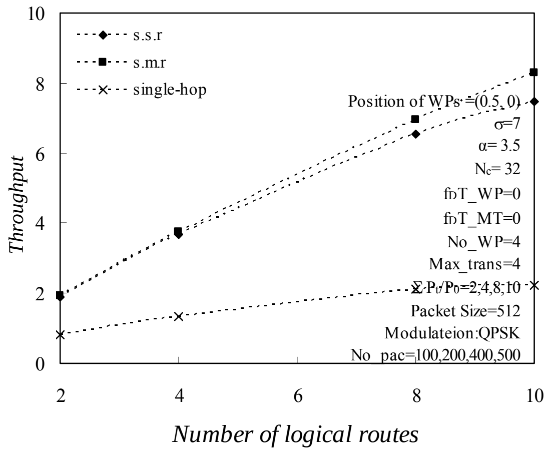


Fig. 8: Impact of the number of logical routes.

B. *Impact of the transmit power*

Fig. 9 shows the impact of transmit power on routing and allocation schemes mentioned in Sect. 2 when the no of logical routes is 10. We can see that s.m.r allocation outperforms s.s.r allocation at lower transmit powers. Even at lower transmit powers, in s.m.r allocation by choosing subcarriers from more number of candidates in multiple routes greater degree of route and frequency diversity gain can be achieved to improve the throughput performance than in s.s.r allocation in which the candidates of subcarriers is lesser. At higher power, however since the channel conditions are good, the number of candidates of subcarriers to choose from does not affect the throughput.

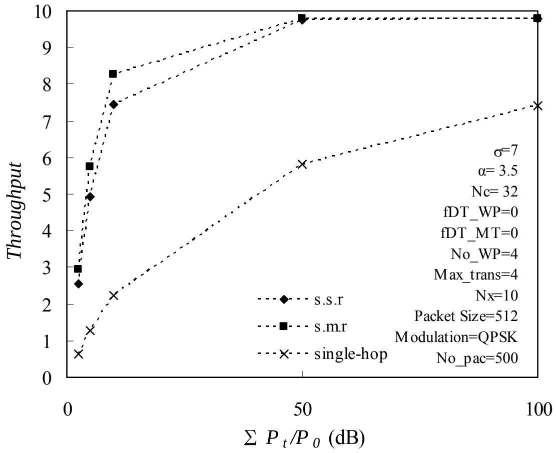


Fig. 9: Impact of the transmit power.

C. *Comparison of the throughput performances of even and uneven packet transmission protocols*

Figs. 10, 11, and 12 make a comparison of the throughput performances of even and uneven transmission protocols in s.s.r allocation, s.m.r allocation and single-hop transmissions.

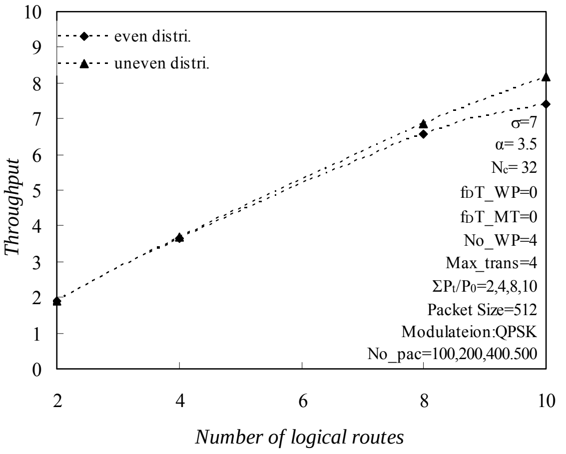


Fig.10: Selected single route allocation.

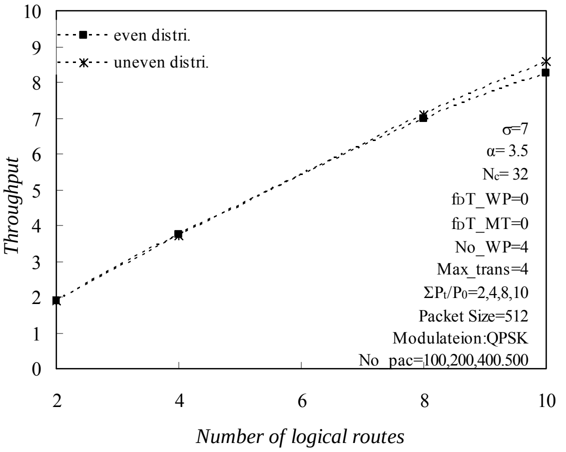


Fig. 11: Selected multi- route allocation.

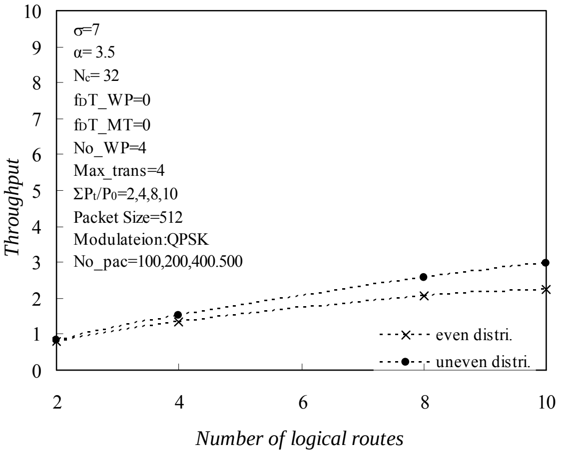


Fig. 12: Single-hop transmission.

We can 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. In even distribution protocol, since equal number of packets are sent though logical routes with better channel conditions as well as the logical routes with less better channel conditions, the transmission delay in sending all the packets through the logical routes with less better channel is more than that in the routes with better channel conditions. Therefore, the transmission delay in sending the total number of packets increases. However, in uneven distribution protocol, by sending more packets through logical routes with better channel conditions, the transmission delay in routes with less better channel conditions can be decreased. As a result, the total transmission delay to send all the packets through all the logical routes decreases, increasing the throughput.

5. Conclusion

In this paper an efficient routing with subcarrier allocation for multi-route parallel packet transmission in OFDMA 2-hop network, in order to increase the expected throughput, was studied. Moreover, throughput performance of uneven packet transmission protocol in which more packets are sent through logical routes with better channel condition is evaluated by computer simulation. It was shown that better throughput performance can be achieved in the multi-route parallel packet transmission than in the conventional single-route parallel packet transmission and that uneven packet transmission protocol further improves throughput performance at higher transmission rates.

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