The Research of Inter-user Communication Method in Ultra-dense Networks

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Abstract

Focused on the requirement of Gigabit level throughput of 5G networks, an efficient transmission protocol scheme was designed for direct communication between users in ultra-dense networks on the basis of the two backhaul network architectures. Different users can implement communication directly through multi-hop relay without macro base stations forwarding. Additionally, according to the characteristics of millimeter-wave coverage in ultra-dense networks, the paper presents the millimeter-wave dynamic bandwidth improvement mechanism of multi-user communication. However, the interference problem caused by small-area intensive deployment and the multi-hop transmission caused by the small coverage of small base stations will reduce the network capacity and user experience, so a throughput enhancement scheme based on hierarchical multi-hop physical layer network coding is proposed. Simulation results show that the effectiveness of the proposed scheme and correctness of the protocol analysis compared with the traditional mechanism, which can be seen that the proposed scheme improve the bit error rate (BER) performance effectively.

Keywords

Ultra-dense networks; Millimeter-wave; physical layer network coding; Bit error rate; Throughput.

1. Introduction

The vast network devices enable us to gain enormous information conveniently and the traditional cellular network system architecture may be powerless to meet the gigabit level of data traffic[1]-[2]. In order to improve the system spectrum efficiency and increase traffic volume significantly in wireless communications, the multiple input and multiple output (MIMO) with millimeter wave communication technology can increase the spectrum efficiency by 10 to 20 times [3]. However, typical wireless channel always suffer from multi-path fading and shadowing, which dramatically reduce the system capacity. A remedy for this crucial issue is the use of ultra-dense networks (UDNs) in combination with the opportunistic relaying, which can provide an effective transmission link.

In order to achieve the wireless transmission rate of gigabit per second, UDN architectures involved with multi-hop relay, small cell and other deployed nodes can meet users' experience and improve network throughput [4-5]. The network can more effectively meet user needs and improve network throughput by using smaller and more specific cells

At present, the research on backhaul link of UDN is widely concerned. M. Coldrey proposed a feasibility solution for the ultra -dense small cell backhaul link in the NLOS (Non Line-of-Sight) environment[6], which is based on simulation and measurement results, the solution of wireless backhaul is a powerful choice for ultra-dense networks. Then, Ge analyzed the influence of different frequency bands on the energy efficiency of backhaul network in two typical UDN backhaul scenarios and found that the distributed solution is more advantageous than the centralized solution and is suitable for the future 5G network environment [7]. However, most of solutions require macrocell base station (MBS) or a specific small cell base station (SBS) to forward from source to destination. Moreover, the short range technology may be impractical when two users are far from each other[8].

Therefore, an efficient protocol can be proposed to improve the network throughput and reduce the BER to some extent. The research show that dynamic bandwidth performance is superior to dynamic bandwidth mechanism in ultra-dense network[9].

In order to reduce the mutual interference between adjacent nodes and enhance the network throughput, Zhang et al. first proposed the concept of physical layer network coding (PNC) for the first time[10]. In [11] and [12], Burr proposed the application of linear physical layer network coding in multi-hop wireless network and ultra-dense multi-hop wireless network, respectively. The author analyzes the influence of different coding methods on PNC from the algebraic perspective. Considering the use of PNC for multiple relays, it does not describe the performance impact of the proposed method on multi-relay multi-hop networks compared to other relay processing methods. A throughput enhancement scheme in UDN based on hierarchical multi-hop PNC is proposed in this paper, which can effectively improve the throughput of the network and reduce the interference of the network.

The main contributions are as follows:

1) A high efficient teansmission protocol for inter-user communication in UDN is proposed, the problem of the long distance communication without BS forwarding can be solved.

2) Millimeter-wave dynamic bandwidth enhancement is investigated compared with traditional dynamic bandwidth mechanism.

3) A throughput enhancement scheme in UDN based on hierarchical multi-hop PNC is presented compared with the relay decoding and forwarding directly scheme.

2. System Model

2.1 Centralized network architecture

The centralized network architectures can be seen as Fig. 1. It is assumed that an MBS is located in the center of the macrocell, all SBSs are evenly distributed in the area, and all SBSs have the same transmission power and coverage area. As shown in Fig. 1, the traffic of the small cell is transmitted to the MBS through the millimeter-wave communication link and then the backhaul traffic aggregated in the MBS is forwarded to the core network through the fiber to the cell (FTTC) link. The two logical interfaces of S1 and X2 are used to forward backhaul traffic in a centralized architecture. S1 can be seen as a feeder from the advance gateway to the MBS user data, the advance gateway is the core network entry. X2 enables interactive information to be exchanged among small cells.

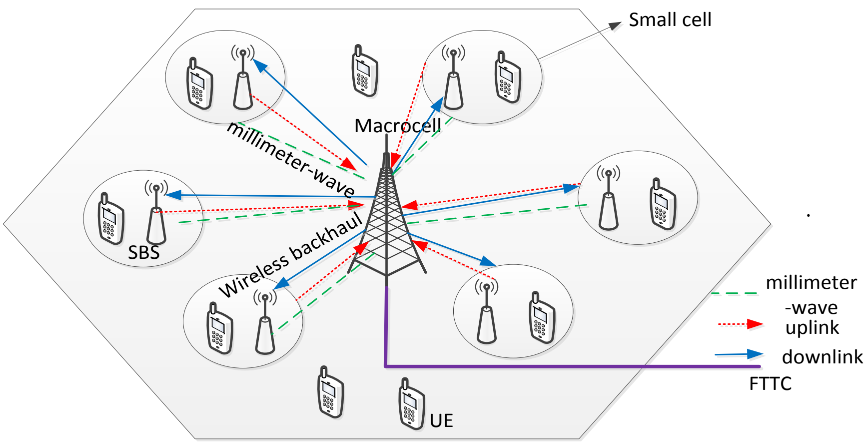

Fig.1 Centralized network architecture for wireless backhaul networks

The backhaul traffic in a centralized solution includes the uplink and downlink traffic. Assuming that the number of small cells in a macrocell is N , the uplink and downlink throughput of the macrocell are TH_u^1 and TH_d^1, respectively. The uplink and downlink throughput of the small cell are equal to TH_u^2 and TH_d^2, respectively. Therefore the total throughput of uplink backhaul is $\mathrm{TH}_u = \mathrm{TH}_u^1 + N \cdot \mathrm{TH}_u^2$, where thr throughput of downlink backhaul is $\mathrm{TH}_d = \mathrm{TH}_d^1 + N \cdot \mathrm{TH}_d^2$. The total backhaul throughput of the centralized solution is $\mathrm{TH}_s = \mathrm{TH}_u + \mathrm{TH}_d$.

2.2 Distributed network architecture

The distributed network architecture is shown in Fig. 2. Compared to the centralized architecture of Fig. 1, there is no MBS to collect all the backhaul traffic from the small cell, and the backhaul traffic is transferred to the SBS cluster. Assuming that all SBSs are evenly distributed in a given region, the backhaul traffic of the SBS is transmitted to the adjacent SBS by using millimeter-wave communication. All backhaul traffic from neighboring SBS will be forwarded to SBS cluster that is connected to the core network via an FTTC link, where the functions of S1 and X2 are the same in both distributed and centralized network.

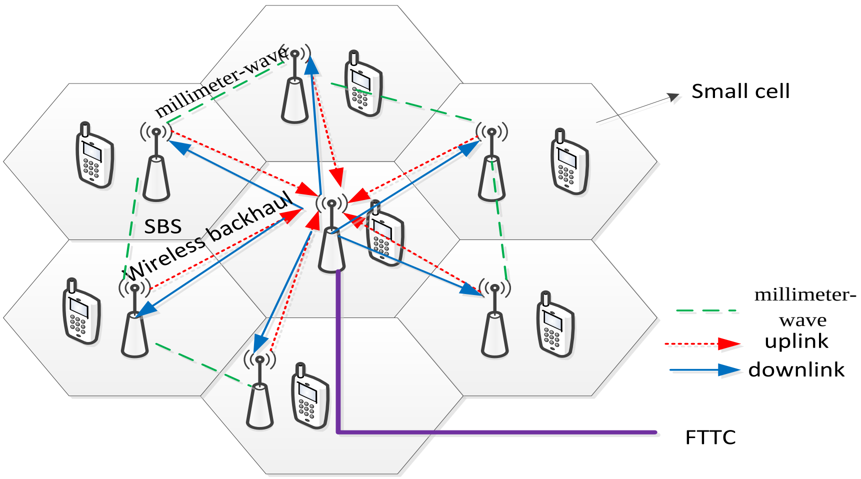

Fig.2 Distributed network architecture for wireless backhaul networks

In a distributed solution, adjacent small cells cooperate to forward backhaul traffic to SBS cluster. Thus, the channel information and the user data are shared in the neighboring cooperative SBS. Generally, the adjacent cooperative small cells constitute a cooperative cluster. Assuming that the number of neighboring small cells in a cluster is K, the uplink and downlink throughput of the cooperative small cell are expressed as $\mathrm{TH}_u{}'$ and $\mathrm{TH}_d{}'$, respectively. So the total backhaul throughput is $\mathrm{TH}_s{}' = K\left(\mathrm{TH}_u{}' + \mathrm{TH}_d{}'\right)$.

3. Efficient Transmission Protocol Design

The centralized and distributed solutions in UDN enable long-range backhaul transmission, and the transmission of information between users through the MBS or SBS cluster forwarding, which will significantly reduce system throughput. Especially when the number of dense small cells of overlapping coverage is raised, the millimeter-wave communication outage probability of the high-frequency transmission will increase dramatically. Therefore, in order to solve this problem, this paper proposes an enhanced scheme for communication between devices. When the transmission is carried out by the proposed method, the data traffic needs to be forwarded to the core network without macro base station or SBS cluster and can be transmitted directly from the source user to the destination user through multi-hop relay.

The proposed scheme improves the capability elements in the frame such as the access point (AP) beacon frame and the user's association request, and implements the multi-hop transmission method between users in a number of basic service sets (BSS) to cover in UDNs to improve the quality of service (QoS) of users.

The specific implementation process can be seen as follows:

The sub-type of the management frame in the IEEE 802.11 is defined in UDN, namely, the reserved field from B30 to B31 of the “VHT Capabilities” element in the information element field of beacon frame can be used to judge whether the device has a direct communication capability or not. Such as the code "1" has this capability, and the code "0" does not have. Capabilities element structure of beacon frame in IEEE 802.11 is shown in Fig. 3, there are total 32 bits from B0 to B31, where bits from B0 to B29 have been standardized in IEEE 802.11, the proposed scheme is compatible with the traditional protocol and the inter-user directly communication can be realized effectively.

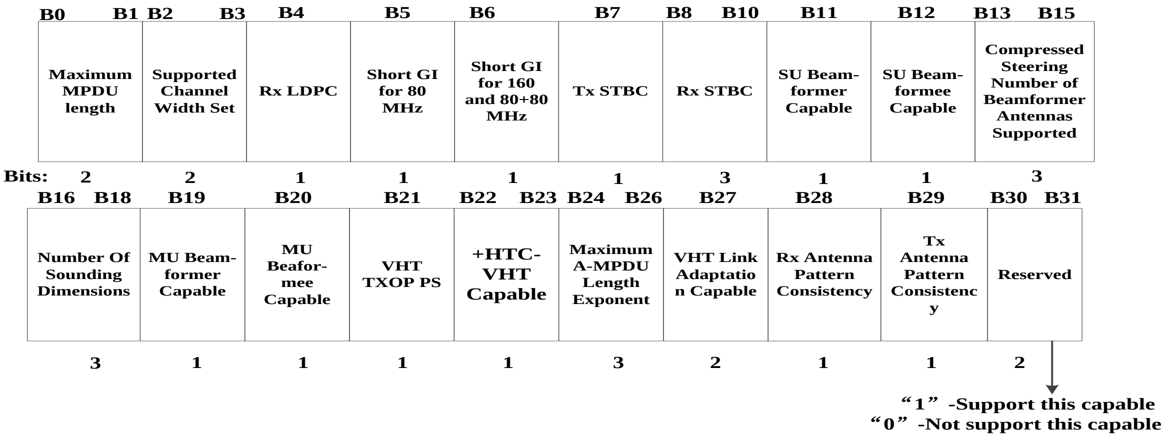

Fig.3 Capacities element structure of beacon frame in 802.11

When the source user A is far away from the destination user B, there are multiple BSS among these two devices. The process of communication can be elaborated as follows:

(1) User A find networks through the beacon frame sent by the associated SBS and transmit the data containing the target address information user B to the associated SBS, where the beacon frame contains the information indicating direct communication capability between users. Then identifying the bit of B30 or B31 to obtain whether users’ associated frame having requirement or not.

(2) After receiving the data, the SBS will match the address information buffered with the address information of the target user B in received frame. If match success, the SBS will send the data to the target user B; but if the match fails, the SBS forwards the data to the SBS.

(3) In the set time period, if match success, the SBS transmits the end-of-frame back to the upper level SBS step by step until it is fed back to the transmitting user A. If the SBS has not been matched successfully in the set time, the next level AP feedbacks the failed information of matching to the next level AP until it is fed back to the source user A, and discard the failed frame. It is noting that the address match can be performed in the order of setting when SBS receives data from multiple SBSs at the same time.

According to the proposed method can greatly reduce the switching costs, and because the path loss is relatively small, so the resulting BER also will be reduced.

4. Dynamic Bandwidth Protocol

An efficient protocol design for inter-user communication is elaborated in the above section. This section focus on the dynamic bandwidth transmission mechanism of the proposed protocol. The IEEE 802.11(aj/ad) task group is mainly to develop WLAN standards, so the proposed method requires to use IEEE 802.11 transmission protocol for communication especially the 60GHz frequency. To meet the demand for ultra wide band system, some newly opened spectrum such as 42.3-47.0GHz and 47.2-48.4 GHz band will be used in the future to support 540MHz and 1080MHz bandwidth[13]. Fig. 4 and Fig. 5 show the spectrum allocation of two channels.

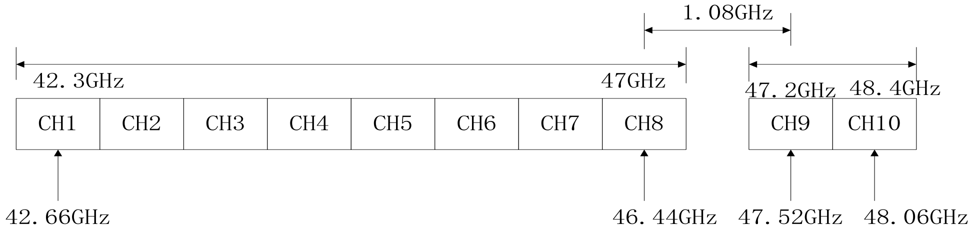

Fig.4 IEEE 802.11aj 540 MHz channel

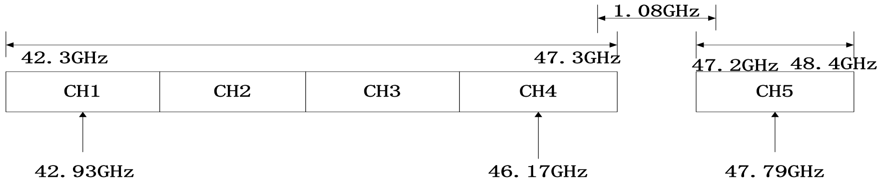

Fig.5 IEEE 802.11aj 1080MHz channel

Compared with the traditional dynamic bandwidth mechanism and the static bandwidth mechanism, the primary channel and secondary channel in the proposed scheme can be used for data transmission at the same time. But some flaws also need to be considered, such as the secondary channel is not available when the primary channel is busy. Therefore, in the new millimeter-wave dynamic bandwidth mechanism, the 45GHz frequency band does not need to consider the forward compatibility of the device of user, the data can access sub-channel transmission when the primary channel is busy.

5. The Realization Scheme of Throughput Enhancement Scheme in UDN Based on Hierarchical Multi - hop PNC

A very simple single-layer topology is shown in Figure 6, which is a hierarchical wireless network, commonly referred to as a network: two sources, two relays and a destination in a single layer hierarchical network. In this case, assume that the destination is associated with both sources.

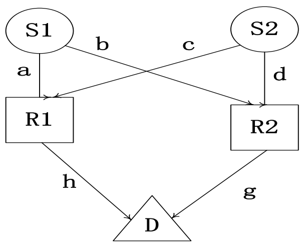

Fig.6 Single layer hierarchical network

The connection device of destination end the is the output of two relays, can be expressed as:

$$\mathbf{s}^{D} = \mathbf{s}^{(1)} = \mathbf{A}^{(1)}\mathbf{s}^{(0)} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} s_1^{(0)} \\ s_2^{(0)} \end{bmatrix}$$

$$\mathbf{y}^{D} = \mathbf{A}\mathbf{s} = \begin{bmatrix} ah & bh \\ cg & dg \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix}$$

$\mathbf{B} = \mathbf{A}^{(1)}$. Since D is associated with both $s_1^{(0)}$ and $s_2^{(0)}$, $\mathbf{B}^{A} = \mathbf{B}$, the two columns of $\mathbf{B}$ must be nonzero, and its nonzero coefficients are reversible. This topology is more flexible than a two-way relay channel because there are four coefficients instead of two, so it is easier to adapt to channel fading.

6. Simulation

The minimum mean square error (MMSE) precoding is used to compare the proposed scheme with the centralized scheme and the distributed scheme. The simulation frequency band is 45GHz millimeter-wave band and the wavelength is $\lambda = 6.7$ millimeter. The paper adopts Rayleigh channel model, the scattering body number is $S_k = 12$, the sub-array antenna unit spacing is $d = 0.5\lambda$ [14]. Assume that the arrival angle and the departure angle of the propagation path subject to uniform distribution of $[0, 2\pi)$.

Fig.7and Fig.8 show the comparison the BER and throughput of the proposed and the traditional scheme. From the simulations, it can be seen that the BER and throughput of the proposed scheme are superior to the centralized and distributed solutions. It is worth noting that the gap in the figure is owing to the proposed solution need not MBS or SBS cluster for forwarding, the offload of MBS and path loss are reduced significantly.

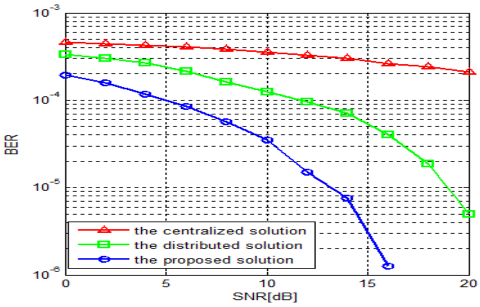

Fig.7 The BER comparison of the proposed scheme with traditional solution

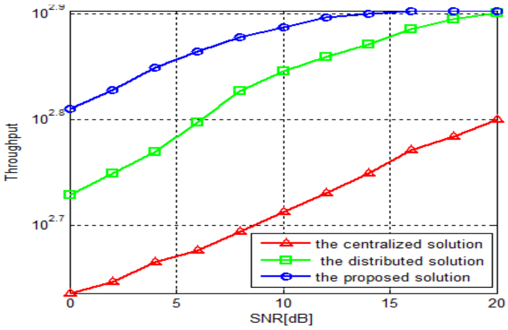

Fig.8 The throughput comparison of the proposed scheme with the traditional solution

Fig.9 and Fig.10 compare the proposed millimeter-wave dynamic bandwidth access mechanism with the traditional dynamic bandwidth access mechanism. The simulation parameters are set as follows: frame length is 10000bytes, the idle power and the transmit power set as 20mW and 100mW, respectively, the Monto Carelo number is 10000.

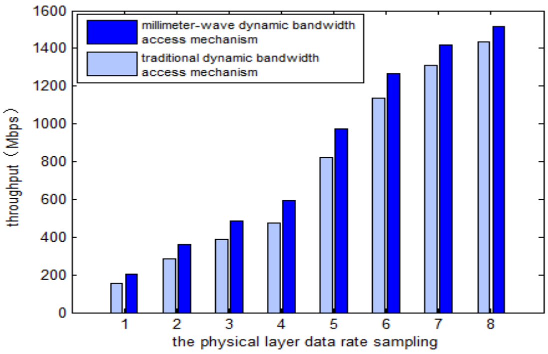

Fig.9 The throughput comparison of the millimeter-wave bandwidth access mechanism with the traditional dynamic bandwidth access mechanism

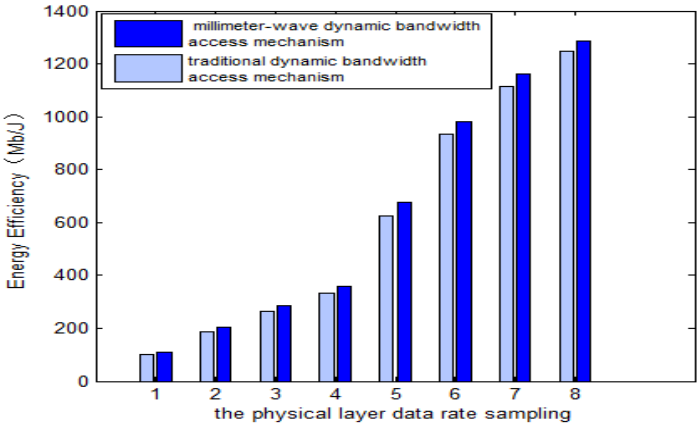

Fig.10 The energy efficiency comparison of the millimeter-wave bandwidth access mechanism with the traditional dynamic bandwidth access mechanism

It can be seen from two figures that the throughput and energy efficiency increase when the physical layer data rate improving, and the millimeter-wave dynamic bandwidth access mechanism are superior to the traditional bandwidth access mechanism.

Fig.11 and Fig.12 show the system throughput and BER of the single layer hierarchical multi-hop PNC method compared to the relay decoding and forwarding directly method when the user transmit power is the same. Considering the Rayleigh channel obey complex Gaussian distributions of $(0,\frac{\sqrt{2}}{2})$,(0,1) and$(0,\sqrt{2})$, respectively.

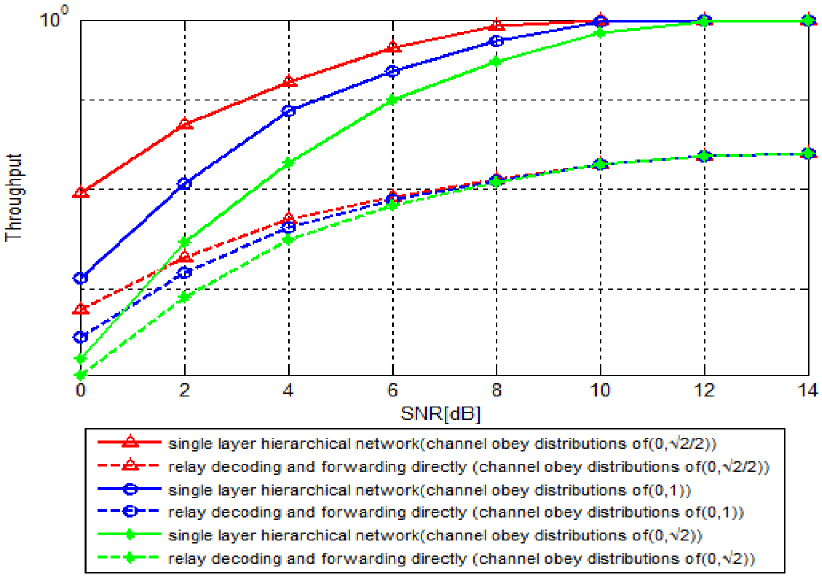

Fig.11 The throughput comparison of the single layer hierarchical multi-hop PNC methodcompared to the relay decoding and forwarding directly method

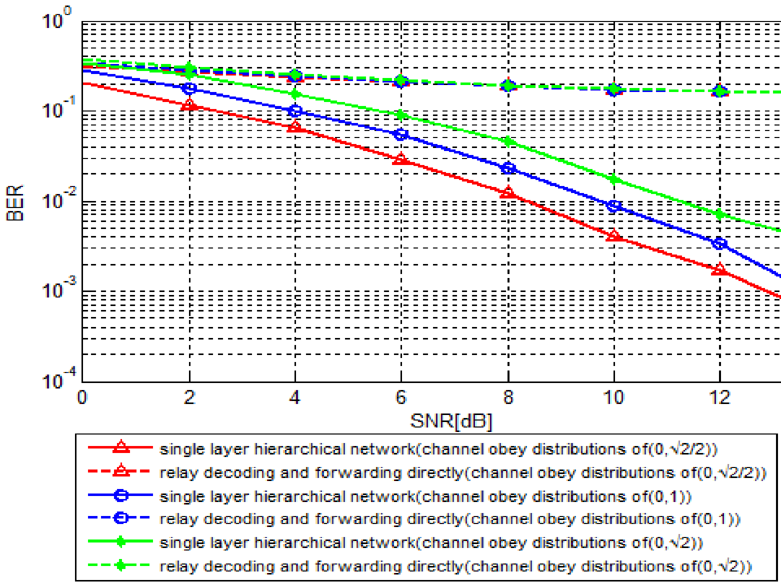

Fig.12 The BER comparison of the single layer hierarchical multi-hop PNC methodcompared to the relay decoding and forwarding directly method

As can be seen from two figures, the throughput increases with the increase of SNR. The smaller the variance of the Rayleigh channel, the greater the throughput. The BER decreases with increasing signal to noise ratio. Rayleigh channel variance value is smaller, the lower the BER. Compared with the relay decoding and forwarding directly method, the performence of single layer hierarchical network method is improved obviously.

7. Conclusion

An efficient protocol was designed for direct communication between users. The simulation results show that the proposed scheme in UDN has better BER performance and higher throughput. The proposed millimeter-wave dynamic bandwidth access mechanism has higher throughput and energy efficiency. For the sake of reducing interference between users, the hierarchical multi-hop PNC method in UDN is presented. Compared with the relay decoding and forwarding directly method, the method greatly reduces the BER of the network, and makes the system throughput Significantly increased.

Acknowledgements

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