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Article

Research on the Handover Strategy of Heterogeneous Network Based on the Dwell Time of Communication Blind Area

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Abstract: For the traditional indoor visible light communication heterogeneous network switching algorithm is only concerned with the research of vertical switching algorithm, however, the research of horizontal vertical collaborative switching combined with multi-carrier modulation technology is seldom mentioned, based on the above, this paper proposes a horizontal-vertical collaborative switching strategy based on the residency time of the communication blind area. Firstly, we use asymmetrically clipped optical OFDM (ACO-OFDM) for signal processing to reduce the bit error rate (BER) of the system by reducing the multipath interference generated during signal transmission. Secondly, the BER is used to determine the communication blind area and to calculate its dwell time. Finally, the threshold time is set as the channel interruption time in the communication blind zone, and the horizontal-vertical cooperative switching is performed by comparing with the dwell time. The simulation results show that the average network throughput is 195.28Mbps, and the average number of handovers is 1.35. Compared with instant vertical handover (IVHO) scheme and dwell vertical handover (DVHO) scheme, the average network throughput is improved by 37.21% and 28.45%, respectively, and the average switching times are reduced by 28.05% and 5.27%, respectively.

Keywords: visible light communication; heterogeneous networking; ACO-OFDM; communication blind area; horizontal-vertical collaborative handover

1. Introduction

With human's continuous research and experiments on information technology, wireless communication technology has been effectively developed, and a novel communication method—visible light communication (VLC) has begun to gradually replace traditional wireless communication technology through continuous experiments and improvements step by step. Compared with traditional radio frequency (RF) communication, visible light communication has the characteristics of low-carbon and environmentally-friendly, abundant bandwidth resources, and high security performance[1,2]. In order to address the problem of maintaining communication stability, even when users receive devices indoors in the case of random movement, it is significant to learn its network handover technology.

Nowadays, visible light communication networking technology has attracted a lot of attention in academic circles due to its unique communication strengths. In visible light communication networking technology, horizontal handover (HHO) represents the handover between multiple visible light networks, and vertical handover (VHO) represents the handover between WiFi and multiple visible light networks[3]. Indoor daily office areas generally use a hybrid network, with the advantage of WiFi can cover the entire area, VHO solution is sufficient for office environments [4]. Hou[5] et al. came up with a dwell vertical handover (D-VHO) scheme, where the vertical handover controller could predict the link recovery time by waiting for a fixed duration. However, what the drawback is that the vertical handover is executed only when the optical link remains blocked at the end of the waiting time. Bao et al[6]. proposed a channel adaptive residence vertical handover (CAD-VHO) scheme, which could use the channel blocking rate and recovery rate to determine the adaptive

residence time, and then determines whether to perform vertical handover. Nevertheless, what the shortcoming is that it does not take the real-time application operation into account. Subsequently, their team members Andrews et al.[7] proposed the technique of hybrid application-aware VHO (HA-VHO), which took real-time applications into consideration. However, they only analyzed the communication in the overlapping region of visible light coverage. Wu[8] made use of mines as an application scenario to learn the heterogeneous networks, proposed an received signal strength (RSS) horizontal handover scheme on the basis of fast fourier transformation (FFT) fading detection for coal mine working faces, and a dynamic residence time vertical handover scheme for roadways, while the communication between coal mine working faces and roadway handover areas failed to consider. Wang et al.[9] proposed a heterogeneous network handover strategy depended on the quality of service of users, using network dwell time as the handover mechanism and combining vertical handover algorithms on top of horizontal handover, but also failed to analyze the communication in the region of severe fading of visible light signals.

For the attenuation characteristics of visible light signals, the area where the visible light signal is attenuated to the point where normal communication is not possible is collectively referred to as the communication blind area. In summary, most of the research on the current visible heterogeneous networking handover technology mainly adopts separate handover technology, which fails to consider the problem of communication stability into the communication blind area. This proposal combines multi-carrier modulation technology with horizontal-vertical collaborative handover technology, and proposes a horizontal-vertical collaborative handover strategy based on communication blind area dwell time, which performs horizontal-vertical collaborative handover by comparing dwell time with channel interruption time to realize the improvement of system performance.

2. Methodology

2.1. Basic Theory of VLC

Line of sight (LOS) and non line of sight (NLOS) are the two main types of indoor optical communication links. The experiment results demonstrate that the received power of indoor visible direct link accounts for 93.03% of the total received power, and the received power of primary reflection accounts for 5.53% of the total received power[10]. In order to reduce the errors generated during the process of calculating the BER, we only adopt LOS is taken in this paper.

The Light-emitting diode (LED) light source distribution obeys the Lambert distribution, and the specific Lambert model[11] can be expressed as:

$$R(\theta) = \frac{m+1}{2\pi} \cos^m(\theta), \quad (1)$$

where θ indicates the radiation angle of the LED light source, m is the number of radiation modes of the light source, which is related to the half power angle of the light source.

In the case of LOS, the channel direct current (DC) gain is calculated by:

$$H(0) = \begin{cases} \frac{m+1}{2\pi d^2} A \cos^m(\theta) T_s(\psi) g(\psi) \cos(\psi), & 0 \leq \psi \leq \psi_c, \\ 0, & \psi > \psi_c \end{cases}, \quad (2)$$

where A is the sensing area, $T_s(\psi)$ is the optical filter DC gain, ψ_c represents the half field of view of the receiver, d represents the position from the light source. The $g(\psi)$ is the gain of the concentrator, which can be presented Eq:

$$g(\psi) = \begin{cases} \frac{n}{\sin^2 \psi_c}, & 0 \leq \psi \leq \psi_c, \\ 0, & \psi > \psi_c \end{cases}, \quad (3)$$

The received power under condition of LOS is:

$$P_R = P_s H(0), \quad (4)$$

where P_s represents the transmit power, and P_R represents the received power under the circumstance of LOS.

In the channel of indoor visible light transmission, the Gaussian white noise is employed paper. There are two main types: the one is scattered particle noise and the other is thermal noise. The scattered particle noise can be expressed as:

$$\delta_{shot}^2 = 2qR \left(P_{R(signal)} + P_{R(ISI)} \right) B + 2qI_{bg} I_2 B, \quad (5)$$

where q is the quantity of electric charge, $P_{R(signal)}$ is the signal received power, B is the noise bandwidth, $P_{R(ISI)}$ is the inter-code interference power, I_{bg} is the dark current, and I_2 is the noise bandwidth factor. The thermal noise can be expressed as:

$$\delta_{thermal}^2 = \frac{8\pi k T_k}{G} C_{pd} A I_2 B^2 + \frac{16\pi^2 k T_k \Gamma}{g_m} C_{pd}^2 A^2 I_3 B^3, \quad (6)$$

where k is the Boltzmann constant, T_k is the absolute temperature, C_{pd} is the fixed capacitance per unit area of the photodetector, G is the open-loop voltage gain, Γ is the channel noise coefficient, g_m is the transconductance coefficient, and I_2, I_3 are both noise bandwidth coefficients. The signal-to-noise ratio (SNR) can be expressed as:

$$SNR = \frac{R^2 P_{R(signal)}^2}{\delta_{shot}^2 + \delta_{thermal}^2}, \quad (7)$$

2.2. The Technology of ACO-OFDM

Due to the problem of multipath interference during the channel transmission by the indoor visible light signal. The orthogonal frequency division multiplexing (OFDM) technology is widely studied and applied, which has the benefits of high frequency utilization, and strong resistance to multipath interference. In order to satisfy the requirement of non-negative real signals and improve the power efficiency of the system at the same time in the situation of introducing OFDM into visible optical communication, researchers came up with a single-polarity real-valued scheme called ACO-OFDM technique[13].

As shown in the above Figure 1, the data input at the transmitter side and the data output at the receiver side are both adopted the binary serial data streams. Due to the limitation that light signals can only propagate in a positive direction, the limiting operation is performed to output a positive real number signal, and the cyclic prefix (CP) is added to eliminate inter-code crosstalk during the channel transmission.

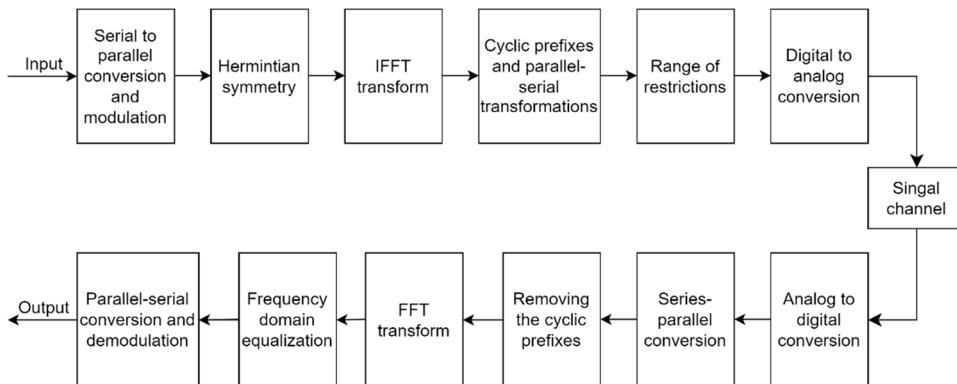


Figure 1. Block diagram of ACO-OFDM system.

3. VLC heterogeneous networking technology research

3.1. Visible light source layout

This program built a square room model with the size of $6m \times 6m \times 3m$, the layout design used to cover the radius of 1m and $\sqrt{2}m$ LED light source, respectively. Among them, the 1m LED light source with the distribution of diamond-shaped layout, and $\sqrt{2}m$ LED light source with the distribution of x-shaped layout. Laying out a WiFi RF communication is laid out in the middle area, where the overall arrangement of light source is depicted in Figure 2:

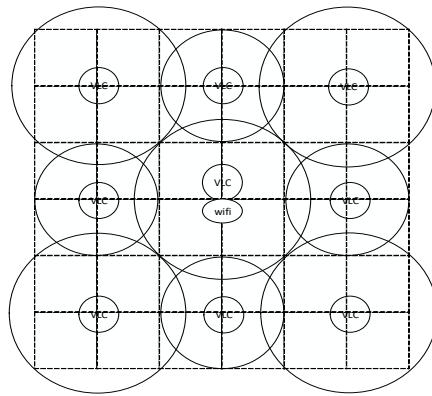


Figure 2. Visible light source layout.

Figure 3 shows the light intensity distribution depended on the visible light source layout, which has a maximum light intensity of $1126.59lx$ and a minimum value of $215.63lx$. Besides the average light intensity is $367.22lx$, which has meet the international standard for indoor lighting[12]. Therefore, according to the figures above, the layout of the visible light source designed in this scheme can provide communication for the user receiving equipment but also take the lighting into account.

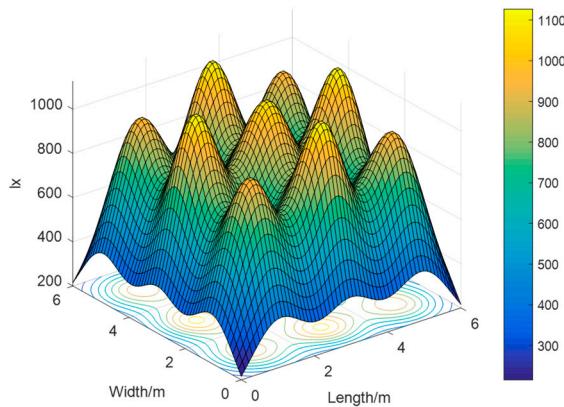


Figure 3. Visible light intensity distribution.

3.2. ACO-OFDM channel processing

In the visible light channel transmission, unlike the traditional method of introducing SNR, we introduce the spatial SNR on the basis of the layout of the visible light source in this article (Figure 4):

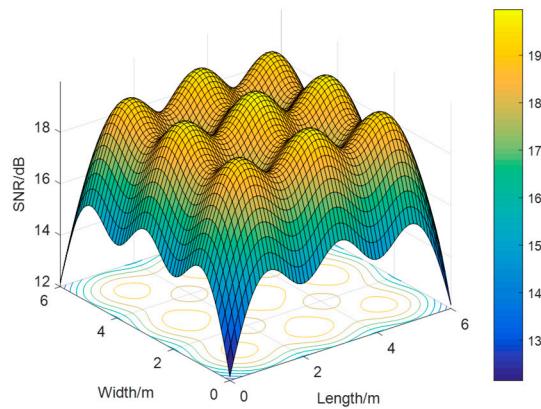


Figure 4. Visible light SNR distribution.

After the operations of quadrature amplitude modulation (QAM), Hermintian symmetry, inverse fast fourier transformation (IFFT) transformation, adding CP and limiting operations in the transmitter, the bit stream can be transmitted in a Gaussian white noise channel through digital-to-analog conversion. Analogously, the receiver side is equivalent to the inverse process of the transmitter side. Finally, we can obtain the BER by calculating the error between the output and the input bit stream at the receiver side, and convert the BER into the indoor spatial distribution (Figure 5):

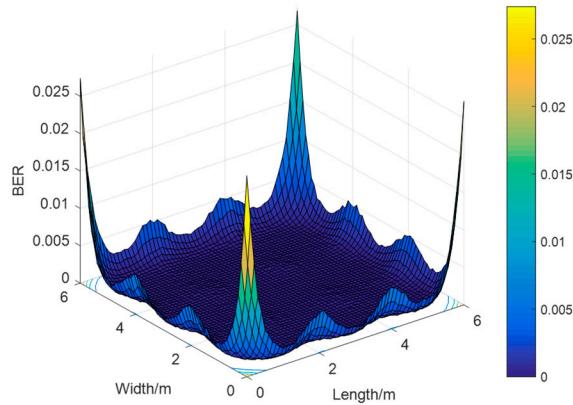


Figure 5. Visible BER distribution.

3.3. CBDHVHO scheme

In this article, we utilize WiFi for uplink data transmission. Meanwhile, we employ both VLC and WiFi for downlink data transmission. Furthermore, we analyze three situations of communication blind area based on the light source layout: (1) The visible light coverage overlapping area. (2) The visible light coverage tangent area. (3) The visible light no coverage area.

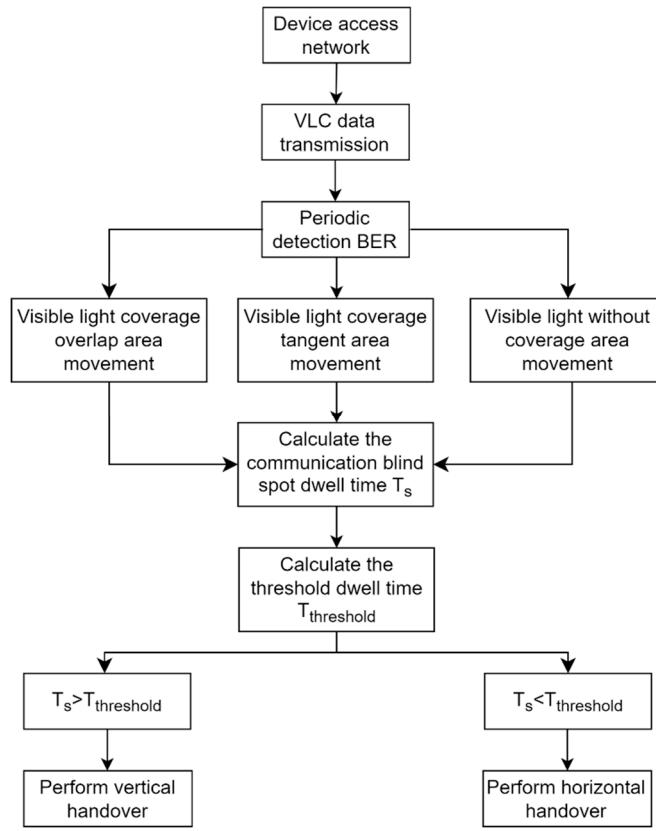


Figure 6. CBDHVHO scheme flowchart.

In this regard, we propose a horizontal-vertical collaborative handover scheme based on the dwell time of the communication blind area(CBDHVHO). The communication blind area dwell time T_s refers to the time from the mobile receiving device entering the communication blind area to its departure. In the case of normal carrier-to-noise ratio, $BER > 10^{-4}$ is chosen as the communication blind area in this paper. $T_{threshold}$ refers to the threshold time, which follows a random distribution in the interval $[T_{res}, T_{max}]$. T_{res} is the time limit of the response time for the user thought stream to continue without interruption[14], and T_{max} is the maximum waiting time for the visible channel interruption. When T_s is greater than $T_{threshold}$, it means that the mobile receiving device in the communication blind area will be affected by the channel interruption. In order to maintain normal communication of the device, we need to access the vertical handover to the user receiving devices. Meanwhile, for the sake of preventing the excessive cost generated by switching signaling, the vertical handover implementation will be maintained until the end of the moving process; When T_s is less than $T_{threshold}$, it represents that the receiving device is basically unaffected by the channel response interruption. In addition, it is the time that the execution of horizontal handover can guarantee higher-quality user communication.

4. Simulation Results

This experiment uses a room layout of $6m \times 6m \times 3m$, where the coordinates of LED light sources with the covering radius of 1m are: (1,3), (3,1), (3,5), (5,3). The coordinates of LED light sources with the covering radius of $\sqrt{2}m$ are: (1,1), (1,5), (3,3), (5,1), (5,5). The user receiving device moves randomly in the speed range of 0.3 to 0.7m/s. The time that the user receiving device moves at a value higher than the normal communication BER is the communication blind spot dwell time, and the time required for network handover is the handover delay time, as shown in Table 1:

Table 1. Simulation parameters.

Parameter	Value
Room size	$6m \times 6m \times 3m$
Velocity	0.3~0.7m/s
Movement time duration	1~30 s
Throughput for VLC	400Mbps
Throughput for WiFi	100Mbps
Number of VLC APs	9
Radius of APs	1m, $\sqrt{2}m$
Number of iterations	1000
Number of RF APs	1
Handover delay time	0.1~1s
Time frame for response time	1s
Maximum waiting time	2 s

In the whole visible light communication networking system, in order to highlight the benefits of high quality communication and low cost power consumption in the CBDHVHO programme, the solutions are mainly as follows: Firstly, we use the average network throughput and average number of handover as the communication performance indexes. In addition, using the IVHO and DVHO schemes as the comparison experiments is also a must. The network throughput can reflect the communication quality of the visible light communication system and guarantee the normal operation of the program when receiving equipment communication. The number of handovers can reflect the signaling cost of visible optical communication systems, and the lower number of handovers can reduce system power consumption. Secondly, adding the number of user receiving devices to detect the impact of each handover scheme on communication performance indicators. Finally, the probability of handover failure is adopted as a performance index to judge whether the communication is stable or not. The comparison experiments can prove that the CBDHVHO scheme with better communication stability performance when we use the probability of switchover failure as the evaluation index.

4.1. Communication quality and cost performance analysis

In this paper, the average number of handovers and the average network throughput are used as communication performance indexes. Besides, the IVHO and DVHO schemes are employed as comparison schemes. The average number of handovers can be calculated by:

$$A_{HO} = \frac{\sum_{r=1}^{N_r} N_{HO}(r)}{N_r}, \quad (8)$$

where A_{HO} presents the average number of handovers and N_r represents the number of executions. $N_{HO}(r)$ represents the number of r -th execution. The average network throughput is calculated as:

$$A_{th} = \frac{\sum_{r=1}^{N_r} \sum_{i=1}^{N_r(r)} O(i, r) \times [T_i(r) - T_d(r)]}{\sum_{r=1}^{N_r} \sum_{i=1}^{N_r(r)} T_i(r)}, \quad (9)$$

where A_{th} is the average throughput, $T_i(r)$ represents the network dwell time when executing the r -th time, and $T_d(r)$ represents the network handover delay time when executing the r -th time.

4.1.1. Comparisons of the average number of handovers

As Figure 7 shows the average number of handovers under the comparison of various schemes, a total of 1000 experiments were performed, where CBDHHO represents the horizontal handover of the CBDHVHO scheme and CBDVHO represents the vertical handover of the CBDHVHO scheme. From the figure, it can be seen that the IVHO scheme has the highest average number of handovers

because the number of handovers in this scheme increases with the change of the VLC network. The DVHO_{t=0.5} scheme sets the dwell time under the VLC network to 0.5s, and does not perform handover when the dwell time of the user receiving device under a VLC network is less than 0.5s. Thus the average number of handovers is reduced by 24.05% compared to the IVHO scheme, and reduced by 44.53% when compared with the same type of DVHO_{t=1} scheme. The average number of handovers in the CBDHHO scheme is decreased by 46.35% compared with the IVHO scheme. However, considering that the channel response interruption time in the communication blind area is very short, the total number of handovers is increased a little compared with the DVHO_{t=1} scheme in order to maintain continuous and stable communication of the user receiving equipment with the assistance of the CBDVHO scheme.

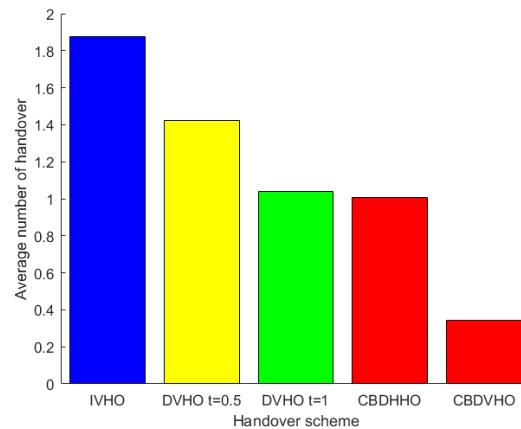


Figure 7. Average number of handover.

4.1.2. Comparisons of average network throughput

Figure 8 shows the average throughput of the network under the comparisons of various schemes. The IVHO scheme has the lowest average network throughput due to the ping-pong effect caused by the frequent handoffs required. The DVHO_{t=0.5} scheme does not perform handover when the dwell time in the lower part of the VLC base station is below the set threshold time, so the average network throughput is increased by 6.81% compared with the IVHO scheme, and the average network throughput is increased by 11.98% in the DVHO_{t=1} scheme. The CBDHVHO scheme takes the continuous and stable communication of user receiving devices into account, and the handover technology achieves a seamless connection. Furthermore, the average network throughput is increased by 37.2% compared with the IVHO scheme.

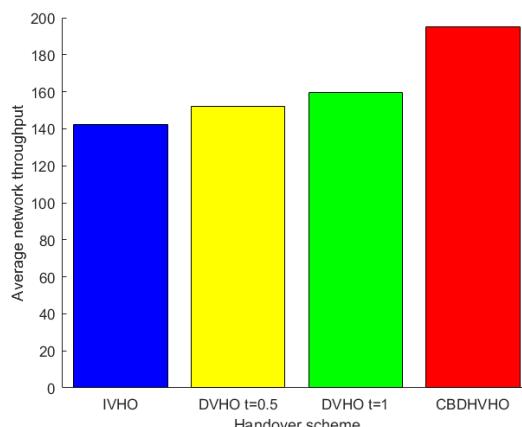


Figure 8. Average network throughput.

Figure 9 shows that the different mobile speeds have different effects on the average network throughput. The change of movement speed affects the dwell time and communication blind zone residence time under the VLC network. With the increasing of the movement speed, the network dwell time and communication blind zone residence time become correspondingly shorter. Since the IVHO and DVHO schemes are vertical handover types, the average network throughput shows a downward trend, while the CBDHVHO scheme focuses on the horizontal handover type, and the shorter the communication blind spot residence time will perform more horizontal handover, so the average network throughput shows an upward trend. Compared with the IVHO scheme and DVHO scheme, the average network throughput of CBDHVHO scheme increases by 6.2%, 5.9% and 3.3% when the movement speed is $0.3m/s$, respectively; and the average network throughput of CBDHVHO scheme increases by 76.01%, 68.08% and 81.62% when the movement speed is $0.7m/s$, respectively. The above data show that the scheme has good applicability to mobile speed.

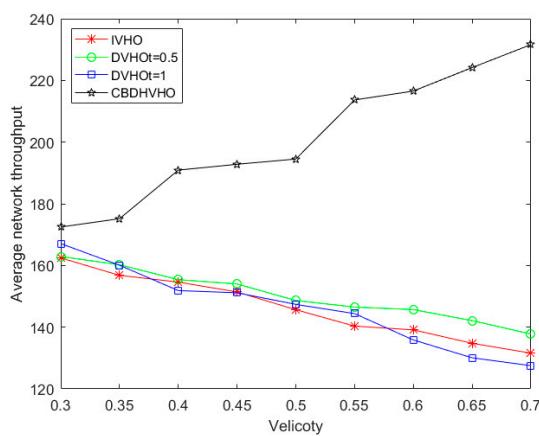


Figure 9. Impact of velocity on average network throughput.

4.2. Communication stability performance analysis

In this paper, the handover failure probability is used as the performance evaluation index with the following equation:

$$F_{HO} = \frac{\sum_{r=1}^{N_r} \frac{P(r)^B - P(r)^{B+1}}{1 - P(r)^{B+1}}}{N_r}, \quad (10)$$

where F_{HO} is the handover failure probability of the specified scheme, $P(r)$ is the utilization of the RF communication uplink server after r iterations, and B is the maximum queue length of the RF communication uplink.

As Figure 10 shows the comparisons of handover failure probability for various scenarios. It can be seen that the IVHO scheme has the highest handover failure probability, which is caused by frequent switching. The DVHO_{t=0.5} scheme and the DVHO_{t=1} scheme do not perform switching during part of the dwell time, thus reducing by 11.11% and 27.78%, respectively, compared with the IVHO scheme. The CBDHVHO scheme is 50% lower compared with the IVHO solution by virtue of its lower handover cost and seamless connectivity. Because the handover failure probability is closely related to the number of handovers, more handovers will result in more delay time and more dwell packets, so the probability of handover failure will be increased.

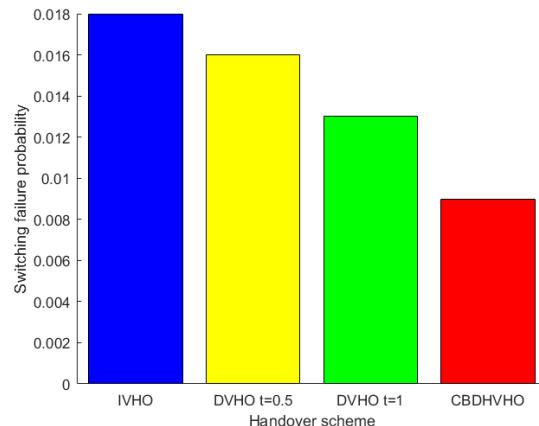


Figure 10. Handover failure probability.

5. Conclusions

Depending on the extensive data analyses above, the combination of ACO-OFDM technology and visible light networking handover technology can not only reduce the BER of the communication system, but also improve the recognition of the communication blind area. Furthermore, it also can establish a horizontal-vertical collaborative handover strategy according to the stability of the communication blind area. Compared with the schemes of IVHO and DVHO, the average number of handovers can be reduced by 28.05% and 5.27%, respectively. Obviously, the ping-pong effect can be effectively suppressed. Besides, the communication quality is effectively improved and the average network throughput can be increased by 37.21% and 28.45%, respectively. The communication stability is significantly improved and the probability of handover failure is reduced by 50% and 43.75%, respectively.

The main innovations of this paper are as follows:

1. Combining multi-carrier modulation technology (ACO-OFDM) with network handover technology not only reduces the BER of the communication system, but also improves the recognition of communication blind areas and provides readiness when performing group handover.
2. Simplifying the random motion model, which only needs to consider the BER and communication blind area dwell time, replacing the complex factors such as motion direction, speed and time.
3. Considering many types of communication instability places, closer to real-life scenarios, while a network handover mechanism is established for horizontal and vertical collaborative handover based on the dwell time of communication blind area.

Author Contributions: The contributions of the authors in this paper are the following: conceptualization: C.Z. and Y.F.T.; investigation: C.Z.; methodology: C.Z. and X.Z.W.; project administration: Y.F.T. ; software: C.Z. and Y.Z.; validation: X.Y.L. and C.Z. Authorship must be limited to those who have contributed substantially to the work reported.

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Nomenclature

OFDM	Orthogonal frequency division multiplexing
ACO-OFDM	Asymmetrically clipped optical OFDM
BER	Bit error rate
IVHO	Instant vertical handover
DVHO	Dwell vertical handover
VLC	Visible light communication
RF	Radio frequency
HHO	Horizontal handover
VHO	Vertical handover
CAD-VHO	Channel adaptive residence vertical handover
HA-VHO	Hybrid application vertical handover
RSS	Received signal strength
FFT	Fast fourier transformation
LOS	Line of sight
NLOS	Non line of sight
LED	Light-emitting diode
DC	Direct Current
SNR	Signal-to-noise ratio
CP	Cyclic prefix
QAM	Quadrature amplitude modulation
IFFT	Inverse fast fourier transformation

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