A Fuzzy Logic QoE Enhancement VHO Scheme for VLC-RF HetNet in an Indoor Environment

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Abstract

Owning to the complementary characteristics of visible light communication (VLC) and radio frequency (RF) in both coverage and capacity, the combined use of both for data transmission could have advantages over a single media. However, a technical challenge for vertical handover (VHO) strategy arises for such an integrated system. This article proposes a dynamic quality of experience fuzzy logic (QFL) scheme, which combines the advantages of VLC with the advantages of RF. The QFL scheme enables the QoE of the user equipment (UE) to be enhanced, when VHO is performed from one network to another, taking into consideration the data rate and the bandwidth of the networks. Our proposed scheme has the ability to handle any contradictions and indecision that might have arisen out of the decision metric. From the simulation results, our scheme outperformed other VHO schemes, with a better QoE performance, lesser queuing of packets in the uplink, least handover failure probability to RF, good performance for short interruption and an excellent performance when it comes to VHO execution delay.

Keywords

Quality of experience (QoE), Visible light communication (VLC), Vertical handover (VHO) scheme, Heterogeneous system, Fuzzy Logic, Immediate Vertical Handover (I-VHO), Dwell Vertical Handover (D-VHO), Radio Frequency (RF).

1. Introduction

Both VLC and RF networks complement each other in heterogeneous networks. A normal line-of-sight (LOS) VLC link has the capacity to have a data transmission rates as high as 1-10 GB/s, with a small coverage area. On the other hand, the RF network has a bigger coverage area, that span's several square kilometers, with lower data rates of 10-1000 Mb/s [1]. The complementary role of the two schemes in both capacity and coverage has motivated the authors to con-sider deploying both data transmission in an integrated system. The prospective benefits of such a system is reducing delay in the uplink and hence enhancing the quality of experience (QoE) of user equipment (UE). In this work, we analyze the benefits the user will gain in terms of QoE when executing a VHO and simultaneously reducing delay or delay cost. There are fundamental differences in the properties and the mechanisms of physical and data link layers between such heterogeneous wireless networks, this result in a lot of challenges for mobility management when these systems are combined. Whereas, when the UE transit the coverage boundary of two different systems, its connection for an ongoing call must be switched seamlessly to a new net-work with guaranteed QoE. Such an inter-system transmission of a continuing connection is usually referred to as inter-system, inter-technology, or vertical handover (VHO) [2]. This key integration of the networks can be categorized into two main parts: the design model (architecture) of VHO and algorithm for the VHO decision making. The VHO design deals with the approach and how system configuration is deployed to deal with the connection or restoration in a handover process. Algorithm for the VHO decision-making determines whether and when a VHO should be executed, which has a critical effect on the performance of the integrated systems, i.e. QoE of the UE. Consequently, this article is concerned with the design and valuation of an algorithm for the VHO decision-making for the proposed integrated LOS VLC and RF system. VLC is limited by line-of-sight (LOS) transmission which can be as a result of haphazard movement of human or UE that can cause obstruction to the VLC link [3] in an indoor environment. On contrary, the RF has a low data rate, small bandwidth, and larger coverage and is not easily blocked. In recent times, multimedia usage has made quality of experience (QoE) of the user a very important prerequisite to achieve a satisfactory perception of the network to the UE. In accessing multimedia applications, a new theory called QoE [4-8] has been introduced which is an indicator to monitor the quality that is offered to the user. QoE is fundamentally about what happens in the user's psyche [9].

In a VLC-RF heterogeneous network, UE may perform handover to the RF network whenever the user experiences a decrease in QoE, as a result of obstruction of the VLC link. When the VLC network link is recovered, a VHO from RF to VLC can enhance the QoE of UE [10]. Therefore, a handover decision must be taken to give the user the best option available at any point in time when there is a decrease or an expected increase in QoE as a result of the non-availability and availability of VLC link respectively. It is not always the right decision to per-form immediate VHO (I-VHO) when the VLC link is blocked since switching on and off, of the VLC link can lead to ping-pong effect. In addition, there may be an increase in the unsent packets in the queue (delay) due to too many handover requests. I-VHO scheme is a traditional meth-od where the UE will handover immediately when VLC link is interrupted. On the contrary, dwell VHO (D-VHO) scheme's time is set as the period of a short interruption in order to avoid the ping-pong effect. In this regard, "dwell or waiting" scheme is used to prevent unnecessary handover. However, the static nature of the I-VHO and D-VHO schemes is a limitation. Besides, these schemes do not consider the impact of vertical handover on the QoE of UE. In addition, the fuzzy-logic (FL)-based decision-making algorithm for VHO has a limitation, QoE and velocity of the UE was not considered as a handover metrics. A handover design for the integration of LOS VLC and RF heterogeneous wireless network (HetNet) was mooted in order to solve these challenges.

In this work we propose a Dynamic quality of experience fuzzy logic method, (QFL) VHO algorithm that combines the advantages of VLC, such as bigger bandwidth higher data rate, un-regulated spectrum etc. with the advantages of RF, like bigger coverage area and its non-blocking nature in terms of enhancement of QoE and reduction in unsent packets, by using the data rates (bandwidth) of the VLC and RF of the user in order to enhance the QoE of the UE when handover is triggered. The fused input metrics gives an output QoE based on which hand-over is executed or not. The VLC has a bigger bandwidth, which means a higher data rate. Therefore the UE always prefer to hook onto the VLC link, the longer the duration of the connection to the VLC link the better the QoE of the UE is enhanced. The bigger the bandwidth of the link or the higher the transmission rate of channels the better the QoE of the UE. The QFL is deployed to make a handover decision in a heterogeneous network, by integrating LOS VLC and RF systems, where VLC and RF complement each other to give a seamless connection to the UE. This is achieved by using a fuzzy logic technique where the fused input metrics gives an output QoE based on which handover is executed or not. The performance of the QFL is com-pared with FL in [11], I-VHO and D-VHO as benchmark schemes.

The condition of the handover largely depends on the condition of the future metrics. The VLC connectivity is preferred over the RF system due to its huge merits such as a bigger band-width; higher data rate etc., hence the concentration on VLC network. In our design, the UE will trigger a handover to RF, only when the VLC network cannot sustain connectivity. The VLC connectivity can be assessed by the UE by considering the QoE reward of the UE, when connected to the candidate's network. We took into consideration the transmission rate of the VLC in order to determine the best QoE value that will ensure to the benefit of the UE when is connected to the VLC AP. Relevant handover metrics such as velocity, the length of unsent packets in queue in the uplink, handover failure probability to the RF, probability of short interruption and performance measurements are described, and the indecision and inconsistency that are en-trenched in decision metrics are addressed by QFL.

Our contributions in this article are shown as follows:

Using input metrics such as velocity, handover failure probability, and probability short interruption and size of unsent packets in queue (delay) in order to achieve a better QoE of the UE.

We propose QFL scheme that is non-static and more responsive to the user's needs and can ensure enhancements of the UE's QoE than the I-VHO, D-VHO and the FL-VHO schemes.

The combined input metrics gives an output QoE that is used to determine whether handover will lead to enhanced QoE of the UE based on the data rate (bandwidth).

Our scheme aims at reducing the number of unsent packets in queue (delay), handover failure probability, and better average QoE of the UE when handover is executed.

The subsequent sections of this paper are organized as follows: Section 2 Related works, Section 3 System design, Section 4 Our proposed VHO decision-making algorithm using QFL is discussed in Section 5 Simulation, Section 6 Results and discussion, and Section 7 Conclusion.

2. Related Works

In this section, we highlight fuzzy logic (FL)-based VHO schemes as well as those schemes that considered the QoE of users for handover decision making in heterogeneous networks (HetNet). A vertical handover decision algorithm (VHDA) based on fuzzy logic (FL) was proposed in [11] to deliver universal access at any time. This algorithm took into consideration the received signal strength (RSS), monetary cost, available bandwidth and user preference as the vertical handover decision criteria. This VHDA deploys the FL method to evaluate the available networks performance.

From the simulation results, the FL-based VHDA makes accurate handover decision, reduces the probability of call blocking and decreases unnecessary handovers. They tried to solve mobility issues in HetNet in order to provide a seamless connection while the user moves. In this regard, the system condition and the user preference were taken into consideration for efficient vertical handover. Aziz et al. [12] proposed an FL-based vertical handover algorithm, referred to as next generation-vertical handover decision algorithm (NG-VDA), to provide the user an efficient vertical handover between LTE and WLAN on the basis of many parameters. In [13] a mobile user can transit between wireless networks since many heterogeneous networks are deployed and this was implemented in a small area. So, therefore, there was a need for vertical handover usage in an effective manner. They proposed two vertical handover schemes that are based on fuzzy interference system and subtracting clustering method in a heterogeneous environment and simulated to verify performance. According to priority, this method can be used for easy and fast handover between different protocol users. Zhang et al. [14] proposed a multiple attributes handover algorithms based on fuzzy logic. They designed an algorithm that utilizes received signal strength (RSS), forecasting RSS, delay, network loads and battery utilization as parameters to design a fuzzy logic system that reduces the gray prediction algorithm. The fuzzy logic method is used to process the parameters, and obtain the quantized value of each of the network parameters membership. This is used to calculate the network performance evaluation values to make a handover decision. Also, their algorithm considered the group user types and priority. They sort to use the simulation scenario to test their algorithm effectiveness. The experimental results showed that their proposed handover scheme can reduce the handover, reduce network load and ensure good QoS. The aim of their work was to present a fuzzy logic based on motion trend of vertical handover algorithm. They used two algorithm the predetermined fuzzy logic control and handover decisions process. They deployed a predetermined procedure, according to the motion of trends of mobile network (MN) and the received signal strength of the WLAN to filter out appropriate information and decrease the amount of unnecessary data and system overheads. After that the RSS, network available bandwidth and the cost was fed into the fuzzy logic controller. A comprehensive final value of the performance of the network (VCPN) was achieved by the normalization process and the final decision is made according to VCPN and the dwell time. Their simulation results showed that, the proposed algorithm can make handover decision effectively eliminates ping-pong effects and improves the network switching performance [15]. Wang et al. [16] proposed an FL-based dynamic handover scheme that appropriately assigns users to either RF or LiFi access points (APs). They considered the channel state information (CSI), user speed and desired data rate to determine whether a handover needs to be triggered. Their proposed scheme shows a performance improvement of approximately 40% in terms of both data rate and user satisfaction level when compared with the conventional handover algorithms. Mou et al. [17] considered service types such as voice, video, and data and their QoS requirements for handover decision using fuzzy logic between macrocell and femtocell networks. In this work, received signal strength indicator (RSSI), data rate, users velocity, and interference level (signal-to-noise plus interference ratio) were used as input parameters for handover decision making.

Hou et al. [18] exploited the strength of FL to handle conflicting scenarios involving different interruption types and traffic modes. Their scheme achieved excellent performance in terms of packet transfer delay when compared with benchmark designs. One of the drawbacks of the above VHO schemes is the lack of attention paid to the actual QoE of a mobile user. Motivated by this state of affairs, some authors have critically considered QoE for vertical handover. A handover design based on media independent handover (MIH) for a heterogeneous mobile wireless multimedia network was proposed by Jailton et al. [19]. The media independent handover IEE 802.21 proposal extends its design with QoE-aware seamless mobility, video quality estimator, dynamic class of service mapping, and the set of content adaptation. The proposed design considers QoE needs and offers the best connection for mobile clients and available wireless resource in IEEE 802.11e and IEEE 802.16e service classes. Zineb et al. [20] proposed a QoE-fuzzy vertical handover algorithm with QoS management and QoE decision. They sought to find a balance between maintaining the requested QoS and keeping a satisfied QoE during a VHO process for HetNet. The simulation results showed performances improvement for throughput and delay. Quadros et al. [21] tried to solve the problem in a HetNet and how QoE can be used to support emerging video applications in diverse operator environments. This problem was solved by deploying QoE handover architecture for converging heterogeneous wireless networks (QoEHand) to maximize the QoE of wireless clients. Bao et al. [22] proposed a VHO scheme to maximize the QoE of a user in VLC HetNets, by applying Markov decision process (MDP) to enhance the QoE and reduce the handover cost of the user. The simulation results showed that our proposed VHO scheme attained a relatively high average QoE when compared with benchmark schemes. So far, only a few authors have exploited the strength of FL for handover decision making under conflicting scenarios in VLC HetNets. To the best of our knowledge, no scheme has applied FL to safeguard QoE in VLC HetNets despite the uncertainties surrounding it. In this paper, we present a VHO scheme based on FL that takes into account the QoE of ongoing users in VLC HetNets as a critical parameter for handover decision making.

3. System Model

The VLC-HetNet network is composed of an RF access point (AP), a number of overlapping VLC hotspots, UE and a control center that is connected to an external network as shown in Figure 1. For our combined VLC and RF system, a categorized structure is preferable. In this configuration VLC and RF cover in an indoor “hotspot” to provide broadband wireless access. A collocated VLC and RF cover a much bigger area and offer much greater mobility to the UE, although with a small bandwidth. We assume that the RF AP has a queue for processing the uplink packets of the UE with buffer size and a downlink queue for transmitting data packets. An UE can download data via a VLC hotspot or RF AP, contingent on the state of the VLC link and UE's transmission mode. The RF links are assumed to cover the whole room.

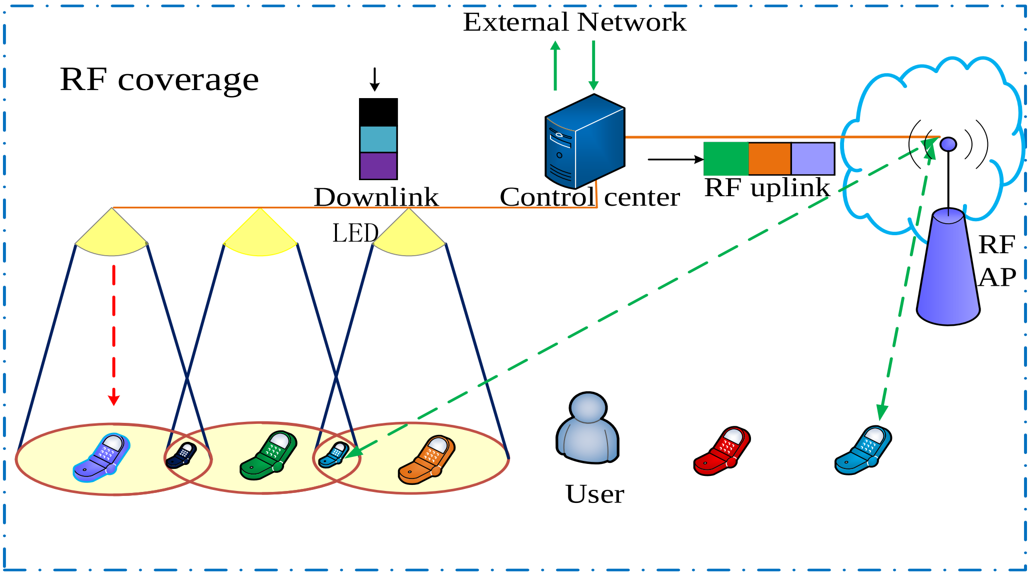


Figure 1:The Design Model

An overlap region is an interference area among two or more VLC hotspots. The overlap region is also termed the interference region. This happens as a result of two waves of the same frequency adding up to form an amplitude that will either be larger or smaller than the individual waves, depending on whether or not their peaks and troughs match up [23]. This causes serious degradation of the UE's QoE when the user is found in this region. Since a UE moves in a random manner, the duration of time spent in and out of the VLC hotspot is a random variable. The movements of UE can be described by their directions d (radians), velocities v (m/s), time durations t (s) and pause time pt (s). An access point (AP) mode [24] is used for both wireless net-works, in which all communications between UEs or between a UE and a conforming host (CH) essentially go through a control center (CC). The control center handles the handover process by receiving requests, processing them and executing handover. A multimode UE can use both media VLC or RF to offer data and execute VHO and switch to RF radio when the LOS VLC link becomes blocked during transmission. If the VLC link is recovered, the UE instantaneously execute a handover to the VLC which is the preferred choice due to its broadband attributes. However, in any of the handover instances, some amount of handover triggering delay occurs during the process. In practice, maximization or enhancing QoE, availability of bandwidth, minimizing delay cost are the main concerns of the user. Therefore, we use the number of unsent packets or average delay of transferring packets during the blocking period of the LOS VLC as one of key performance metric and also the velocity of the UE. Since these have a direct influence on the QoE of the UE and the performance of the handover process. There are two kinds of blocking when the VLC link is unavailable. The first kind is an out-of-coverage blockage; this occurs when the UE moves out of the VLC hotspot. When it happens, it normally lasts for at least few a seconds until the UE returns to the VLC link. The second kind is the LOS VLC link blockage or unavailability of the VLC link caused by haphazard movement of objects or human beings in a hall or when the UE is found in the overlapping area of two VLC links [25]. This kind of block-age is not long and momentary, since its time duration is normally less than $0< t \leq 2$ s, t is the blocking duration time. We can easily differentiate one type of blocking from the other by taking into consideration the time duration, i.e. the minimum duration of the out-of-coverage block-age is quite longer than the maximum duration of the LOS VLC link blocking. Average interruption probability (AIP) represents the average proportion of the time that a channel experiences a blockage or an interruption. AIP = $\gamma 1$ D1, where $\gamma 1$ represents the mean blockage rate of occurrence and D1 represents the time the LOS VLC link is blocked.

The blockage of the VLC link follows an exponential random process. $\gamma 1$ and $\gamma 2$ are the mean duration of the VLC channel when not blocked and blocked, respectively. The rate of change of the

VLC channel from non-blocked to blocked is denoted as 1/γ1 (s -1) while 1/γ2 (s -1) represents the rate of change of the VLC link from blocked to non-blocked. The main problem of an indoor LOS VLC networks is the two types of interruption. For VHO among the VLC and RF networks, we have an out-of-range blockage of the VLC link, also when the UE is found in the overlap region of the VLC hotspots. However, obstructions of the VLC link will result in the reduction of QoE and bandwidth of the UE. In this instance, the VLC optical signal strength varies haphazardly, which makes it problematic to detect when a blockage occurs. Therefore, the key objective of the RF VHO schemes is to find a blockage happening and execute VHO timely and correctly. On the contrary, for the VHO among LOS VLC and RF networks, the two blockages occur. But the detection of a blockage occurring is limited the LOS VLC link. When a blockage happens, QoE considerably decreases suddenly, which affect the QoE of the UE negatively, this phenomenon is easily noticed by LOS VLC receiver. The main problem of this VHO algorithm is to determine which blockage happened and when handover is to be executed. Hence, the key challenge in the two VHOs conditions is that they are not the same and therefore, a suitable handover metrics and approach have to be adopted for the integrated LOS VLC and RF systems.

As the non-blocking of the VLC which is the broadband medium is determined by blockage, making a VHO decision, we can use the blockage type as one of the metrics. The input metrics are velocity of UE, number of unset packets in the queue (delay), the probability of short interruption and handover failure probability to RF. During the handover decision process, another essential factor taken into account is the probability that a handover to the RF link may fail. This can happen as a result of the unavailability of free RF link to connect an incoming handover re-quest. In other words, when the uplink buffer size is full; this will lead to longer delay or lead to call drops and loss of data broadcast. Hence, delay in reassigning data during the blockage process mainly depends on a number of parameters: the time taken for an interruption, the delay that occurs during VHO execution, the number of unsent packets and the handover failure probability of the RF link. These parameters depend on the variables whose network and traffic conditions are transitory. In our integrated system, these parameters can be used as handover decision metrics. However, these prospective handover decision metrics have unclear and contrary behavior. It may be one of the two types of blockage that can happen at a time which the UE is cognizant of. However, dissimilar kind of blockage needs different handover decisions. For long disruption, a VHO to RF should be executed at the earliest stage, since the RF is the only available network. While for a short disruption, VHO should be executed only if the block-age is not momentary, as to shun needless handovers. The number of packets in the uplink has an impact on a handover decisions, in multimedia transmission, the number of packets in the queue can vary drastically depending on the traffic mode. A larger number of packets take a longer time to transmit on a narrowband channel and therefore, VHO is not the best decision in this case for short blockage. On the contrary, switching a smaller number of packets to the RF link for transmission during the time of VLC broadband unavailability can fast track data transfer. Additionally, when the RF link, is unsuccessful in accepting any handover request at that instant, executing handover to the RF link could lead to longer delay by implication delay cost or dropping of the connection. On the other hand, un-used RF link means a lower handover failure probability, therefore, is good to switch service. Hence, a complete VHO decision algorithm must be able to handle these undefined factors and solving contradictory problems, when these metrics indicate divergent handover direction. The QoE of a UE is defined according to three types of services: audio, video, and data transfer. Basically, UE's QoE can be obtained from the mean opinion score (MOS) of data traffic [26]. The MOS has five values from 1 to 5 indicating user's satisfactory degrees: "Bad," "Poor," "Fair," "Good," and "Excellent," respectively [27]. In video traffic, the MOS primarily depends only on the loss of a slice of a frame from the video stream [28]. The MOS can be simplified as a function of the peak signal-to-noise ratio *(PSNR)* with some transformation [29]. The QoE function Q_{video} is given as:

$$Q_{video}(P_{snr}) = 4.5 - \frac{3.5}{1+\exp(b_1(P_{snr} - b_2))} \quad (1)$$

where b_1 and b_2 are the parameters determining the shape of the function and P_{snr} is the experienced *PSNR*. Where $b3$ and $b4$ are determined by the required maximal and minimal throughputs of the network [30]. For audio traffic, the QoE function Q_{audio} is defined by a nonlinear mapping of the *R* factor:

$$QoE_{audio} = 1 + 0.035R_f + 7\times 10^{-6} \times R_f(R_f - 60)(100 - R_f) \quad (2)$$

where R_f is the *R* factor defined by ITU to reflect the audio quality impairment from different [31, 32]. In order to translate end-to-end (E2E) QoE parameters, such as delay *(D)*, data rate *(R)* and packet loss ratio *(Pl)*, into QoE values, the following models can be applied according to service types:

$$Q_{audio}(R_f) = 1 + 0.035R_f + 7\times 10^{-6} \times R_f(R_f - 60)(100 - R_f) \quad (3)$$

$$QoE_{video} = 4.5 - \frac{3.5}{1+\exp(0.5\times(PSNR - 30))} \quad (4)$$

$$MOS = 0.45\times\log(DBW) + 2.4 \quad (5)$$

where DBW is the downlink bandwidth of the connection [33].

3.1 The two basic types of VHO algorithms

Based on the previous analysis above, it can be realized that: the best approach to achieve a minimum delay (delay cost), is either executing a VHO immediately or waiting for the VLC link, i.e. broadband to resume its recovery. The two types of algorithms that are used to discover the prospects of the integrated LOS VLC and the RF system and to serve as a standard to assess the performance of the QoE fuzzy logic (QFL) based VHO decision algorithm is deployed. We have the immediate VHO (I-VHO) and the dwell VHO (D-VHO) algorithm. The flow chart for the algorithm is shown in Figure 2. The UE transmits data on the VLC link. The VHO decision process will be executed when an interruption happens, so has to decide a dwell time before the VHO is performed. If the LOS VLC link is recovered before the dwell time of the timer elapses then, the UE will continue its disruption using the LOS VLC link; or else a VHO will be executed to the RF link. There is no undesirable delay time when a long interruption occurs, for the I-VHO scheme, there is no dwell time and hence, no undesirable delay time when long disruption occurs. On the contrary, the D- VHO algorithm sets the dwell time as the maximum duration of a short disruption in order to avoid too much delay, which is occasioned by switching the transmission of huge data to the narrowband RF radio link when a LOS VLC link is blocked. After some handover delay performance, if handover attempt is successful; else, the link will be switched to the RF link: or else, the UE goes through a process of handover failure recovery. In the recovery process, the UE will continuously send a handover request until a predetermined time elapses. Then if the UE gets feedback that its handover initiation to RF link drops, it will reconnect to the LOS link after the network is recovered. An UE in RF observes the state of the VLC and executes a handover back to the LOS VLC link once it recovers after some handover performance delay.

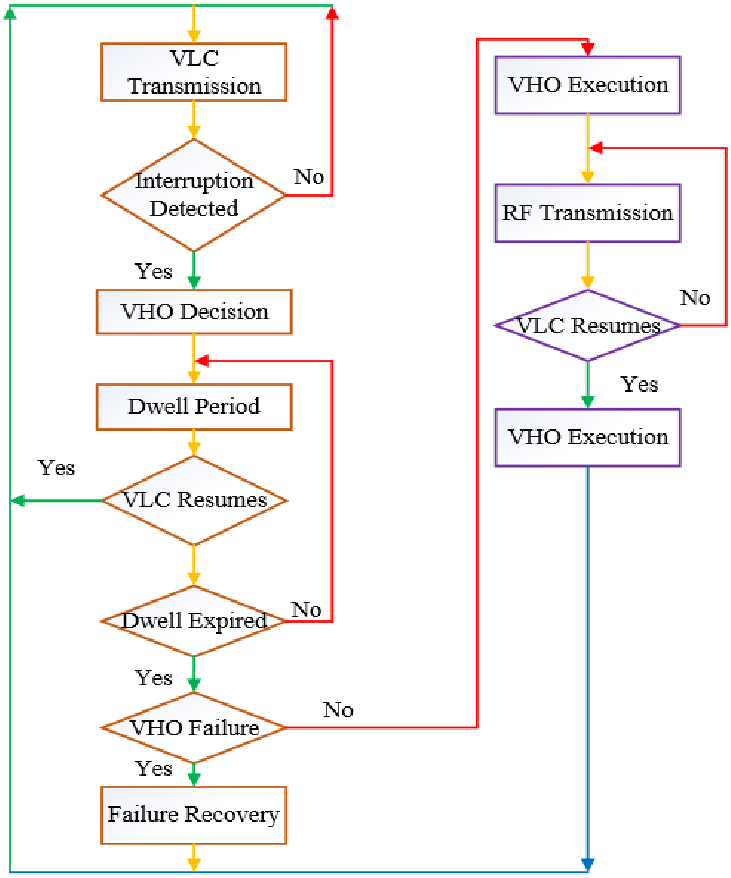


Figure 1: Flow diagram for the VHO algorithm

4. VHO Decision-making algorithm using the QFL-VHO

$$R\upsilon - \rho^{(n)} = B\log_2(1+SINR) \quad (6)$$

Where R is the achievable data rate of the channel, B is the bandwidth of the channel; SINR is signal-to-interference-plus-noise ratio. The Shannon capacity is used for estimating the achievable data rate between user equipment υ and VLC access point (AP) ρ. Under this condition, the whole bandwidth can be used for data transmission in the VLC system. The achievable data rate can be expressed as Change in the *SINR* of the UE i.e., the difference between the *SINR* after handover decision and SINR before handover decision as shown below. The UE measures the QoE of VLC and that of the RF through the control center, in accordance with the Δ*SINR* = *SINR* (after the decision) - *SINR* (before decision). This is achieved by using the achievable data rate method, given by $R = B\log_2(1+SINR)$ as defined in equation (6).

QoE is an output indicator, which determines whether a handover should be performed between the VLC and RF or not, taking into consideration the benefits the UE will derived. Handover is triggered when the VLC link is blocked or unblocked; the UE measures its QoE from the APs of the VLC and the RF through the control center to determine whether a handover should be executed or not. The QoE of the UE is directly proportional to the R of the user; this also implies that the UE's QoE increases when B of the channel increase of the i.e. QoE = KB where K is a constant of proportionality. We assume that $R_{VLC} = B\log_2(1+SINR_{VLC})$, is the data rate in VLC i.e. 1Gbps and $R_{RF} = B\log_2(1+SINR_{RF})$ is data rate in RF (10Mbps). $R_{VLC} > R_{RF}$ So when the UE is found in the VLC hotspots its QoE is enhanced than when the UE is within the RF coverage. When the VLC link is blocked, the UEs QoE degrades drastically, in order to prevent a complete degradation of the signal which may result in breakdown in communication; a handover is triggered to the RF network.

When the VLC link is blocked, handover to RF only occurs when $R_{VLC} > R_{RF}$ QFL has the ability to respond to the user's movement and demand in order to better the UE's QoE. Again we propose a novel algorithm that deploys QFL to make the VHO decision. A good handover decision must be made according to link and traffic conditions. Since, these main metrics change is non-static, they are then processed to make fuzzy sets, and their dynamic nature is resolved by fuzzy reasoning so that it can produce an exact and adjustable decision. Four input fuzzy variables are recognized: the likelihood of short interruptions, the handover failure probability to RF, and the number of unsent packets in queue (delay), and velocity of the UE. In the system, the numbers of short and long disruptions that occur are recorded. Once another disruption happens, the UE computes and assess the likelihood of a short disruption, which acts as an input for the QFL decision system.

$$P_{short} = 1 - \frac{P^{\beta}}{P^{\eta} + P^{\beta}} \quad (7)$$

where P^{β} = long interruption P^{η} = short interruption recorded before by an UE.

Two input fuzzy sets are defined for the fuzzy variable "the probability of a short interruption": "High" and "Low". The complementary, membership functions are illustrated in Figure 3(a) when there is a long interruption, it is better to handover immediately to the RF, so that the UEs QoE is not further degraded. For short interruption, the D-VHO is preferred to prevent ping-pong effect, i.e. frequent handover to and fro the VLC hotspot and the RF coverage. The number of VHO, in the D-VHO, is reduced; hence the handover request to the uplink is decreased, thereby reducing the number of handover request to uplink. In the case of the short interruption meaning the VLC will not take a long time to recover when its links blocked, therefore, it makes sense for the UE to wait for the VLC link recovery.

4.1 The four input metrics for the first phase of Fuzzification.

As shown in Figure 3(b), the velocity of the UE is used as input metrics to show the speed of the UE. The velocity shows how fast or slow the user moves, because the velocity the UE will affect the QoE of the, when the user velocity is fast the QoE of the UE decreases.

We assume, the first short interruption for FL is 75% (o.75) as illustrated in Figure 3(b) which means there will be frequent handover, so in our proposed QFL scheme the short interruption is taken to be 70% (0.7) as in [18] its membership in "High" is unity this means that the occurrences of the short interruption are reduced to limit the number of handover request, in order to have good system performance. And long interruption is increased from 25% (0.25) to 30% (0.30) its membership in "Low" is unity to make sure that "the controller will keep the HO request for sometime so that the momentary unavailability of the VLC is restored before switching back to the VLC links. The number of unsuccessful handovers is recorded, and the total number of handover executed, correspondingly, and their ratio acts as an estimate of the failure probability of handover to the RF link.

$$P_b = \frac{N_f VHO}{N_u VHO} \quad (8)$$

Where P_b handover failure probability to RF link, $N_u VHO$ and $N_f VHO$ is the total average number of vertical handovers and the average number of unsuccessful handover stated respectively. Also, the two input fuzzy sets "High" and "Low" are defined for the fuzzy variable "the handover failure probability to RF link" [18]. The two membership functions complement each other, as illustrated in Figure 3(c). The number of unsent packets (delay) is also an input fuzzy variable that is used in this research. When a disruption happens, not all the packets in the queue may be transferred and some of the other packets may still delay in the queue as shown in Figure 3(d). When a Long interruption occurs, it is not always advisable to perform an immediate handover. But if short interruption occurs, executing handover to the RF link is more likely to succeed. Our scheme is determined by the following four metrics: the velocity of the UE, the number of unsent packets in queue (delay), probability of short interruption, and handover failure probability to RF. For long queue of packets in the queue, long VHO execution delay, and short interruption duration, the D-VHO scheme is preferred since it obtains much less delay or delay cost than the I-VHO method. Whereas I-VHO is preferred to the D-VHO when there are short queue of packets, short duration VHO execution, and long-interruption-duration conditions

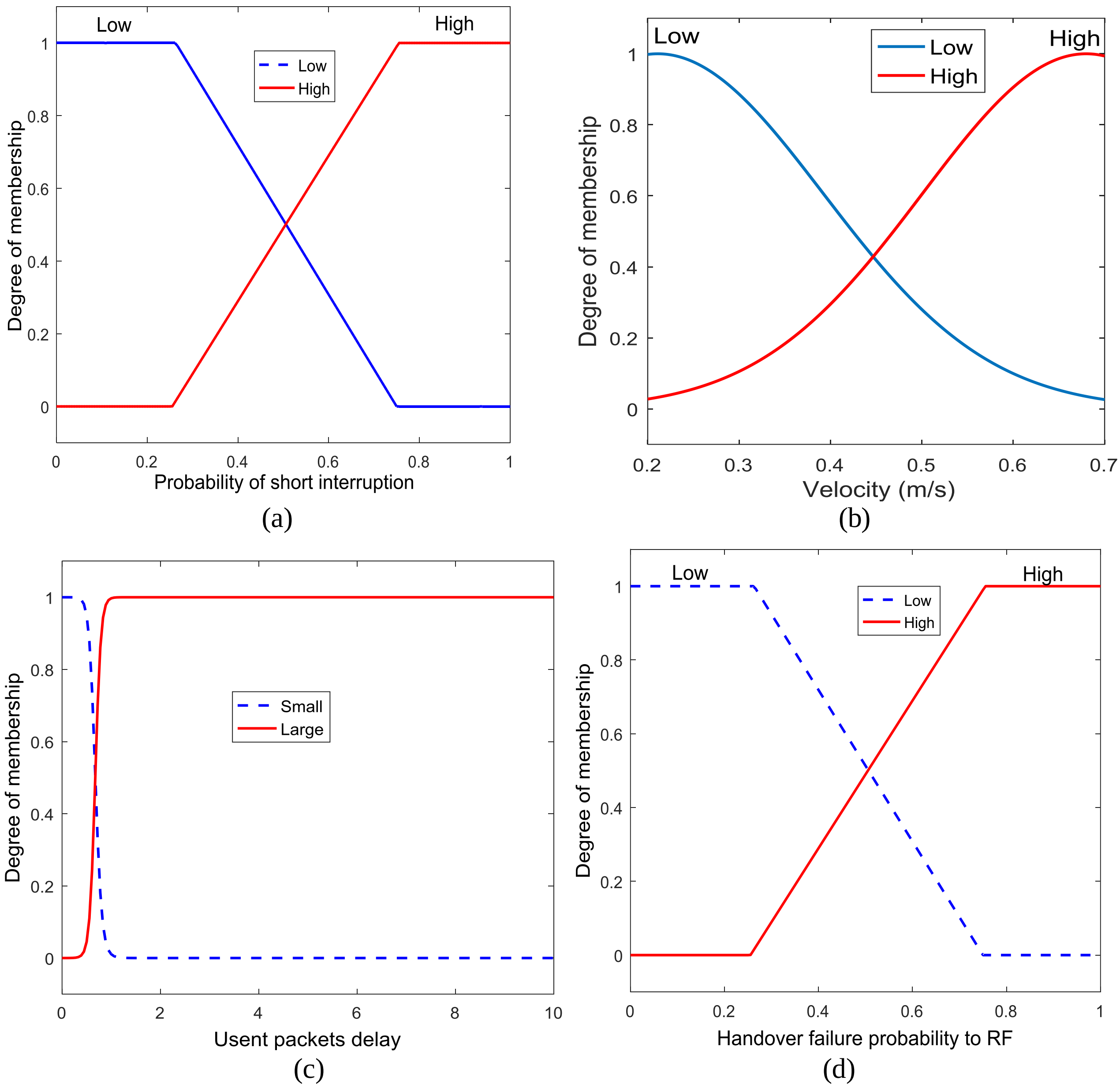


Figure 3: Membership function of input metrics (a) Probability of short interruption (b) Velocity (c) unsent packets (delay) and (d) Handover failure probability

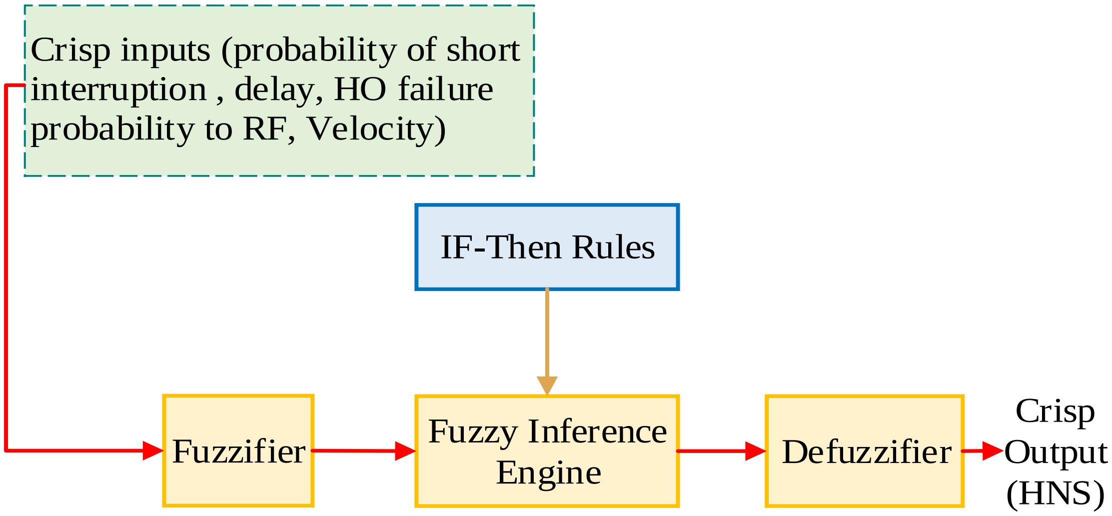


Figure 4: shows the block diagram for phase one of the QFL systems for our proposed VHO schemes.

4.2 First phase of fuzzification process

A fuzzifier, fuzzy inference engine, and defuzzifier are deployed in this work. The input metrics such as velocity, the probability of short interruption, handover failure probability to RF and number of unsent packets in the queue are fed into the fuzzifier. The fuzzifier converts these input variables into the fuzzy inference engine. Then the fuzzy inference engine maps the input fuzzy sets into output fuzzy sets by using the fuzzy rules in the rule-based. The output fuzzy set are finally fed into the defuzzifier for defuzzification into crisp output value i.e. heterogeneous network stability (HNS), which is a measure of how stable the HetNet is. HNS is determined by the probability of a short interruption, velocity, handover failure probability and the number of unsent packets in the uplink (delay). In our design, we used four fuzzy input variables and each fuzzy set contains two variables; hence the maximum number of rules is given x^n, where n is the input fuzzy variable and x is the fuzzy set for each variable. Therefore the number of maximum rule base possible is $2^4 = 16$. Below are some selected IF-THEN-RULES

Phase 1 IF-THEN- RULES

If the velocity is low, the handover failure probability is low, the probability of short interruption is low, the number of unsent packets (handover delay) is large, then HNS is High

If the velocity is low, the handover failure probability is low, the probability of short interruption is low, the number of unsent packets (handover delay) is small, then HNS is High

If the velocity is low, the handover failure probability is low, the probability of short interruption is Low, the number of unsent packets (handover delay) is large, then HNS is Low

If the velocity is low, the handover failure probability is low, the probability of short interruption is High, the number of unsent packets (handover delay) is low, then HNS is High

If the velocity is High, the handover failure probability is High, the probability of short interruption is low, the number of unsent packets (handover delay) is large, then HNS is Low

If the velocity is High, the handover failure probability is low, the probability of short interruption is low, the number of unsent packets (handover delay) is Small, then HNS is High

If the velocity is High, the handover failure probability is High, the probability of short interruption is low, the number of unsent packets (handover delay) is large, then HNS is Low

If the velocity is High, the handover failure probability is High, the probability of short interruption is High, the number of unsent packets (handover delay) is Small, then HNS is Low

4.3 4.3 The second phase of the fuzzification process

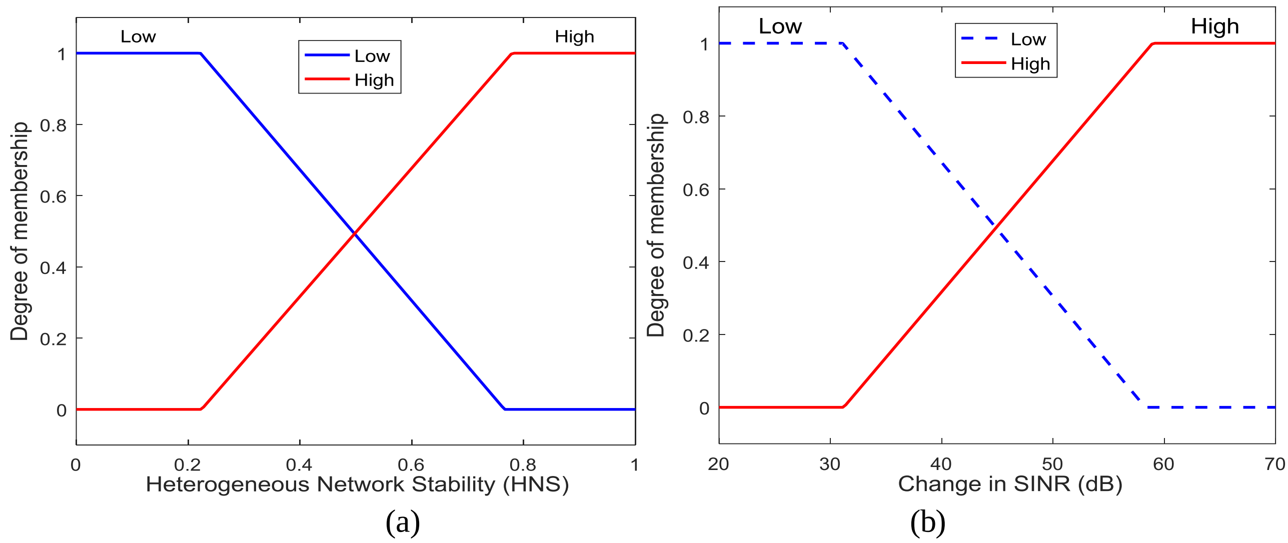


Figure 5: Membership function of input metrics (a) Heterogeneous Network Stability (HNS) (b) Change in SINR (dB)

The two input metrics for the second phase of the fuzzification process is illustrated in Figure 5(a, b). The heterogeneous network stability (HNS) is a measure of how stable the HetNet is. If the network, is stable it enures to the benefits of the user. The more stable a network is the better and higher it's QoE. The HNS is an output indicator of the first phase of the QFL process; the HNS is subsequently fed into the second stage as one of the inputs to the second phase of the fuzzification process with the SINR as the second input.

Signal-interference-Noise Ratio (SINR): This key concept was introduced into VLC by [12, 15, 34] to show the quality of a received signal or signal reception. SINR can be used as the standard for calculating the performance of parameters of wireless networks, like network channel, interrupted probability and coverage due to its essential importance. The higher SINR is the better the quality of the received signal from a network.

The SINR is defined as:

$$\text{SINR}=\frac{\frac{E}{L(r)}}{W+\sum_{i=1}^{N(R,r)}\frac{E}{L(r+r_i)}} \tag{9}$$

where E is the transmitter power of VLC node. For clarity, the transmitting power of all the nodes is supposed to be the same. This assumption is comparatively valid in small hotspot. r_i is the distance between transmitting and reception nodes , W is the noise power, $N(R,r_i)$ represents the number of Poisson points in a circular ring with area $\pi(R^2-r_i{}^2)$ is generally expressed as:

$$N(R,r_i)=N(\pi(R^2-r_i{}^2)) \tag{10}$$

To underscore its relation with Poisson processes, a small transform to the definition of SINR will lead to more convenient expression.

$$SINR = \frac{\frac{1}{L(r)}}{\frac{1}{SINR} + \sum_{i-1}^{N(R,r)} \frac{1}{L(r+r_i)}} \qquad (11)$$

where SNR is the signal-interference-noise ratio on transmitting end [35].

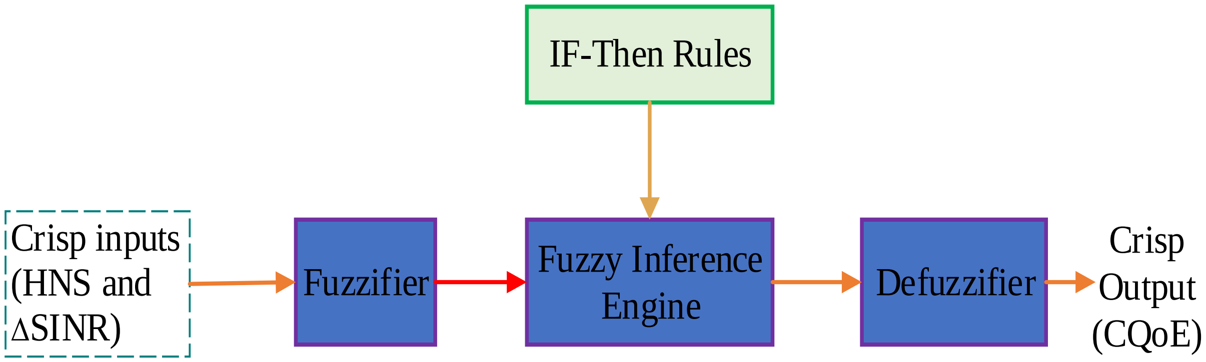


Figure 6: shows the block diagram of the second phase of Fuzzification

Figure 6 shows the block diagram for the final stage of QFL system for our proposed VHO schemes. A fuzzifier, fuzzy inference engine, and defuzzifier are deployed similarly as in Figure above. The input metrics are HNS which is an output of the first phase and the Δ SINR are fed into the fuzzifier at the second stage. The fuzzifier converts these input variables into the fuzzy inference engine just as in the first phase. Then the fuzzy inference engine maps the input fuzzy sets into output fuzzy sets by using the fuzzy rules. The output fuzzy set is finally fed into the defuzzifier and then converted into crisp output value as corresponding QoE (CQoE). The CQoE is the QoE the user will experience after handover is executed. The CQoE directly correlates with the data rate the bandwidth as stated in equation (6). When the CQoE of candidate network is high, the bandwidth of that candidate network is expected to be bigger and vice versa.

Phase 2 IF-THEN- RULES

From VLC to RF

If HNS is high and ΔSINR is high, then CQoE is enhanced and handover is executed

If HNS is high and ΔSINR is low, then CQoE is reduced and handover is executed

If HNS is low and ΔSINR is low, then CQoE is reduced and handover is not executed

If HNS is low and ΔSINR is high, then CQoE is reduced and handover is not executed

From RF to VLC

If HNS is high and ΔSINR is high, then CQoE is enhanced and handover is executed

If HNS is high and ΔSINR is low, then CQoE is reduced and handover is not executed

If HNS is low and ΔSINR is low, then CQoE is reduced and handover is not executed

If HNS is low and ΔSINR is high, then CQoE is reduced and handover is not executed

5. Simulation

5.1 Simulation Scenario

Using MATLAB, simulation is carried out to compare the performance of the QFL-VHO scheme with that of the benchmarks schemes I-VHO, D-VHO, and novel FL. We use velocity, handover failure probability to RF, the probability of short interruption and number of the unsent packet in a queue as performance metrics. The two traditional schemes used are I-VHO and D-VHO schemes. For the I-VHO, the control center will trigger a handover immediately when the VLC link is blocked or unblocked, also when the UE moves from the VLC hotspot to RF only coverage and vice versa. On the contrary in the D-VHO, the controller switch sets the handover time to a predetermined time to trigger handover. The novel fuzzy-logic (FL)-based decision-making algorithm for VHO, which is capable of combining the advantages of both schemes to attain excellent handover in terms of packet transfer delay for all the cases was considered. The simulation scenario is set up in a small hall with 9 overlapping VLC hotspots and an RF AP. Each VLC hotspot has a coverage radius of 2.0 m. The overlap areas of VLC hotspots are regarded as out-of-VLC coverage due to the interference of existing optical signals. The locations of the 9 VLC APs are as follows: (2, 2, 8), (2, 5, 8), (2, 8, 8), (5, 2, 8), (5, 5, 8), (5, 8, 8), (8, 2, 8), (8, 5, 8), and (8, 8, 8). The RF AP can be accessed anywhere in the room. We assume that the uplink and downlink queues of the RF AP are M/M/1/K systems with maximum lengths of 10 packets [36]. Initially, a UE is connected to a VLC hotspot. The UE undergoes random movement in a uniform random direction within 0 and 2 *pi* radians. The velocity of UE is defined as the speed of movement in a particular direction. The range of UE's velocity is from 0.3 to 0.7 meters per second, which is somewhere between a slow walk and a quick stroll [37]. The period of time for UE to move to a new position is referred to as the movement time duration. The pause time is the period of time an UE remains at a new position. The random movement continues until the total simulation time (1 hour) elapses. The random movement of the UE leads to the blocking and unblocking of the VLC link.

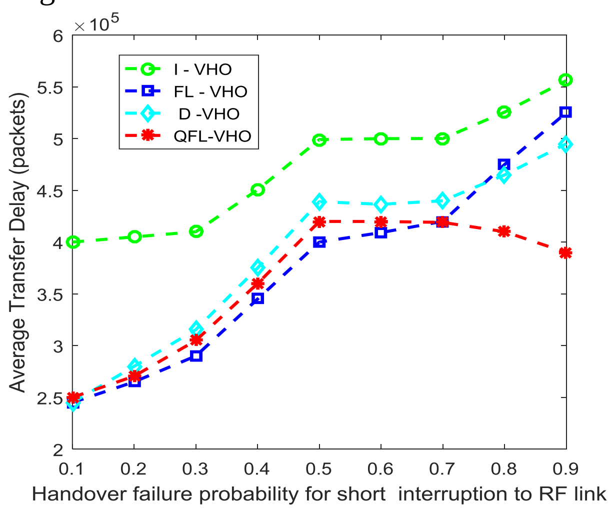
Table 1 Simulation Parameters

Parameter	Value
Hall dimensions	10 m x 10 m x 8 m
Number of VLC APs	9
Radius of APs	2 m
Velocity of mobile user v	0.3-0.7 m/s
Movement time duration t	1-10 s
Pause time pt	2-10 s
Direction d	0-2π radians
Bandwidth of VLC BV	1950 MHz
Bandwidth of RF	9.5 MHz
Signal to Noise Ratio in VLC SNRV	60 dB
Packet arrival rate λ	1 packet/s
Packet departure rate of VLC μV	2 packets/s
Packet departure rate of FR μRF	1.1 packets/s
Downlink queue length of ith user Li	20 packets
Users in the RF in the uplink	1-10
Dwell time t0	1, 0.5 s
Simulation time	4000s
Number of iterations	2000

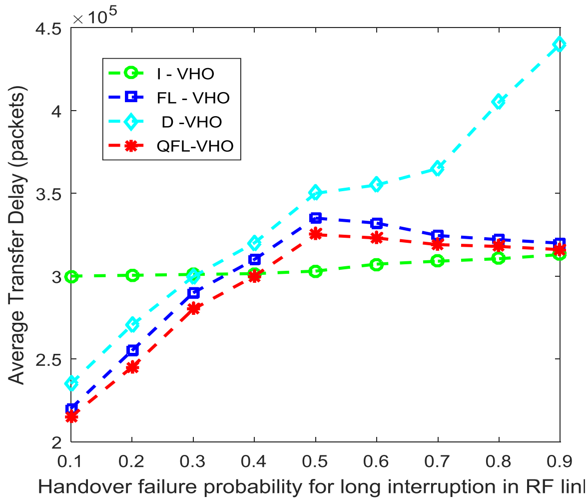
When the UE moves out of or into VLC coverage, the mean duration of blocking and non-blocking of VLC channel is updated. The Q-VHO algorithm utilizes this information for handover decision making. Our vertical handover scheme is compared with the immediate and dwell-based vertical handover schemes [38]. We deploy a network simulation to assess the performance of the two basic types of VHO algorithms for an integrated system. A QFL-VHO scheme that will enhance the QoE of the UE, decrease handover failure probability to RF and reduce the number of unsent packets in the queue (delay). Four input metric variable was used to derive an output that will enhance the QoE of the UE when handover is triggered. The Table (1) is the summarization of the simulation parameters. The arrival processes of new packets at the uplink are assumed as an independent Poisson process with mean rate λ (packets/s). And also we assumed that the length of the new packet obeys the geometric distribution rule [39]. With average length a^{-1} (packets per message), the duration of long and short interruptions are uniformly distributed between 4.9-5.1 *s* and between 0.125-2 *s*, respectively [18]. 100 Mb/s [40] is the bite link rate for the LOS VLC, and for RF is 10 Mb/s [24]. The fixed packet length *H* is 1Kb [41] and the number of UEs *N* is 20.

6. Results and Discussion

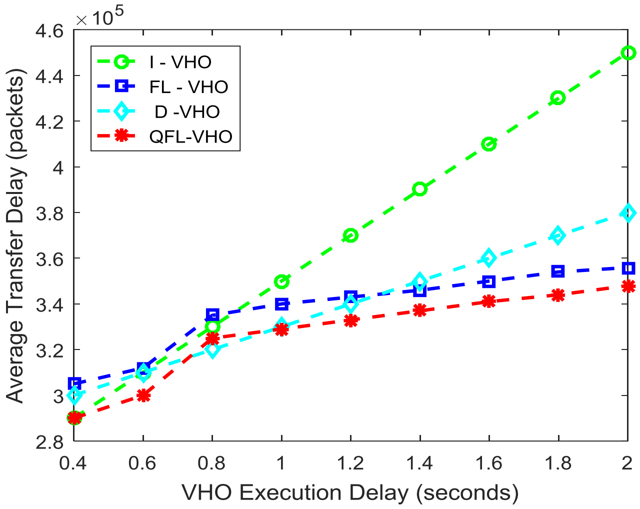
The impact of average transfer (packets) delay on handover failure probability for short interruption to RF link is shown in Figure 7(a). When there is a short interruption, the I-VHO shows worse performance. As seen in the case of the short interruption, the I-VHO always exhibits the worse performance. This will occur when the VLC link is interrupted, but the RF link is busy or inaccessible at that moment due to other subscribers from the external link. The I-VHO scheme may experience a sharp increase in average transfer delay; because the I-VHO may perform handover immediately as the short interruptions occur. This can result in queuing in the uplink, which may lead to an increase in transfer packet delay and eventually lead to frequent handover failure. Our proposed scheme shows a very good performance in terms of decreasing handover failure probability, as the transfer delay keeps on increasing with a corresponding increase in handover failure probability, beyond a certain threshold. This is good for the UE's QoE enhancement. Since our scheme is more dynamic to the user's needs, the UE makes few handover requests after a certain threshold. In this instance, the UE may connect more to the RF when the VLC link is interrupted. This may give the UE a better and more secure connection than the other schemes. The FL-VHO scheme has similar handover delay performance like our proposed scheme. In the short interruption, the penalty or cost for handover failure induces excessive or longer delay; which is normally more than the waiting or dwell time, until such a time when the short interruption ends. The D-VHO therefore, often has a better delay performance than the I-VHO a scheme, with its handover delay performance increasing gradually. Next we analyze the impact of average transfer packets (delay) as shown in Figure 7(b), initially when there was short interruption the D-VHO performs better than the I-VHO, on the contrary, the I-VHO outperforms D-VHO when there is a long interruption, assuming the packets size of the message are the same.



(a)



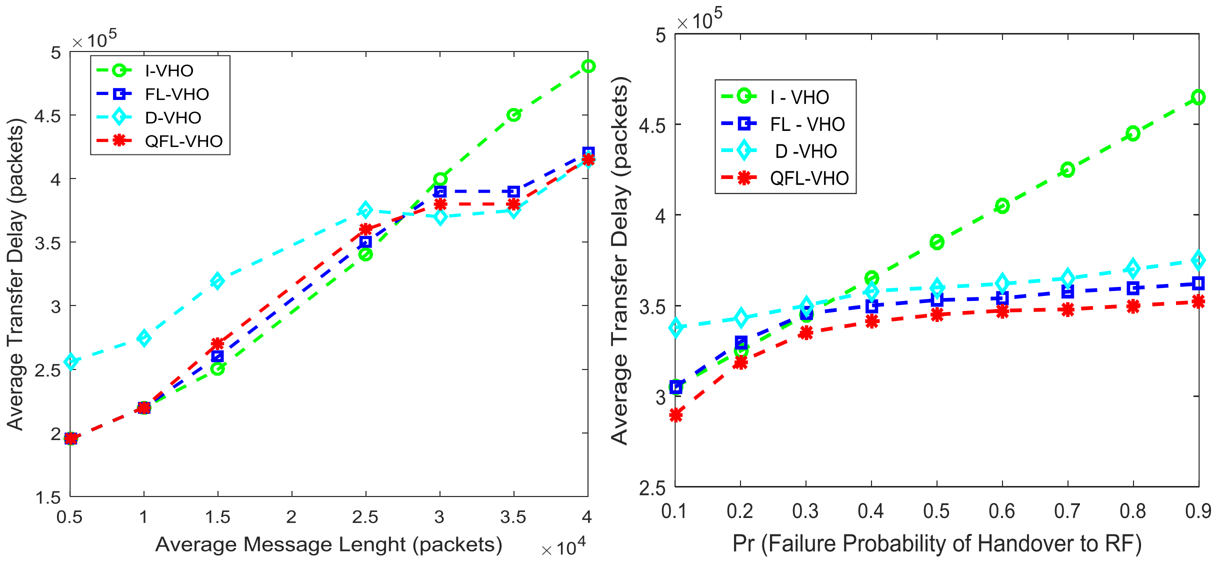
(b)



(c)

Figure 7: The impact of (a) handover failure probability for long interruption in RF link handover (b) handover failure probability for short interruption in RF link and (c) on average transfer delay (packets)

Because in this regard the D-VHO, always requires additional time “waiting” to execute handover. As stated earlier, the I-VHO execute handover immediately when an interruption occurs, so there would not be too much dwell time or “ waiting” before the handover is executed hence its better handover delay performance than the D-VHO in this circumstance. Because these schemes normally fail when the schemes reconnect back to the VLC and the VLC link is not recovered. When the handover request is small, the average transfer packets and handover failure probability are small. As the handover request keeps on increasing as a result of long interruptions, both average transfer delay and the handover failure probability for all the schemes increases. The FL-VHO and QFL-VHO schemes have similar delay performance, but our scheme performs better due to the fact it is more responsive to user’s needs when the VLC link is blocked or available. This will lead to more acceptable QoE performance for the UE.

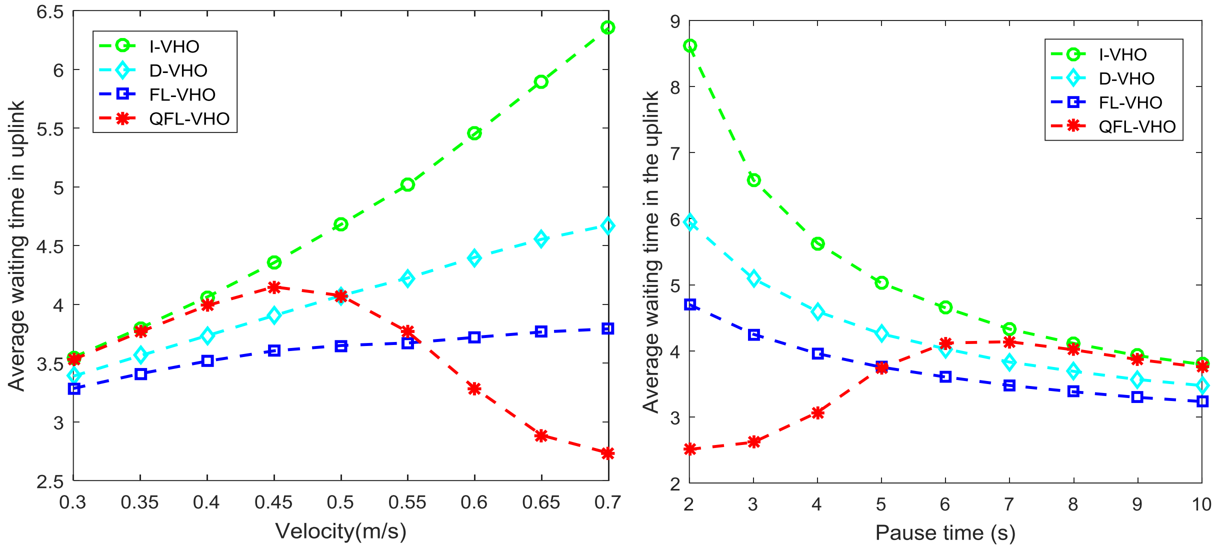


(a) (b)

Figure 8: The impact of (a) average message length (packets) (b) Pr (Failure probability of handover to RF on average transfer delay (packets)

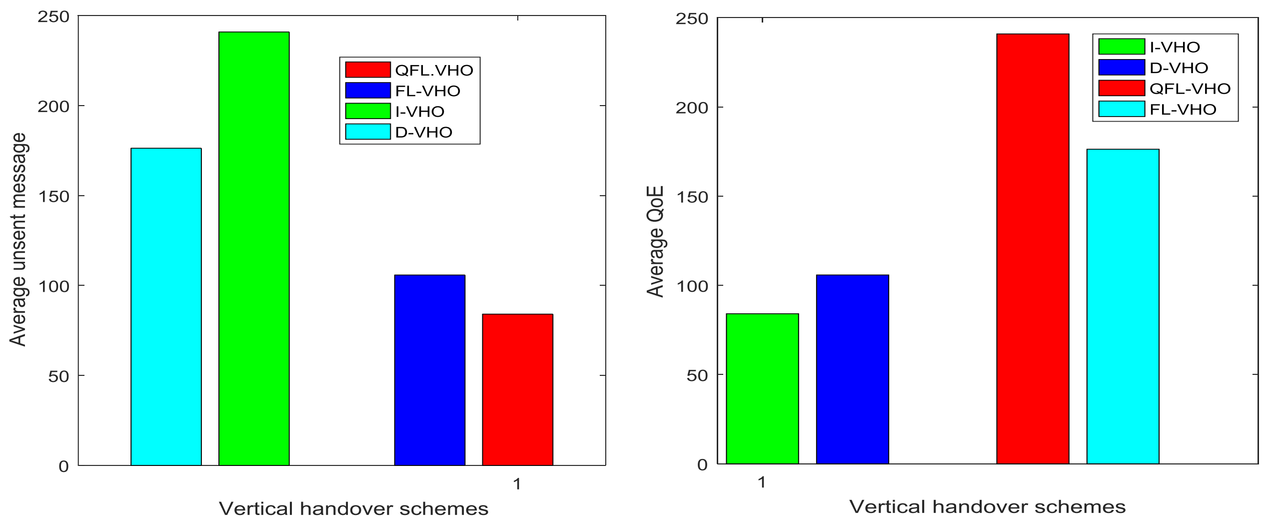
We analyze the impact of VHO execution delay (s) on average transfer delay (packets) as shown in Figure 7(c). The fuzzy logic scheme FL-VHO and QFL achieve an excellent result when it comes to delay performance, with respect to the VHO execution delay issues. It can be observed that the four schemes increase gradually when there is an increase in VHO execution delay. In this scenario all the schemes execute handover in the earliest time or in the later time, when there is a long interruption, VHO execution delay is bound to increase as average transfer delay (packets) increases. The D-VHO scheme most of the time will perform better than I-VHO scheme when a long interruption occurs. On the contrary, when a short interruption occurs, a lot of packets can be transmitted quickly after switching to the RF link if the VHO execution delay is very small. For this reason, the I-VHO exhibits less delay than D-VHO under this condition of small- execution delays. However when the VHO execution delay increases, the cost or penalty that emanate from the I-VHO increasingly outweigh its benefits and therefore, I-VHO may have a worse delay performance than D-VHO. Though the fuzzy logic scheme may have some challenges with regards to the interruption mode, FL-VHO and QFL-VHO scheme will prefer to wait in most instances, when the execution delay is large in order to have an acceptable QoE and is more likely to employ the I-VHO when the time for execution delay is comparatively small. In Figure 8(a), the fuzzy logic methods always get closer to the best performance of two fundamental strategies. Eventually, it is difficult to predict the type of the next interruption, the fuzzy logic scheme behaves similarly like, the I-VHO when the size of the unsent message is small, and therefore handover failure probability is low. In the beginning, when the average transfer delay of packets and average message length increases after a certain threshold, the I-VHO begins to loss its advantages to the D-VHO. When unsent packets begin to increase, the control center will automatically switch to the D-VHO scheme. We set the lowest HO failure probability as the low failure probability of the handover. Under current network conditions, I-VHO outperforms D-VHO case of a small message, while D-VHO outperforms I-VHO when the size of average unsent packets is large. The excellent delay performance of the two fuzzy logic schemes under the interruption from the Figure 8(a): it always approaches the best performance of the two basic strategies this will result in a better QoE performance for the UE. Although a current interruption mode makes it hard to predict the types of the next interruption, the FL-VHO algorithm makes a decision in favor of I-VHO when the size of unsent packets is small, the probability of handover failure is low, and it automatically switches to D-VHO style in the case of large unset packets. Our scheme is generally outperformed all the other schemes. Figure 8(b) illustrates the impact number failure probability to the RF link on the average transfer delay, for the various schemes. When there is an increase in the probability (Pr) from 0.1 to 0.9. The handover failure probability to the RF link increase. From the figure, it can be seen clearly that, initially when the average transfer delay of the packet is small, the handover failure probability to RF is minimal, but as transfers delay of packets astronomically increases in I-VHO scheme, this will result in frequent handover failures. Due to the fact that the D-VHO is designed to perform VHO only when dwell time occurs. Therefore the will be a lesser number of unsent packets in the queue, hence the gradual increase in failure probability of handover to RF. The FL-VHO and QFL-VHO schemes show very good performance as these schemes are intelligent, schemes that can respond to traffic mode in both the VLC and RF network conditions. And also take the best handover decision when there is short interruption or long interruption in order to enhance the UE's QoE. The two fuzzy logic schemes have similar performance patterns. Our scheme outperforms the other schemes, since it's more dynamic and can respond to the needs of the user by providing a more secure connection for better system performance.

We investigate the impact of velocity v and pause time p_t on the average waiting time in the uplink of the UE. We investigate the impact of velocity v on the average waiting time in the uplink as shown in Figure 9(a). As v increased from 0.3m/s to 0.7m/s the average waiting time in the uplink increased, for I-VHO, D-VHO, and FL-VHO schemes respectively. As v increases in this instant, the UE does a lot of transition between the VLC hotspots and the RF coverage, because of frequent interruptions of the VLC links. These may result in queuing of packets in the uplink hence the increase in the average waiting time in the uplink. In our QFL-VHO scheme, as v increases from 0.3m/s to 0.45m/s, the average waiting time the uplink increases. As the QFL-VHO increased beyond 0.45m/s the schemes performance decreases. The user prefers to hook onto the RF, as this may lead to the reduction of handover requests in the uplink. As the UE moves from one location to another with increasing velocity, we expect the average waiting time in the uplink to increase for all the methods. As the UE *v* increases we usually we expect UE to have a bad connection, but for the proposed method has a different outcome. As *v* is increased, the average waiting time in the uplink decreases this gives the UE better connection of service. We initially set p_t to 2s and increased it by uniform intervals of 1s to 10s. We examined the impact of pause time *pt* on the average waiting time in the uplink as shown in Figure 9(b), as *pt* increased from 2 to 10s.



(a) (b)

Figure 9: The impact of (a) Velocity (m/s), (b) Pause on average waiting time in uplink



(a) (b)

Figure 10: The impacts of (a) average unsent packets (delay) and (b) average QoE on vertical handover schemes

The average waiting time in the uplink for I-VHO, D-VHO and FL-VHO all decreased. Because as the *pt* increases, the UE spend much time connected to one of the coverage, therefore transition between the VLC and RF decreases consequently the number of handover request to the uplink reduces hence the gradual decline in the uplink. For the QFL-VHO the, when *pt* increased from 2 to 6s, QFL-VHO increased. As *pt* is increased from 6 to 10s, the QFL-VHO decreased. After a certain threshold, there is a gradual decrease in the uplink waiting time as *pt* increases. Initially, our proposed method has gotten less uplink waiting time which is good for the UE. The waiting time increases as the person is stationary for the first few minutes but once the UE connection is well established after some threshold, the uplink waiting time will start to decrease as pause time is increased further giving the UE better and better service. Our scheme generally outperforms all the other schemes.

Now we analyze the impact of the unsent message (handover delay) on the VHO schemes as shown in Figure 10(a). The I-VHO performs worse in this regard owing to the fact that when the number handover request increases in the uplink due to frequent interruption of the VLC links. When the buffer size becomes full, any subsequent handover request may be in a queue or drop. This can lead to handover delay, consequently handover delay cost.

Hence it will have a lesser handover request to the uplink thereby improving its performance. The novel FL again performs better than the I-VHO and D-VHO, because it leads to fewer handover requests; this phenomenon improves the QoE of the UE. Our proposed scheme has the least number of unsent packets which is good for system performance because when our scheme realizes that the number of unsent packets is becoming large the UE will hook unto the RF until the VLC link is recovered for a better connection and QoE enhancement. It shows that QFL is more responsive and dynamic to the UE's movements and needs. The impact of average QoE on vertical handover schemes is illustrated in Figure 10(b), the QoE of the I-VHO scheme is the least because it has the highest VHO request. That is, there will be frequent handover request when the VLC is blocked or unblock, due to its design to trigger handover whenever there is an interruption of the VLC link. This will lead to delay, that can reduce the QoE of the UE significantly. The D-VHO scheme will perform better than the I-VHO because this scheme makes lesser handover request, this results in better system performance. The fuzzy logic scheme outperformed the two traditional schemes, due to the fact that the novel FL scheme, takes into account the input metrics to determine whether the handover decision that would be taken will enure to the enhancement of QoE of the user before the handover is triggered. Therefore, the FL-scheme the UE will experience a less transition between VLC hotspots and the RF coverage. Our scheme outperforms all the other schemes, because our scheme is more adaptive to the user movement, and handover will only be performed if it will lead to the enhancement of the QoE of the UE.

7. Conclusion

We explore the potential of an integrated VLC and RF system for audiovisual transmission. There is a significant reduction in the delay in transferring of packets, and therefore, QoE of the UE is enhanced when handover is triggered. However, in our work traffic conditions and network vary dynamically but the two traditional handover schemes are static, nevertheless, the I-VHO and D-VHO perform better under certain circumstances. The FL–VHO which is a benchmark scheme performs generally better than the traditional schemes in all conditions. We proposed a new QFL-based VHO decision that has the capability to adapt to network and traffic changes and integrating uncertain and inconsistent metrics to make a handover decision that will enhance the QoE of the UE and reduce handover delay or cost. In this research, our proposed scheme generally outperforms both FL-based and the two traditional schemes. From the simulation results, the QFL scheme outperforms the other schemes in terms of enhance QoE, less waiting time in the uplink, less number of handover failure probability to RF and better unsent delay performance. It is worth noting that, even though the focus of the proposed scheme is on the integration of the VLC and RF, we can adapt its application and could be applied in other areas with of wireless medium with the characteristics of LOS. Moreover, our scheme is more dynamic. The bandwidth of the network is a consideration factor for handover execution, in order to enhance the QoE of the UE.

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