Computer Networks 116 (2017) 63–78

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Coverage optimization of VLC in smart homes based on improved cuckoo search algorithm

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ARTICLE INFO

Article history:
Received 16 June 2016
Revised 22 November 2016
Accepted 20 February 2017
Available online 22 February 2017

Keywords:
Coverage optimization
Cuckoo search
Smart home
Visible light communication

ABSTRACT

Light-emitting diodes (LEDs) are often placed on the ceiling in smart homes for visible light communications. However, the layout of LEDs will lead to the uneven distribution of the received optical power and signal-to-noise ratio (SNR) on the same receiving plane, which cannot guarantee fairness of communication. To solve this problem, we used an LED source array and introduced a power adjustment factor to determine a set of optimal power regulators to improve the power distribution on the same receiving plane. We proposed an improved cuckoo search (ICS) algorithm based on chaos theory and dimension cells to solve the normal CS algorithm convergence problem. The chaos mechanism will optimize the random distribution of the initial solution for chaotic distribution, and it can achieve an improved quality of the initial solutions. Moreover, we divided the multidimensional solutions into several dimension cells to avoid interference between dimensions. Simulation results show that the accuracy and the convergence rate of the ICS algorithm is better than that of CS, particle swarm optimization, and evolutionary algorithm. Furthermore, the fairness of the received optical power and SNR on the same receiving plane can be clearly improved.

1. Introduction

Smart home is a product of many types of technologies, such as Internet of Things (IoT) and cloud computing, and is one of the most important applications of IoT [1]. Smart home can make home appliances and various information terminal equipment become highly intelligent [2–4]. Many smart devices in smart homes require Internet access. However, several rooms in these homes and the locations of intelligent devices are dispersed. Thus, ensuring that all devices are able to access the network is an important issue for resolution. Bluetooth, WiFi, radio-frequency identification, ZigBee, and other short-range communication technologies have been extensively used in smart homes [5–9]. With the rapid increasing of the intelligent devices in smart homes, a mount of sensors, controllers and devices will come to our house. Moreover, the home entertainment and multimedia systems such as virtual reality entertainment systems may need high speed networks.

Bluetooth has the characteristics of low energy cost, fast connection time, stable quality of service (QoS) performance and high level security, and it can be regarded as a useful technology for the applications of smart homes [10]. In Bluetooth Classic, there are 79 channels, each with a channel bandwidth of 1 MHz and a raw symbol rate of 1 M symbol/s [11]. Bluetooth Low Energy (BLE) evolved from classical Bluetooth technologies for enabling short-range communication in different services and systems. BLE has many advantages over classical Bluetooth technologies, including lower cost deployment and lower power consumption [12]. However, the data package of Bluetooth cannot be lager because it uses the frequency-hopping spread spectrum [13]. Moreover, the theoretical number of connections by using Bluetooth is only 8 [14]. Therefore, the plans that only using Bluetooth in smart homes have certain limitation.

A WiFi router based on the IEEE 802.11n protocol is often used in homes and can theoretically accommodate 254 users. However, the memory and capacity of the wireless chip module of the common home WiFi router are limited. Thus, the throughput capacity of wireless communication is restricted. Wireless routers based on the IEEE 802.11ac protocol led to the introduction of multi-user multiple-input and multiple-output (MU–MIMO) and beamforming technologies to improve user capacity [15]. However, IEEE 802.11ac

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http://dx.doi.org/10.1016/j.comnet.2017.02.014
1389-1286/

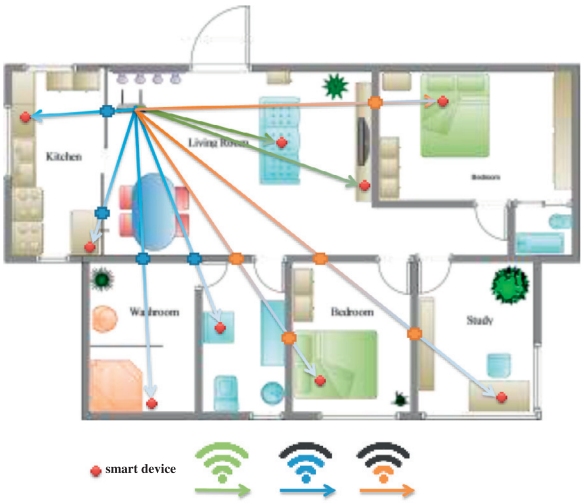

Fig. 1. Effects of wall and other obstacles on WiFi signals.

works in a 5 GHz band. Thus, a considerably high carrier frequency will lead to significantly short carrier wavelength. Given the limited transmission power, signals that cross walls based on the IEEE 802.11ac [16] protocol are weaker than those based on IEEE 802.11n [17]. Another challenge encountered in smart home networks is the complex electromagnetic environment. A smart home is a multi-network environment and many indoor short-distance communication technologies are working in the 2.4 GHz industrial scientific medical (ISM) band. ISM band has been demonstrated that it has not impact on human health. However, the hybrid electromagnetic environment may cause serious electromagnetic interference between devices that reduces communication quality.

The indoor wireless communication systems usually include two kinds of channels that are the line-of-sight channels and the multipath channels [18]. The transmitted signals introduce multipath reflections as it bounces off walls, ceiling, floor, furniture and even people where the transmitter is often with a wide-beam antenna. Therefore, the multipath channel will make the signals to produce a number of reflected waves called multipath waves, and the arrived time of these waves from the transmitter to the receiver may be different so that causing the inter symbol interference [19]. Therefore, the signals are fading considerably through the multipath channel. In addition, obstacle is another issue that affect the signals. Fig. 1 shows a typical smart home planar graphs based on WiFi. The solid red dots represent intelligent devices that are placed in different rooms based on their varied functions. Receiving devices receive weak signals because they are either far from the router or the signals are blocked by walls and other obstacles. In worse cases, these devices are unable to access the network. Conversely, numerous smart devices need to connect to networks. However, wireless routers are typically limited to basic network bandwidth, router hardware, and communication protocol, thereby failing to meet the requirements of the routers' actual number of users.

Due to the increase in popularity of light emitting diode (LED) as a lighting source, it is convenient and easy to provide in-home and in-building visible light communication (VLC) using the already existing LED lamps. VLC is an effective method to solve problems concerning network access and coverage in smart homes [20]. VLC can use the visible light band, instead of fiber and other cable channels, as information carrier. Furthermore, VLC can directly transmit signals in the air. VLC is characterized by high bandwidth, rapid communication, strong security, and high system capacity [21]. Therefore, VLC is very suitable for downlink media communications that the multi users can see high-definition films or online TV programs. Moreover, VLC is more secure against hacking, as light cannot penetrate through walls and also offers high data rates, as compared with conventional radio frequency based wireless technologies, such as WiFi and Bluetooth [22]. Lighting lamps can provide natural basis for VLC, given that lamps are the necessary electrical facilities in homes. VLC can use the power line carrier (PLC) technology to obtain signals from networks, thereby achieving effective solutions to the signal coverage problem across the room. The VLC system based on LED array can achieve a considerably high communication rate, substantially large system capacity, and significantly low bit error rate (BER) by using the MIMO technology [23]. The use of this technology will also ensure that all types of intelligent devices have stable access to networks.

The light source needs to consider the two functions of lighting and communication in indoor VLC systems. In the area of illumination, the complete and uniform optical power distribution is recommended by the industry. However, the LED array is often arranged at the center of the ceiling, which will cause a non-uniform power distribution reception on the optical signal receiving plane. This distribution is characterized by the rapid attenuation from the center of the receiving plane to the edge, thereby hampering the same quality of service to smart devices located in different areas of the room. Moreover, the non-uniform received optical power may even result in communication failure caused by the lack of received signal power. Therefore, optimizing the VLC power coverage in a smart home is crucial to ensure that all devices can have successful access to networks.

In this paper, we proposed a novel improved cuckoo search (ICS) algorithm based on the initial solution optimization and dimension cells to solve the VLC power coverage problem in smart homes. The proposed ICS algorithm employed chaos theory to optimize the structure of the initial solutions, the quality of the initial solutions can be improved as the chaotic distributions so that it can avoid the non-uniform distribution of the solutions, thereby laying a good foundation for the coverage rate. Furthermore, ICS divided the multidimensional solutions into several areas by using the concept of dimension. The dimension cell mechanism can update the solution cell by cell instead of updating them simultaneously. This method can avoid the interdimensional interference so that reducing the repeated computation times. Therefore, it can enhance the coverage rate and the accuracy of the solutions. Moreover, simulations are carried out to verify the performance of the proposed approach.

The rest of this paper is organized as follows. Section 2 introduces the related works in this fields. Section 3 discusses the VLC system models and the fitness function. Section 4 introduces the optimization method based on ICS algorithm, while Section 5 presents its numerical simulations results. Section 6 summarizes the findings and concludes the paper.

2. Related works

VLC communication systems have their own characteristics but many classical communication and network technologies can be used for VLC [20]. A new VLC communication scheme called color coded multiple access (CCMA) is proposed in reference [24]. The orthogonal frequency division multiplexing (OFDM) modulation method is adopted to achieve a considerably high signal-to-noise ratio (SNR) and substantially low BER. This scheme can effectively improve system capacity, but the optimization of optical power distribution in each room is not mentioned. Moreover, different from CCMA, the proposed ICS based optimization method can use single color LEDs as the transmitter, this can make the lighting environment better in smart homes. In addition, ICS based method mainly focuses on the optimization of the network coverage per-