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Internet of light: Technologies and applications

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Abstract: Intelligent lighting has attracted lots of research interests to investigate all the possible schemes to support this need as human has spent more and more time indoor. Semiconductor-based illumination network is an ideal bearer to carry on this mission. In this paper, we propose the concept of Internet of Light (IoL) and define its key functionalities by introducing the information and communication technologies to the illumination networks. Our latest research progress on high-speed transmission, resource optimization, and light stroboscopic irradiation experiment based on IoL platform show that IoL can not only provide value-added services such as positioning and information transmission but also act like a sensor network as part of Internet of Things infrastructure. It confirms that with sensors for different purposes integrated into the lamp, IoL helps people be aware of the environmental changes and make the adjustment accordingly, can provide cost-effective information service for Internet of Things applications, and supports the non-intrusive optical therapy in the future.

Key words: Internet of Light; visible light communications; dimming; non-intrusive optical therapy

1 Introduction

Light, whether natural or artificial, plays a fairly important role for evolution of the earth and the civilization development of human beings. How to create light and utilize the light effectively and efficiently, and the relationship between lighting and human health are all fascinated topics for researchers and have been under deep investigation for a long time. Statistics show that people nowadays spend much more time than ever for the indoor activities. This means illumination networks will have much greater impact on people's daily life, and various schemes and solutions have been proposed and implemented to automatically control the illumination more conveniently and eyesight-health friendly. The blue-light light-emitting diode (LED) technology has been successfully commercialized and worldwide proliferation of LED will reach 75% in next ten years mainly due to higher energy efficiency and low cost of LED.

Since LED is silicon-based, it can greatly facilitate deep integration of illumination networks with different electronic and intelligent control mechanisms at low cost. On top of illumination control, researchers from information and communication technology (ICT) areas have demonstrated the feasibility of visible light communication (VLC) by modulating the light intensity of LED (i.e., let energy variation carry information). Various information services such as localization, data transmission, and even optical therapy can be supported simultaneously without bothering human's eyes.

The rapid progress in the related areas of both ICT and human science motivated us to propose the idea of Internet of Light (IoL) as a platform and develop its key functionalities. Different from Lighting 2.0[1] featured by quality of light, control and

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communications, and awareness and sensing, our proposed IoL idea focuses on how to turn the ubiquitous illumination network as part of Internet of Things (IoT) infrastructure. This is done by integrating difference sensors, communication modules, and smart processing units into LED lamp to make each individual lamp as the IoT node, and by adopting telecommunication technologies, such as powerline communications (PLC) and wireless communications (i.e., 5G) as the means of networking. With this arrangement, the interconnection, intercommunication, and interchange of all the related devices can be achieved to support LED illumination with intensity and color adjustment capability and also defined by Lighting 2.0, information services such as communications and localization for IoT applications, and non-intrusive optical therapy for the smart health in an intelligent way in the future.

Figure 1 is the overview of our IoL concept within typical indoor applications, which highlights major functional blocks of the platform. Each LED, as the biggest one in Fig. 1 with detailed information on the major functions inside, can be taken as a sensing node with specially designed sensors to collect all the necessary information, such as light intensity, color, the level of hazard gas, moving objects, etc., and all these nodes constitute a sensor network. One use case is that in the smarting nursing house, the patients' movement can be tracked for safety and security reasons upon permission and the gas leakage in the kitchen can be detected in time. The sensing data collected by these LED nodes, maybe after certain pre-processing locally by means of edge computing, etc., will be sent to the operating center by either wired (i.e., PLC here) or wireless (i.e., VLC and radio frequency signals such as Bluetooth, ZigBee, etc.) method, or both for the robustness of the data delivery. The operating center will analyze the collected data, make the decision, and send the feedback with the corresponding actions needed, based on different application scenarios. For example, when a gas leak is detected with concentration above certain threshold, an alarm will be fed back immediately to the residents, facility management team, and even the hazard prevention team while the ventilation system will be activated automatically and the evacuation path will be clearly indicated by the illumination network (i.e., some LEDs are in red showing the path while others

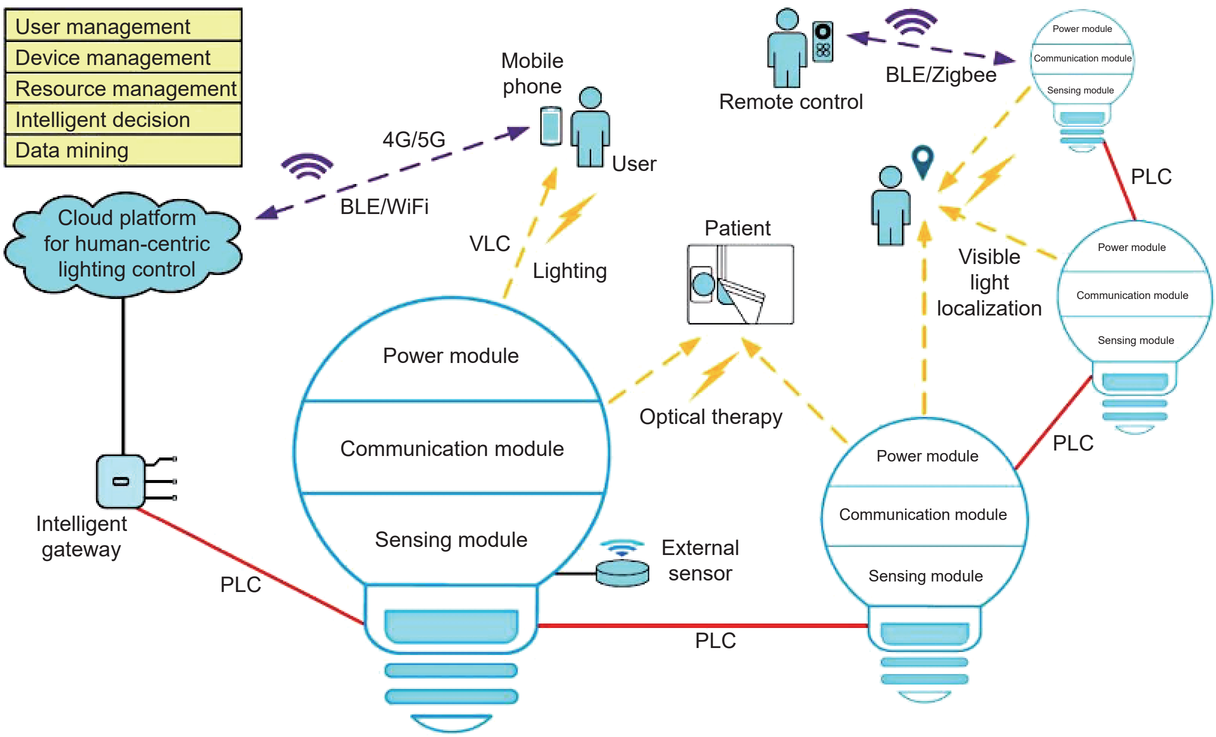

Fig. 1 Illustrative functional blocks of IoL.

are flashing for the alarm purpose) before the maintenance people actually arrive to the field. These functions are critical for the safety to the residents, especially for senior patients in the nursing building. The light intensity and color will change intelligently according to the particular user preference, creating more comfortable environment to help adjust the psychological mode of the people and even conduct optical therapy on the people.

From these highly representative cases, one can clearly see three layers of IoL (similarly to those in IoT networks) in the following, and they are:

(1) Sensing Layer for joint and comprehensive sensing and perhaps data pre-processing using mobile edge computing and other related technologies to insure the accuracy and coverage from a sensing perspective;

(2) Network Layer of heterogeneous structure consisting of coordination and control mechanisms of heterogeneous networks (wired and wireless) for reliable access under the burst mobile environment; and

(3) Intelligent Lighting Control Layer which could potentially provide the possibility for non-intrusive optical intervention therapy.

To accommodate aforementioned functionalities of IoL effectively and efficiently, we have been conducting research and demonstration work from different areas and the main contributions of our work can be summarized in the following.

First, a new concept of IoL is proposed with the general network structure and key functionalities are defined. With careful arrangement, lighting quality can be sensed and controlled, information services such as positioning and data delivery can be supported, and non-intrusive optical therapy can be deployed.

Second, individual technologies have been deeply investigated to facilitate key IoL functionalities for information services including real-time beam alignment VLC design and experiment for transmission, resource optimization under different constraints such as communication and location services, communication and illuminations, and data freshness.

Third, possibility of non-intrusive optical therapy based on IoL infrastructure has been investigated. By the careful design on the experiment of the light stroboscopic irradiation with flicker frequency of LED light, the feasibility is validated by the preliminary results.

2 Real-time beam alignment visible light communication

Visible light positioning (VLP) is believed as a promising positioning solution because of the advantages of low cost and high accuracy[2]. A 3-D indoor VLP system based on the received signal strength technique is proposed to reduce the average horizontal error to < 2 cm[3]. Recently, VLP systems with both photo-diode (PD) and low-cost camera are investigated to improve the system performance[4]. VLC has been considered an important complementary technology to RF-based wireless communications in the dawn of 6G, and VLC also finds its unique advantages when being applied to those scenarios with RF signal strictly prohibited or absolutely unavailable. Most previous works usually considered high-speed VLC systems with stationary receivers or assumed precise alignment being realized when being received. Few studies were aiming at improving the mobile adaptability of VLC systems and a mobile receiver scheme based on artificial neural networks was proposed recently[5], which can effectively reduce error rate by predicting the threshold of binary amplitude keying demodulation in the moving scene. Ahmad et al.[6] proposed a simple transmitter-lens-decenter based beam control scheme in imaging VLC links with experimental results showing that bit-error rates are below the forward error correction limit for receiver coverage diameter of 75 cm and 60 cm for 1.25 Gbps and 1.5 Gbps data rates, respectively. Another interesting and important topic in driving LEDs is how to allocate working frequencies and determine optimal operating point to accommodate different services simultaneously.

In IoL, the user movement will inevitably bring significant changes to the channel characteristics from transmission perspective, which prevents the user from obtaining a high-speed and stable data transmission rate. The real-time beam alignment VLC sub-system can swiftly adjust the direction of the emitting light source according to the user's position. Therefore, the user can receive higher signal power, which improves the signal-to-noise ratio of the data transmission link, and this method can be applied to maintain high-speed communication while the user is moving.

As users on IoL may be highly possible to be under the mobility even though the indoor movement speed is relatively low, the research on mobile reception is indispensable to ensure the comprehensive support of different applications for IoL. To improve the communication performance of the mobile users, we propose a real-time beam alignment method through image recognition and real-time mechanical control tracking[7]. In principle, this real-time beam alignment visible light communication system derives the changes of the receiver position by imaging recognition. Then, the system adjusts the emission angle of the light source to realize mobile adaptive tracking communication. The system captures the images of the receiver for 30 frames per second. The Hough circle method is used to identify the receiver in the pictures and the pinhole camera model is used to calculate the coordinates of the receiver center. Then the deflection angles of the mirrors in the galvo scanning system are calculated. The control commands are sent to the galvo scanning system to adjust the angle of the mirrors quickly, thus changing the direction of the light beam. To further improve the accuracy of beam alignment, the system also identifies the spot of the emitting light on the receiver. Also, the coordinate deviations between the center of the light spot and the center of the receiver are calculated. Thus, the system can fine-tune the angle of the mirrors accordingly. In experiments, the transceiver moves at a speed of about 0.2 m/s. The maximum communication distance of the system mainly depends on the position recognition accuracy of the camera to the receiver (i.e., the PD), and the operating accuracy of the reflector angles. When the communication distance increases, the image taking area captured by the camera will be enlarged, which will improve the recognition error for the receiver position. Meanwhile, the displacement accuracy of the light spot on the receiver is limited by the minimum rotation angle of the mirrors, which will also be enlarged with the increasing of the communication distance.

The transceivers in the system are over half meter apart, and one transceiver moves within the angle range of 20-degree relative to the other one. The camera at a transmitter captures the images indicating changes in the position of its related receiver, PD. Then the current coordinates of the receiver and the beam adjustment angles are calculated by the image processing algorithms at the transmitter. The computing unit of the transmitter outputs the control parameters, and the galvo scanning system adjusts the incident angles of the mirrors so that the light beam can still be focused on the receiving area of the PD. As shown in Fig. 2, the light source of the transmitter is a red laser diode. The light beam is collimated by a lens and reflected twice by scanning mirrors in the galvo scanning system to the receiving area of the PD. In the experiments, the system realizes real-time transmission. When the left transceiver moves along the slide rail, the beam direction will deviate from the PD position, resulting in a temporary interruption of transmission. At this time, the system will adjust the beam direction accordingly, trying to quickly reconnect the communication link. When the connection is successfully re-established, the communication transmission rate can reach more than 80% of its full throughput (i.e., 800 Mbps) in less than 0.5 s.

3 Resource optimization under different constraints

3.1 Resource optimization for the communication and location services

To successfully support the multiple functions by IoL, careful design or optimization to allocate the power and different frequencies is indispensable to requirement of the key performance indicators such as bit-error-rate for data transmission, accuracy for the positioning, granularity of the dimming control, etc. For the co-existence of IoL and other systems using PLC as an example, frequency below 500 kHz is

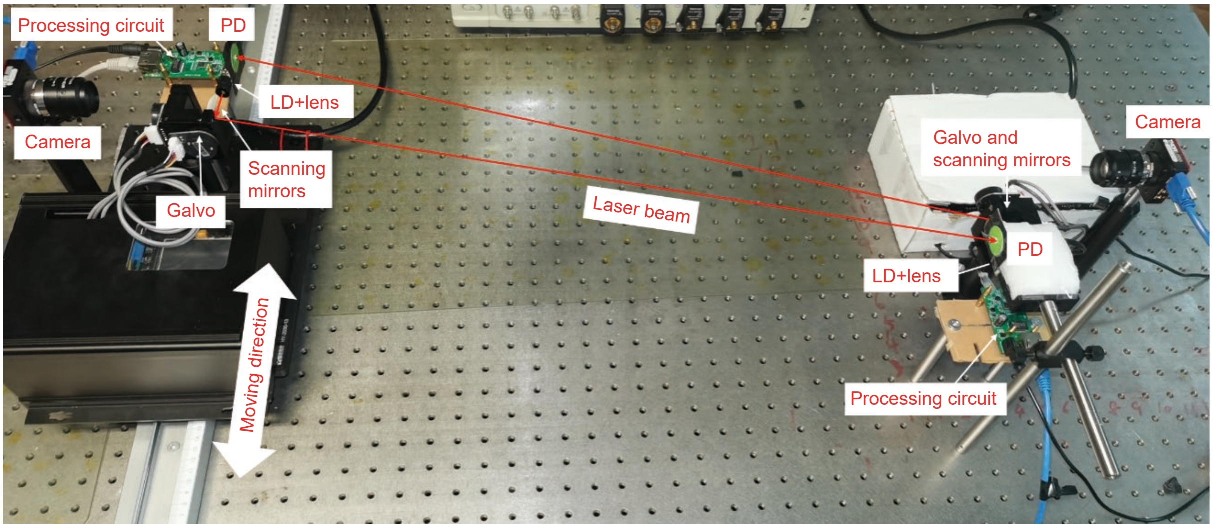

Fig. 2 Real-time beam alignment VLC system.

allocated for both automatic meter reading for narrowband PLC and positioning signal for LED, respectively, while signal occupying bandwidth starting from 2 MHz is proposed to support the integrated VLC-PLC system with the same digital baseband specifications.

The systematic diagram for the optimal operating point determination is shown in Fig. 3 in a support of both positioning and data transmission when both PLC and VLC are used within the system, and the same methodology can be applied if multiple services need to be supported.

Since the orthogonal frequency division multiplexing (OFDM) signal is more sensitive to the optimal operation point in VLC system, an experiment was conducted for the optimal power allocation between data transmission and positioning functions simultaneously. A Manchester code of 4 kbps generated in LED by on-off keying (OOK) for positioning service is applied while an OFDM signal of 16-QAM constellation mapping occupying frequency range from 2 to 10 MHz is transmitted by PLC system through a power cable of 100 m. With the forward error correction coding rate of 0.6, the payload data rate is around 21.7 Mbps, capable to support several high-definition video streams. At LED, this OFDM signal is amplified and then aggregated with the OOK signal by an appropriate bias to support video transmission and positioning services.

Table 1 gives the measurement results under different amplitudes of OOK signal showing the optimal operating point and Fig. 4 shows the experimental results with OOK waveform (Fig. 4a), amplitude variation of the combined signal on oscilloscope (Fig. 4b), and the successful video transmission (Fig. 4c). The bias of OFDM signal is fixed at 3 V with the range of OOK signal from zero to $V_{p\text{-}p}$ in Table 1 and detailed experimental setup is described in Fig. 3.

3.2 Resource optimization for the communication and illuminations

For the multifarious applications of IoL, not only the convenient wireless communication with high data rates should be realized, but also the human-centric lighting needs to be taken into account even at much higher priority, as shown in Fig. 5. The IoL network can support different scenarios and types of users, which will also bring a variety of illumination requirements including illumination intensity and uniformity[8]. In combination with the communication requirements, the comprehensive requirements need to be fed back to the base station and the network in a suitable way, such as RF uplinks based on Bluetooth[9]. The integrated module of dimming control will adjust and control the visible light signals, achieving the required illumination performance and communication coverage. In order to keep the original lighting effect

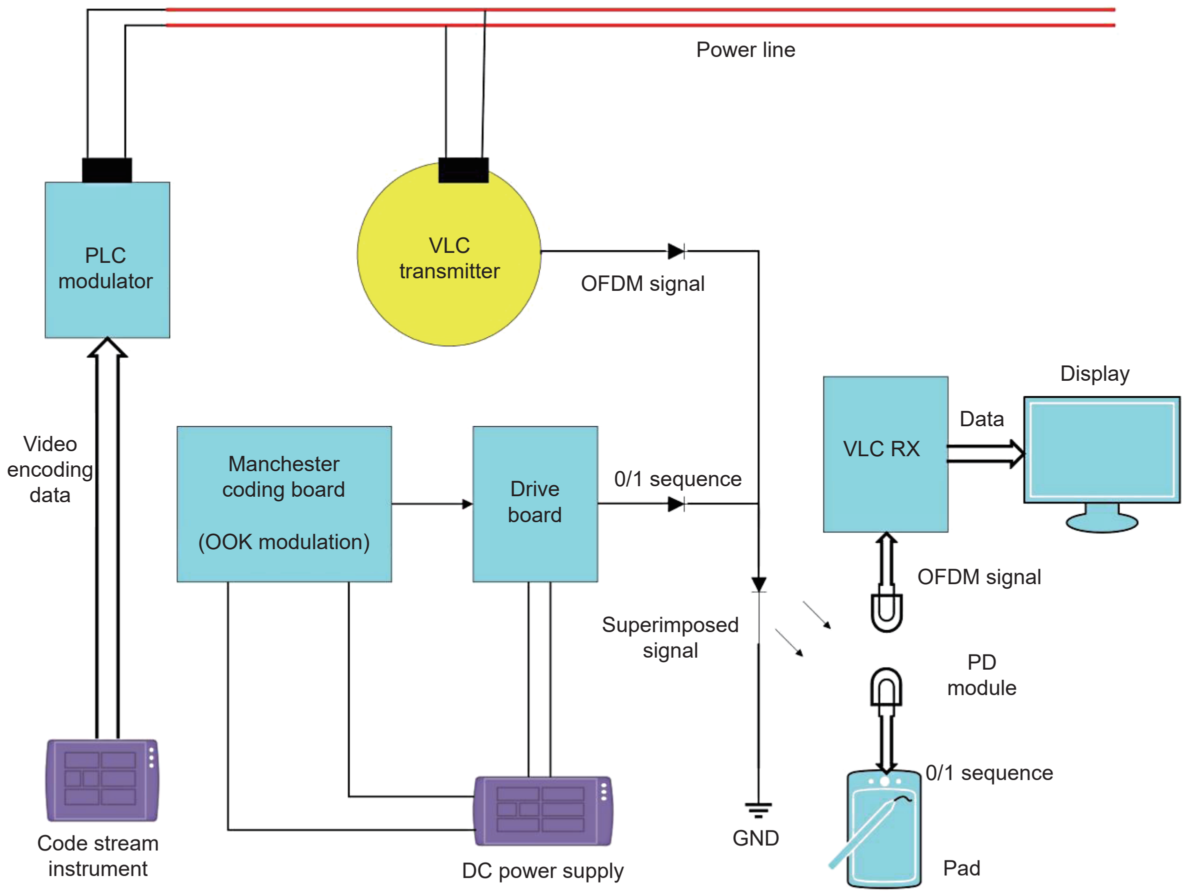

Fig. 3 Systematic diagram for the optimal operating point determination when positioning and data transmission are needed simultaneously in VLC-PLC system.

Table 1 Test results for the influence of OOK $V_{p\text{-}p}$ on OFDM system.

$V_{p\text{-}p}$ for OOK (V)	OFDM signal demodulation	OOK signal demodulation
2.9	Normal	Unable
3.0	Normal	Unable
3.1	Normal	Normal
3.3	Normal	Normal
3.4	Normal	Normal
3.5	Normal	Normal
3.6	Bit error	Normal
3.7	Bit error	Normal
3.8	Fail	Normal
3.9	Fail	Normal

unchanged and meet the enhanced requirements of lighting not to disturb people[10], it is necessary to investigate the impact on the illuminance of visible light in terms of channel coding, modulation, framing, and other signal processing techniques.

Under various scenarios, the human vision has different requirements for the light illuminance of VLC. For instance, the appropriate illuminance for human eyes is 300 and 30 lx in reading and computer work, respectively[10], which clearly indicates that the flexible dimming schemes with high precision should be achieved for the practical human-centric lighting. According to the signal domain involved in the processing of optical signals by dimming control, the current technologies can be classified based on multiple dimensions such as amplitude, time, space, etc.[11, 12] Moreover, for the multi-dimensional joint design and optimization of dimming, it needs not only to avoid the performance limitation of single-dimensional optimization, but also realize the joint optimization of multiple optimization objectives[13].

Compared with conventional modulation technologies, the multi-dimensional modulation technology is more flexible in implementation. They can adjust the corresponding relationship of

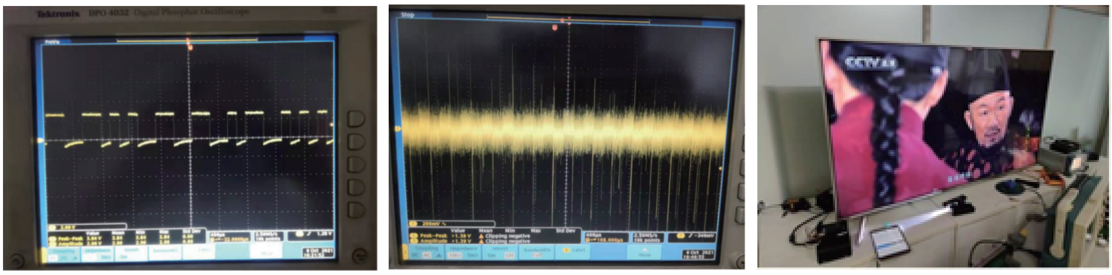
(a) (b) (c)

Fig. 4 Experimental results with (a) OOK waveform for positioning, (b) amplitude variation of combined signal in time-domain, and (c) successful video delivery.

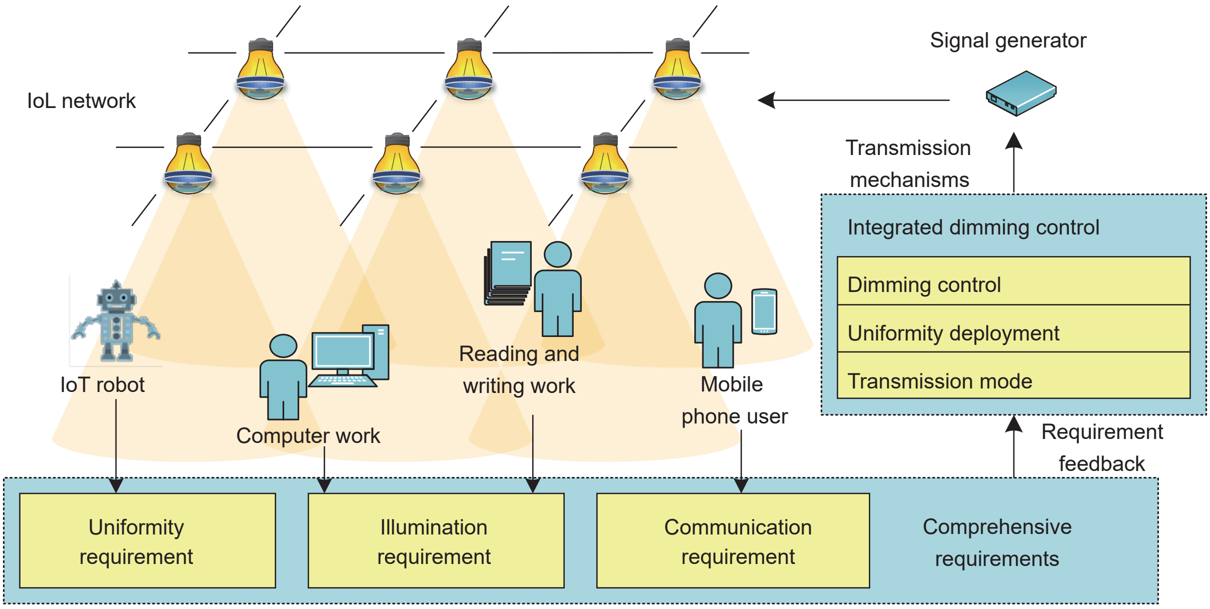

Fig. 5 Integrated dimming control for comprehensive requirements in IoL networks.

information and the number of activated resources, in order to achieve trade-off in spectral efficiency, energy efficiency, complexity, delay, and so on. Therefore, it has attracted extensive researches and discussions. For instance, the communication and dimming scheme based on the joint design of frequency and amplitude domain can maintain the wireless communication with high spectral efficiency and control the dimming in a wide range, meeting the lighting requirements in many scenarios[14]. In addition, the block diagram of hybrid dimming scheme based on the joint design of spatial and amplitude domain is illustrated in Fig. 6, which can improve the spectral efficiency further while realizing the flexible dimming with high or low precision demands[15].

Meanwhile, according to the characteristics of visible light channel, the path loss will keep increasing rapidly with the increase of the relative distance and angle of the transceivers, so the receiving performance of mobile users will be much worse compared with that of fixed users[16]. It means that the tolerance of IoL to the mobility of users will increase with the improvement of lighting uniformity, which is also an important part of illumination requirements. According to the IEEE standard 802.15.7, the minimum of the light illuminance needs to be no less than 0.7 of the average[17]. Therefore, the lighting uniformity is significant for the fairness of VLC users in different locations, and the uniform lighting environment is more suitable for IoT devices with higher mobility and ubiquitous characteristics.

The lighting and communication requirements have been considered comprehensively in Ref. [18]. The alternating iterative algorithm of lamp deployment and

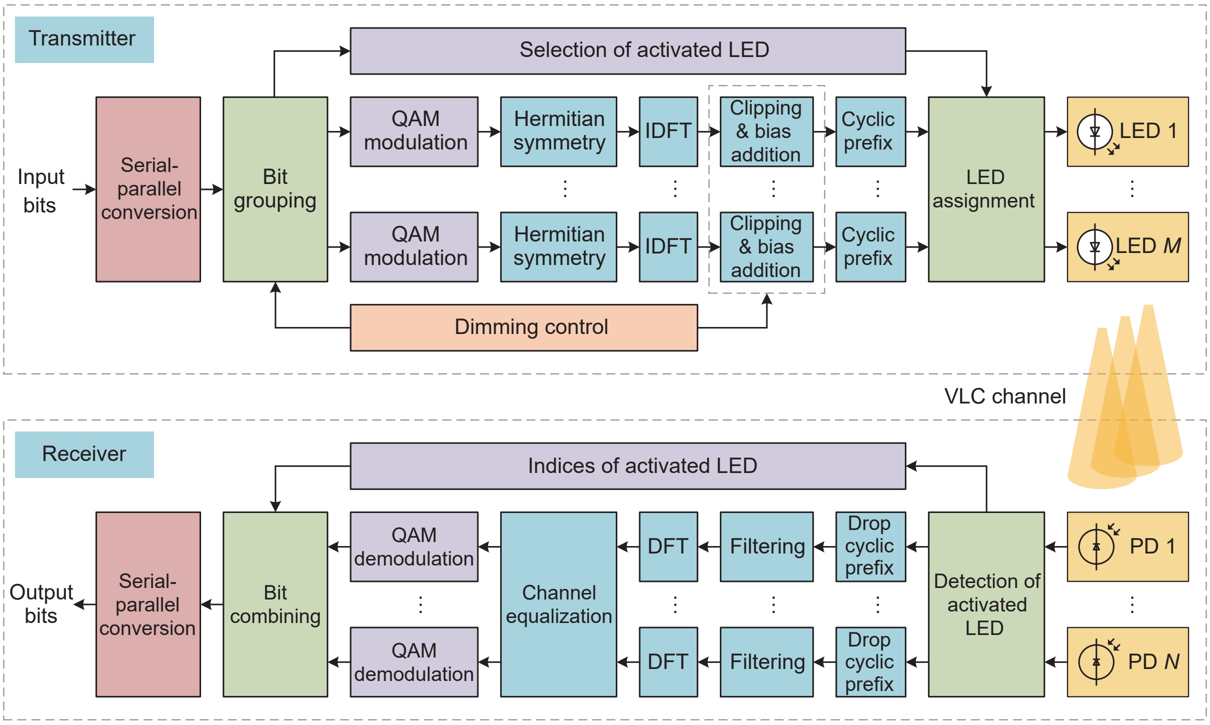

Fig. 6 Block diagram of hybrid dimming scheme based on joint design of spatial domain and amplitude domain.

transmit power is proposed to realize joint optimization, which can realize the optimization of both the illumination uniformity and the average achievable rate of the whole room. Furthermore, the average achievable rates under diverse uniformity constraints are also maximized based on different room sizes and various numbers of lamps, achieving the trade-off between uniform lighting and communication performance. It can be found that the illumination uniformity can be improved significantly with less loss of the communication capacity, achieving superior uniform illumination and better communication performance in the meantime. The scheme is applicable to the ubiquitous characteristics of IoT devices, and can be used to guide the practical deployment of IoL systems and the implementation schemes of lighting network control.

4 Data freshness optimization under different constraints

The integration of VLC/PLC networks has to satisfy various demands from users and support the higher layer applications such as video transmission and real-time positioning, as depicted in Fig. 7. To meet those heterogeneous requirements from users under communications resource constraints, it is crucial for the base station or the network gateway of IoL to design effective incentives and proper scheduling algorithms for the fairness and efficiency of the networks upon different user scenarios.

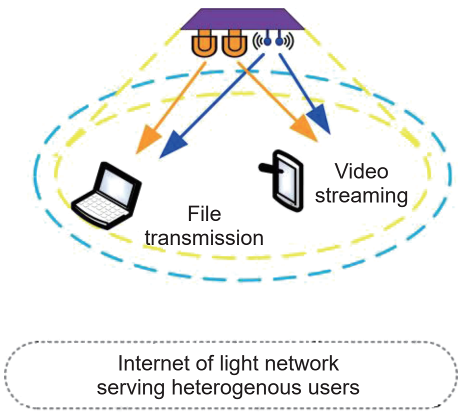

Fig. 7 Integration of light heterogenous networks.

Moreover, in these real-time service scenarios, data freshness is of vital importance for the user experience, especially for those cases which are time-sensitive. However, traditional communication metrics like throughput and delay cannot fully describe the data freshness at the user side. To address issues, the new metrics including Age of Information (AoI)[19] and Age of Synchronization (AoS)[20] have been proposed recently. By definition, AoI measures the time elapsed since the newest packet stored at the destination was generated. AoS focuses on the time interval since the user and source became desynchronized.

Figure 8 gives a sample path of the AoI and AoS evolution, where U_i is the generation time, and T_i is the reception time. By definition of AoI and AoS, it is obvious that they both focus on the data freshness at the user side. However, as depicted in Fig. 8, they are different in essence. For example, if a source updates slowly, the AoI of the user will still grow linear while AoS will remain zero for a long time, which apparently may cause different scheduling results. Therefore, the scheduler should choose the proper metric for the system optimization. For example, considering a network with random updates, maybe AoI is not fair since slowly updated sources will always have large AoI and high scheduling priority.

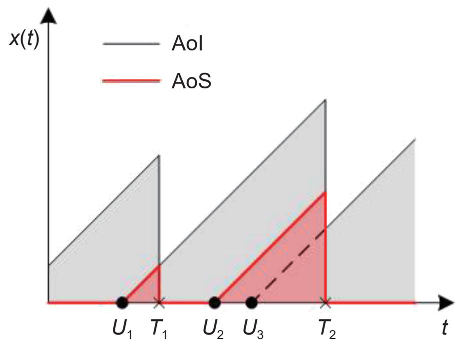

Fig. 8 An evolution sample path of AoI and AoS.

To satisfy the need of collecting fresh data under a communication bandwidth constraint, we proposed a truncated scheduling algorithm in Ref. [21]. As depicted in Fig. 9, Tang et al.[21] considered the network with $N = 8$ sensors and the bandwidth constraint $M = 2$, which is the maximum number of sensors to be scheduled at one time. The power constraint is denoted by ρ_n, where lower ρ_n means stricter power constraint. Figure 9 depicts the scheduling probability (histogram) under different channel state (q) and AoI (x). It is revealed that sensors whose data are already out-of-date or whose channel states are currently good are given higher priority in the proposed scheduling policy. When data are updated by external sources, we proposed a scheduling algorithm based on the Whittle's index algorithm[22].

To satisfy user requests collecting fresh file copies with low delay, we proposed to download and save the latest version of file in the local cache of the base station. We designed an adaptive file update rule in Ref. [23] that can meet the time-varying demands of users. Moreover, when data transmission duration is time-varying as well, we proposed a scheduling algorithm that can reduce the time average AoI of user requests by 35%[24], as depicted in Fig. 10.

Moreover, when the demand in the network is heterogeneous and congestion control algorithms are implemented in a distributed manner, we revealed that the throughput optimal flows will take up most of the

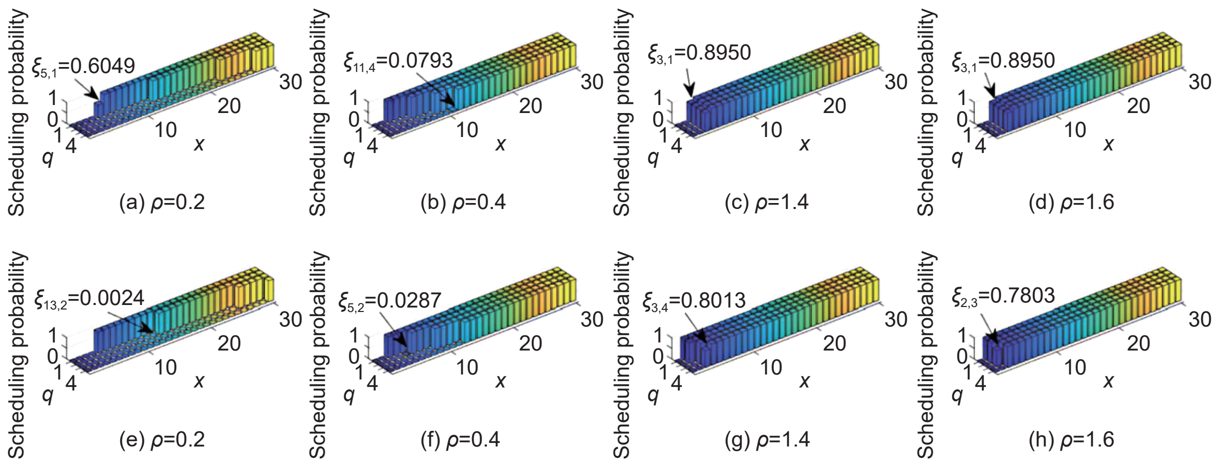

Fig. 9 (a)−(d) Scheduling decisions for sensors with different power constraint ρ_n in a network with $N=8$ sensors and $M=2$. (e)−(h) Scheduling decisions for single sensor with different power constraint ρ_n and with no bandwidth constraint[21].

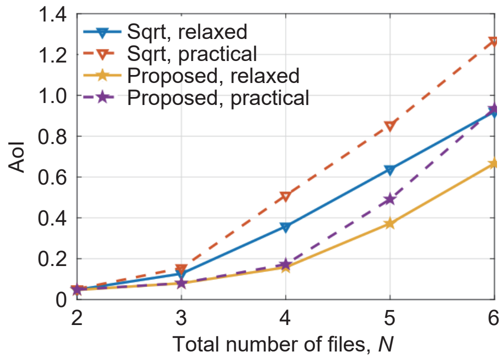

Fig. 10 Average AoI versus total number of files *N*[24].

bandwidth and the requirement of the data freshness flow cannot be satisfied. To relieve this phenomenon, we propose an early dropping mechanism[25] as an incentive to relieve the bandwidth occupying behavior of the throughput-optimum flow. Under such mechanism, we have shown that theoretically, the Price of Anarchy (PoA) on the congestion control Nash equilibrium can be decreased.

5 Possibility study on the optical therapy by IoL

Scientists have been keenly studying the impact of light, either natural or artificial on human, and have discovered molecular mechanisms controlling the circadian rhythm. It is found that higher organisms are normally light-sensitive and the biological clock can be taken as a functional system. In 2002, Berson et al.[26] discovered the third type of photoreceptor cells in human body which can affect human biorhythm by controlling the secretion of melatonin. Yasukouchi and Ishibashi[27] found that there are two main neural pathways in the human brain when light signals are transmitted from the retina to the cerebral cortex. The first pathway forms vision information, and the second pathway transmits non-visual information, which is not only related to the endocrine and biological rhythm but can influence human emotions and electroencephalographic arousal levels. In 2015, Stringham et al.[28] showed bright light exposure to the elderly before sleep can relieve insomnia symptoms and improve sleep quality. Meanwhile, some researchers also attempted to use light to treat certain dermatoses or neurodegenerative diseases, showing the possibility for the optical treatment in a non-intrusive manner. This motivates us to explore this possibility based on our IoL platform.

To demonstrate the feasibility of the non-intrusive optical therapy by IoL concept and also get the preliminary results for this purpose, we have designed an experiment of light stroboscopic irradiation with flicker frequency of LED light controlled by our own developed platform. The light stroboscopic irradiation experiment with volunteers is succinctly described as follows, which is shown in Fig. 11. The experimental environment simulates a typical office environment, the LED light used in the experiment is mounted in the central position of the ceiling, and the subjects should sit quietly under the LED light during the experiment. The LED light is 600 mm × 600 mm with voltage and power of 140 V and 160 W, respectively, and its light intensity, wavelength, modulation depth, and flicker frequency can be adjusted based on our platform. The control variable of this experiment is the flicker frequency of the light, and in the future more control variables such as light intensity, color temperature, duration, flicker waveform, etc. will be included. The Biopac MP160 wireless physiological data acquisition system is chosen to collect the physiological data from four dimensions including the photo plethysmograph, body temperature, electrocardiogram (ECG), and electrodermal activity (EDA).

EDA signal is considered as a robust indicator of underlying emotional arousal within human behavior research[29], reflecting activity of the sympathetic nervous system (i.e., the activity of which is dependent on physiological and emotional activation). Since our experiment mainly focuses on the effect of light stimulation on emotions, EDA signals which can provide direct sympathetic changes are chosen to characterize the emotional changes in response to the different flicker frequencies of the light.

During the experiment, the volunteers are supposed to sit quietly under the LED light and wear the data acquisition equipment which had been configured. When the experiment starts, the flicker frequency of the light will be adjusted to 0 Hz, 80 Hz, and 500 Hz successively, and each lasts 10 min called. The volunteers will take a 5-min rest between two tests.

The physiological data of volunteers under different

Fig. 11 Light stroboscopic irradiation experiment with (a) the setup of the environment having irradiation light from the ceiling and (b) the measurement on hand while the volunteer is reading.

flicker frequencies are collected by Biopac and processed by Matlab to confirm whether there is a significant difference before and after the experiment.

Here, the measurement results on EDA from two healthy volunteers participated in the experiment, a male of 33 and a female of 37, were given by the histograms under different flicker frequencies, which are shown in Fig. 12. The X -axis represents the electrical dermatology data value in the unit of microSiemens (μS) of volunteers while the Y-axis represents the proportion of each bin whose width is 0.1 to the whole population.

After preliminary analysis on the data, it was found the EDA data of volunteers under different frequencies had a great difference. Compared with the condition without flicker, the peak value of electrodermal data of the two volunteers has been significantly reduced to even half of the original value. This clearly indicates that flicker can affect the electrodermal data. At the same time, many studies showed that EDA can be regarded as an indirect indicator of human emotion and electroencephalographic arousal, our current experiment verifies that our newly IoL platform can possibly regulate human emotions and electroencephalographic arousal levels by controlling the flicker frequency of the light source intelligently and automatically, while the rationale behind that needs to be further explored in the future with an interdisciplinary study.

In the future, not only much more diversified groups of people with different gender, age, race, background, and even during the different time slot of the day, but also correlation investigation among those four factors including the photo plethysmograph, body temperature, ECG, and EDA will be performed to obtain the results with higher confidence.

6 Conclusion

In this paper, we proposed the idea of IoL by introducing the ICT to the illumination networks, making it possible to be part of IoT infrastructure. We highlighted our recent research progress in several exciting areas which could better support IoL major functionalities. We have developed the algorithm and used hardware experiment to demonstrate the system performance for high-speed data delivery to the users under mobility. We also performed the resource optimization to facilitate the positioning, communication, and illumination simultaneously, with the consideration of information freshness when various sensors are incorporated. Our study on IoL to support non-intrusive optical therapy also confirmed its feasibility through preliminary experiment. In future,

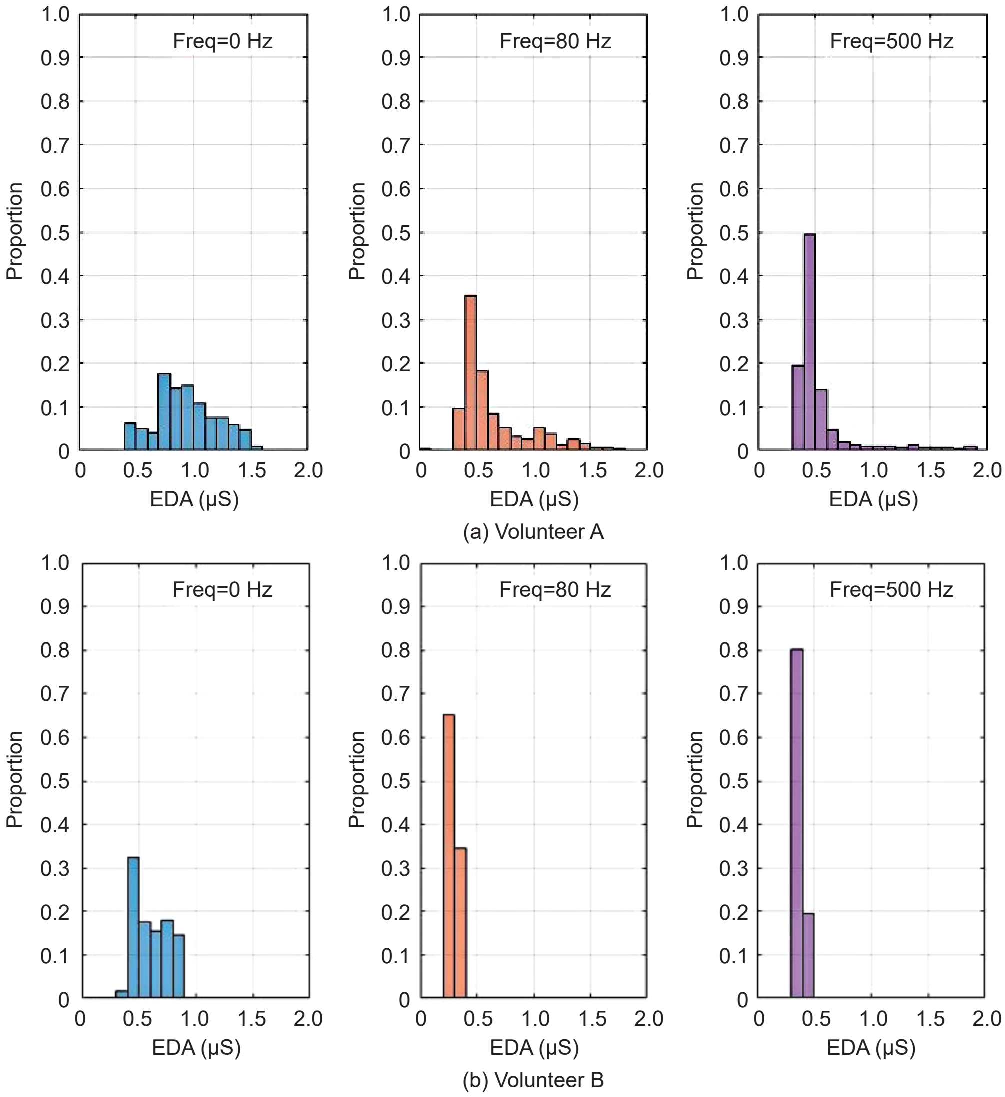

Fig. 12 Histogram of skin electrical data under three typical frequencies for volunteer A and volunteer B.

one research direction is the signal design for the IoL platform to accommodate all the service requirement effectively and efficiently. Another direction is to integrate those individual technologies into one or two critical and highly representative scenarios such as smart nursing where smart sensing, communications, and also resource optimization are needed after various sensors being implemented.

Looking forward, human body is the most comprehensive and precise operating system on the earth, and light has significant impact on human health from vision, physiology, and psychology perspectives through both visual and non-visual neural paths. Human factors lighting is a demand-oriented concept, which aims at improving people well-being from evidence-based and/or data-driven research and design approach to maximize the health benefits out of lighting environment. As for people, lighting and environment altogether consist of a highly interactive, complex, and dynamic system with huge discrepancy and great diversity. The advantages of real-time perception, instantaneous response, and seamless information interconnection supported by IoL can play an important role in bringing human-centric lighting into reality. This will be done by monitoring and analyzing people’s behavior and activities which reflects the current health status, and then making decision to continuously accommodate their conscious and/or unconscious request for the health improvement.

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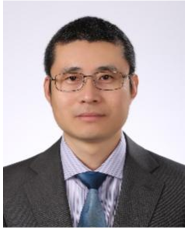

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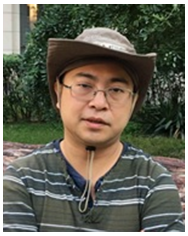

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