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Comparing 5G indoor wireless technologies: optical vs ultraviolet communication

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ABSTRACT

Wireless communication technologies have become one of the biggest technologies that are considered suitable for radio frequency in various types of applications, including indoor applications. This study investigates the differences between optical wireless communication (OWC) and ultraviolet wireless communication (UVC). Several parameters are simulated, including bit error rate (BER), signal-to-noise ratio (SNR), data rate, and received power, to compare the performance of each technology in various scenarios. Owing to its wide bandwidth, license-free frequency spectrum, and low signal attenuation at low carrier frequencies, the OWC is suitable for radio frequency applications in many situations, including indoor environments. The simulation results show that UVC outperformed OWC in terms of BER and SNR. Moreover, UVC has a higher data transmission rate of up to 1.1 Gbps, making it a suitable technology for 5G communication.

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1. INTRODUCTION

Wireless devices are increasing daily because of their user-friendliness, which allows consumers to access real-time information that can help reduce the usage of cables. Internet of things (IoT) solutions have the potential to enhance business verticals while also influencing other elements of our daily lives such as health, safety, productivity, and entertainment [1]. Owing to the rapid expansion in wireless technology, optical wireless communication (OWC) and ultraviolet wireless communication (UVC) have become promising technologies. Khalifeh *et al.* [2] have investigated visible light communication (VLC) as the main wireless technology for indoor environments. Their previous work focused more on the effect of LED positioning in the indoor environment. They used a simulation method to evaluate the performance by allocating LEDs at multiple orientations and used on-off keying (OOK) modulation as the modulation technique. A major cause of data loss can be because of breaks in the optical line-of-sight (LOS) link. When it comes to indoor applications, there are many obstacles, including smoke and furniture. OWC and UVC have some suitable link configurations, such as LOS, non-line-of-sight (NLOS), and diffuse links [3]. Besides OWC, UVC is also one of the wireless communications that is often considered an option to use in the indoor environment. Even though the UVC channel response exhibits different behaviors for different room sizes, it also has harmful effects if humans are exposed for too long. OWC is known to have a wide bandwidth and license-free frequency spectrum, as shown in previous studies [4]. OWC is suitable for complementing radio frequency in many applications including indoor applications. The optical spectrum is described as electromagnetic radiation with wavelengths from 10 nm to 10^3μm and frequencies ranging from 300 GHz to 3000 THz. UVC is included under OWC but with different bandwidths and omnidirectional links with low background noise [5]. Even though the carrier frequency might be low, it has a smaller bandwidth and consequently lower data speeds [1]. Previous research did not directly compare VLC and UVC nor did they assess their performance under identical environmental conditions. So, this research focuses on exploring and evaluating the performance of OWC and UVC in terms of illuminance, bit error rate (BER), signal-to-noise ratio (SNR), data rate, and received power by using OOK modulation that is suitable for indoor applications.

OWC refers to the transmission of light from one point to another in free space, also known as free space optics (FSO) [6]. OWC poses no threat to human safety as it does not emit harmful light. However, OWC has stringent alignment requirements and can be significantly affected by adverse weather conditions [7]. Any obstruction in front of the receiver can lead to data interruptions due to the system's sensitivity to shadows and the limited capacitance of its front-end photodiode. Indoor applications become as crucial as outdoor applications since most work and activities are performed either at home or in the office. OWC-based indoor positioning functionality is in great demand. The method of accepting the signal has generated much interest, where multiple transmitters are used and positioning information is provided by estimating the channel gain of each transmitter [8]. Before applying OWC for indoor applications, this wireless technology can also be used for ultra-short range for nm/mm distance of communication, a short-range which does not need to consume too much power and is low in data transfer such as bluetooth and wireless personal area network (WPAN) [9]. Medium range is when the data transmits between two points and is usually used for wireless local area networks (WLANs). Long-range is suitable for inter-building connections since it can transmit data faster than short-range communication and ultra-long range is used for space communication such as inter-satellite [10]. Due to the revolution of IR 4.0, everyday appliances will remain interconnected around the clock, placing increased demands on resources, whether from the devices themselves or the supporting network infrastructure [11]. In previous research by Gismalla and Abdullah [12] significant improvements were made to the majority of the room's surface area using five optical atto-cells to optimize power distribution within the space.

The emergence of LED technology led many researchers to choose LEDs for signal transmission due to their safety profile when exposed to humans for extended periods. Within the optical spectrum, visible light offers a wide array of LED colors with varying frequencies and wavelengths, making it an ideal choice for communication purposes. VLC uses white LEDs to provide minimal cost and combine lighting and communication features [13]. Compared to LEDs, lasers with core wavelengths of 850, 1,310, and 1,550 nm may easily attain a greater transmission data rate but have a much smaller beam diameter [14]. When there are a lot of other devices that use wireless communication, a larger bandwidth is needed to transmit signals, even at high-speed frequencies. Other than focusing more on indoor applications, other researchers fixate on outdoor applications where they can be used in military-based surveillance and traffic light signals [15]. Chaabna *et al.* [16] have proposed VLC research using the trilateration technique and solar cells that are known as passive components. Based on their paper, the trilateration technique is used to accomplish an exact target, which can be applied to different applications such as human tracking. Ultraviolet light is a naturally occurring radiation emitted by the sun. Unlike OWC it does not require a point-to-point system and offers the advantage of being resistant to electromagnetic interference. However, it is susceptible to drawbacks such as multipath fading and interference [17]. The sun transmits a mixture of wavelengths into space, ranging from infrared to ultraviolet.

NLOS is commonly used in research papers since it is more suitable for ultraviolet communication [18]. UV light has a solar-blind band around 200-300 nm. Usually, the OOK modulation technique is employed, with two transmitters transmitting data from one point to another. Subsequently, photomultipliers receivers are utilized to detect light from the transmitters and convert Alamouti code to the linear spacetime blocks [19]. One of the challenges in designing UV communication systems is the significant impact of radiation scattering characteristics, which are influenced by environmental conditions. Successful development of UV communication tools requires the creation of a comprehensive model that encompasses the transmission channel, optical transmitter, and optical receiver. Various well-established mathematical models account for different versions of NLOS UV channels with diverse geometries and their interactions [20]. There are three UV light types ranked from least to most hazardous [21] which are UV-A which is safe to use, UV-B is dangerous to humans, UV-C is the most dangerous, often used as a disinfectant because it can kill germs. UV-A radiation makes up nearly all of the ultraviolet that reaches the Earth's surface. Borah *et al.* [22] used Monte Carlo simulation, commonly known as the Monte Carlo Method or multiple probability simulation, which is a mathematical technique for estimating the consequences of an uncertain event. The researcher studies the analysis method for single and double scattering events, specifically for NLOS and UV communication systems.

2. RESEARCH METHOD

2.1. Parameters

This research uses MATLAB software as the main method to evaluate and compare both technologies. The simulation parameters are detailed in Table 1, tailored to assess the performance of both technologies as per specific requirements. Three LED conditions were considered for each room size.

The simulation includes varying room sizes with three distinct LED placements, outlined in Table 2. This setup allows for the calculation of illuminance and BER to assess the data channel's performance during signal transmission. BER serves as a reliable metric for gauging the level of errors in transmitted data. Subsequently, SNR calculations are conducted to discern the disparity between the received signal and the noise floor. In data networks, achieving an SNR of 20 dB or higher is considered optimal. These evaluation parameters are applied to both OWC and UVC measurements. The research is constrained by the fact that all presented results were derived exclusively from simulations conducted using MATLAB. Future investigations will incorporate practical measurements to enhance performance comparisons.

Table 1. Simulation parameters

Type	Parameters	Value
Transmitter	Number of LED	1/2/4
	Power radiated by each LED	1W
	Angle of irradiance	70
Receiver	Photodetector responsivity	1A/W
Others	Bit rate	200×106
	Number of bits	1×103
	Background noise	202×106
	Electron charge	1.6×10-19

Table 2. Location of LED according to different room sizes

Size of room (m^3)	1 LED	2 LEDs	4 LEDs
4×4×2	(2.5,2.5)	(2.5,1.5), (2.5,3.5)	(1.25,1.25), (1.25,3.75), (3.75,1.25), (3.75,3.75)
8×8×2	(4.5,4.5)	(4.5,3.5), (4.5,5.5)	(1.25,6.7), (1.25, 2.4), (5.95,6.7), (5.95,2.4)

3. RESULTS AND DISCUSSION

3.1. Power distribution

This study looked into the effects of the number of LEDs and room size on the two different technologies of illuminance distribution while previous studies focused on the impact of modulation on the performance, they did not explicitly address its influence on the technology performance. Figures 1-3 show the distribution of illuminance based on the number of LEDs in a room and the wireless technology used for 4×4×2 and 8×8×2 m^3 rooms. The minimum illuminance for Figure 1(a) (i) is 1,526 lx and when the coordinate of the room is (2.5, 2.5), the peak illuminance is 2,628 lx while for Figure 1(b) (i) the peak illuminance is 2,610 lx. Both technologies have intense illuminance and are evenly dispersed throughout the room. Alterations in room dimensions can impact illuminance levels. It stands to reason that in larger rooms, LEDs would distribute light more uniformly, presenting a potential solution to maintain optimal illuminance levels, neither too high nor too low. Figure 1(a) (ii) peak illuminance value is 2628 lx and minimum illuminance value is 83 lx. There is a slight gap in the illuminance value when the LED is changed to UVC LED. The minimum value for OWC LED is 83 lx and the minimum value for UVC LED is 19 lx, which shows that UVC can reach very small illuminance power.

Two LEDs are used correspondingly in Figures 2(a) and (b) for OWC and UVC where (i) and (ii) are for 4×4×2 and 8×8×2 m^3 room sizes. Similar results were produced for both technologies, where in Figure 2(a) (i) the highest value is 2,932 lx which is shown to be higher than when there is only one LED per room. Figure 2(b) (ii) shows the illuminance graph for two UVC LEDs in a room size 8×8×2 m^3. Similar outcomes are obtained since a room with more LEDs has a larger lumen output, which can result in a light source with a higher intensity.

Based on Figure 3(a) (i), the minimum illuminance radiated by the LED is 560 lx, complying with the ISO standard for everyday office work and houses. However, this may cause some risk since the average illuminance for UVC 4 LEDs is 1,825 lx, which is more suitable for detailed drawing work, very detailed mechanical work, electronic workshops, testing, and adjustments. If it is used in a house or office, it may cause discomfort to the user since the strong exposure to light would make their eyes tired. The difference for OWC in Figure 3(b) (i) is that when there are 4 LEDs, the average illuminance is 1,300 lx which is suitable to use for everyday drawing work. Light illuminance is evenly dispersed starting from the center towards the corner of the room. Figure 3 used 4 LEDs per room. UVC LEDs in Figure 3(a) (ii) have a slightly lower highest illuminance compared to OWC LEDs in Figure 3(b) (ii) where UVC LED only dispersed 2,729 lx while OWC LED dispersed 3,096 lx. Even though the results show that UVC LED has better results than OWC, other risks need to be considered to bring comfort to users. The obtained data for the average illuminance is summarised in Table 3.

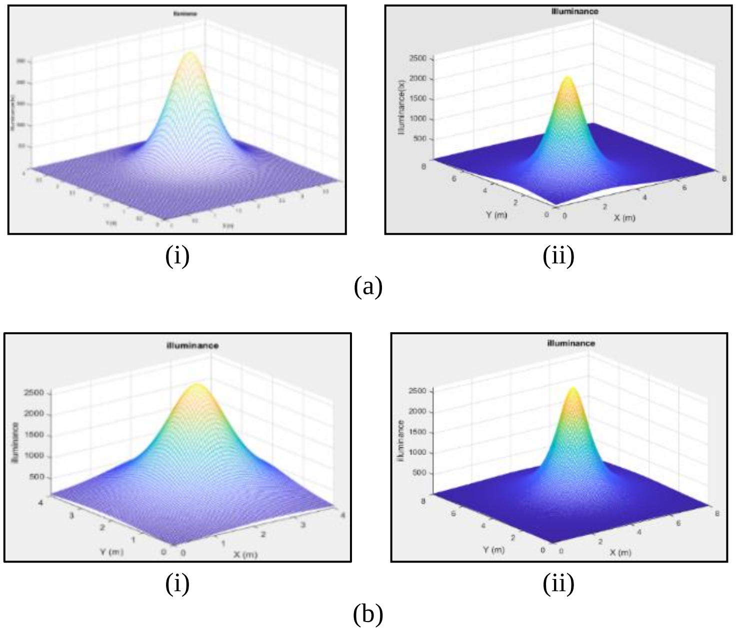


Figure 1. Illumination for 1 LED in a room measuring (i) 4×4×2 m^3 and (ii) 8×8×2 m^3 using (a) VLC and (b) UVC

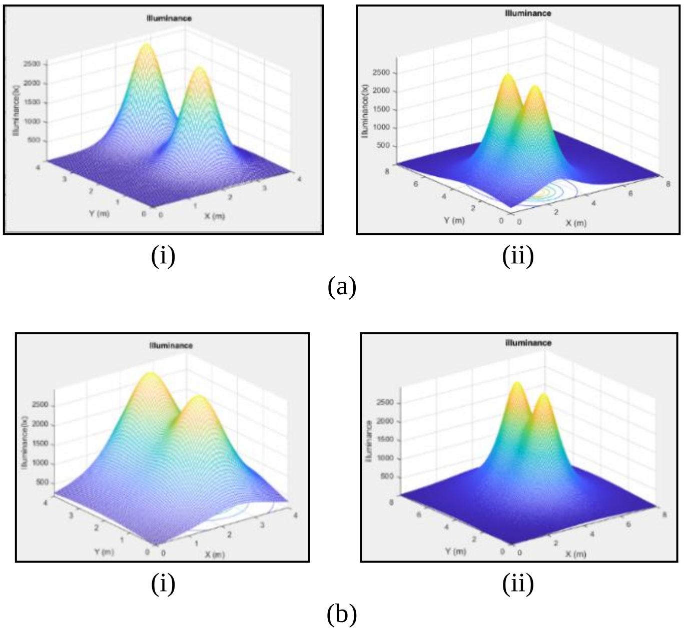
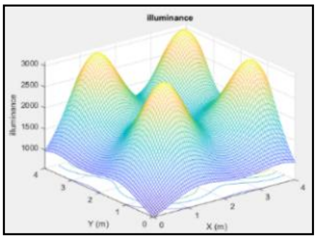
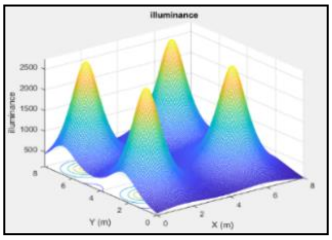


Figure 2. Illumination for 2 LED in a room measuring (i) 4×4×2 m^3 and (ii) 8×8×2 m^3 using (a) VLC and (b) UVC

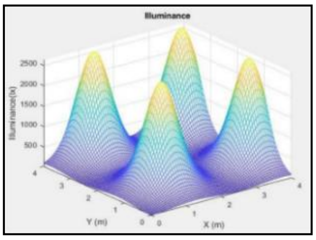


(i)

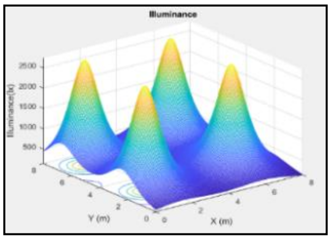


(ii)

(a)



(i)



(ii)

(b)

Figure 3. Illumination for 4 LED in a room measuring (i) 4×4×2 m^3 and (ii) 8×8×2 m^3 using (a) VLC and (b) UVC

Table 3. Average of illuminance value

Size of room (m^3)	1 LED		2 LEDs		4 LEDs	
	OWC (lx)	UVC (lx)	OWC (lx)	UVC (lx)	OWC (lx)	UVC (lx)
4×4×2	1,260.89	1,260.89	1,379.33	1,381.35	1,258.07	1,825.00
8×8×2	1,272.02	1,299.72	1,443.28	1,453.36	1,450.33	1,260.33

3.2. Bit error rate

The error rate performance vs SNR for the three LED conditions is listed in Table 4. After simulating the three conditions of LED and two room sizes for each technology, the results show the same value of BER. A bit rate of 200 MHz is standardized for all three LED arrays. The lowest performance occurs when there are 4 LEDs in a room, while the best performance is observed when there is a single LED. Analysis of Table 4 reveals that as SNR increases, the BER decreases. This correlation stems from the fact that higher SNR levels correspond to lower BER values, indicative of superior performance. Rooms featuring a single LED exhibit better signal quality compared to those with four LEDs. A robust signal diminishes the likelihood of errors, as a low BER necessitates a high SNR. Having multiple LEDs in a room enhances signal transmission capabilities compared to a single LED setup. However, in smaller rooms with multiple LEDs, there's a risk of signal overlap, potentially compromising signal integrity. To mitigate this issue, identifying the optimal angle of view is imperative. Table 4 presents the comparison between BER and SNR for OWC and UVC based on results generated in MATLAB software. The data pattern indicates that with four LEDs in the room, the error rate is higher compared to scenarios with two or one LED. Higher SNR levels correspond to lower BER values. For instance, in a single LED configuration, the BER is lower at an SNR of 12 compared to the lowest SNR, indicating acceptance of the hypothesis that high SNR and low BER can enhance the efficiency of transmission [23]. However, when contrasting one LED versus four LEDs, the error rate significantly rises for the latter configuration compared to the former.

Table 4. Comparison between BER and SNR for OWC and UVC

Array	OWC		UVC	
	BER	SNR	BER	SNR
1-LED	0.2573	1	0.2643	1
	0.0001	12	0.0001	12
2-LED	0.57407	1	0.5814	1
	0.04674	12	0.0444	12
4-LED	0.77663	1	0.7852	1
	0.31923	12	0.3246	12

The results for UVC LED and OWC LED show no difference in BER results since the parameters used for both technologies are the same. As with OWC, simulations for rooms with only one LED align more closely with theoretical expectations. The BER serves as a crucial metric for assessing the efficacy of data networks. It represents the key parameter governing the occurrence of errors in data transmission, whether via wireless or cable telecommunications, at the output port. In OWC, acceptable BER refers to the receiver's ability to generate a minimum of one error for every 10^{-9} bits of transmitted data. Therefore, achieving a BER of 10^{-9} or better is desirable.

3.3. Data rate and received power

To prove which wireless technology has a better signal transmission to use in an indoor environment, the data rate of the transmitter and power received by the receiver play a crucial part since high data rates are imperative for achieving robust wireless communication [24] and the receiver needs to have strong receiving power. The distance between the transmitter and receiver increases, and the number of bits transmitted from one device to another diminishes. Both technologies exhibit similar trends in graph behavior but exhibit substantial differences in data rate values. In a VLC system, the peak value is 0.125, observed when the transmitter and receiver are 1 meter apart, whereas, for UVC, the value is 7.5×10^{14} at the same distance. Based on the results obtained, UVC boasts the highest data rate and fulfills the criteria for facilitating extensive 5G transmission. Figure 4 illustrates the comparative data rate results between VLC and UVC, utilizing identical parameters and the number of LEDs per room. Based on the observation, UVC shows massive speed of data rates at the same time fulfilling the requirement for 5G transmission.

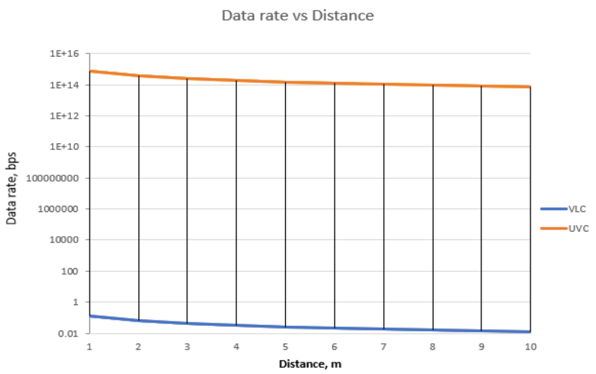


Figure 4. Comparison of data rate between VLC and UVC

Received power refers to the power level that the receiver can capture from the transmitter. To achieve a better receiver performance, it's essential to ensure a higher received power within the system. As indicated by the aforementioned data rate outcomes, UVC appears to have the potential to excel as a technology suited for indoor applications. However, UVC LEDs exhibit a lower received power value compared to VLC systems, as outlined in Table 5. Despite the VLC system having a lower data rate than UVC, VLC receivers are expected to perform better compared to those utilizing UVC LEDs. To determine the power received by the receiver, the received power is calculated using the (1) after which the background noise is removed to obtain the total power received by the receiver.

Table 5. Comparison of received power between VLC and UVC

Array	VLC	UVC
1-LED	0.010286 W	6.3929x10-12 W
2-LEDs	0.020571 W	1.2786x10-11 W
4-LEDs	0.041143 W	4.0915x10-10 W

$$P_{rec} = \frac{P_{trans}A_{rec}\eta_{rec}\eta_{channel}}{d^2 A_{trans}\eta_{trans}} \quad (1)$$

where power, P, efficiency, η, effective area, A, and distance between receiver and transmitter, d.

3.4. Discussion

This study investigated the impact of illuminance, number of LEDs, BER, data rate, and received power for two distinct wireless technologies, namely OWC and UVC, using OOK modulation as the main modulation technique. In contrast, prior studies focused on assessing the performance of a single wireless technology utilizing different modulation techniques and constrained their research to specific room sizes. These earlier studies did not explicitly consider how these factors influence the comparative evaluation of two different wireless technologies in indoor environments. There are variations in the light distribution emitted by LEDs. When considering a single LED, both OWC and UVC achieve a maximum illuminance peak of 2,628 lx. However, with four LEDs in the room, the minimum illuminance peak for OWC decreases to 83,839 lx, while for UVC, it increases to 1,612.36 lx. Illuminance values indicate the brightness intensity emitted by the LED, which we attribute to differences in power output as per the LED datasheet. Based on the illuminance analysis, UVC demonstrates better light distribution in a room due to its higher illuminance levels. Illuminance may vary with the number of LEDs; for example, when four LEDs are positioned at various measurement points within a room, illuminance increases. High illuminance offers benefits such as suitability for everyday office work or household use when the illuminance level reaches 500 lx. Regarding the BER, there is no discernible distinction between OWC and UVC as the parameters remain consistent for both technologies. Adhering to the ITU-T standard, the minimum acceptable BER is 10^{-9}, and the results obtained fall within this range, indicating that this project is well-suited for indoor applications. To enable an innovative lifestyle, millions of sensors are incorporated into cities, automobiles, residences, industries, food production, and toys. Seamless operation of these applications necessitates high data rates coupled with secure connectivity [25]. UVC exhibits significantly higher data rates compared to OWC, meeting the requirements for 5G networks. Despite having a larger data rate for transmission, UVC exhibits lower received power than OWC. Nevertheless, this research shows that, in comparison between OWC and UVC systems, UVC poses a considerable risk for indoor applications due to its emission of high-energy radiation, which can be harmful to human health upon prolonged exposure. However, UVC presents a substantial potential for development and finds practical utility in medical applications such as sterilization and purification cycle processing [26]. Future research may focus on generating and identifying Q-factor in these technologies. Signal quality plays a pivotal role in determining data transmission speed; higher-quality signal ratings correspond to better signal quality. Experimental projects are necessary to validate simulation results and assess signal quality.

4. CONCLUSION

This preliminary study assesses the appropriateness of OWC and UVC for indoor applications in the context of 5G. Through the analysis, VLC is preferred for indoor use due to its lower risk profile when humans are exposed to LED light over extended periods. Moreover, VLC LEDs are more cost-effective as they serve dual purposes of signal transmission and light distribution, unlike ultraviolet LEDs that solely transmit data. While VLC remains the predominant wireless technology, our research demonstrates that both technologies can be viable options for indoor environments. However, it is imperative to consider other potential risks to prevent unforeseen events that may affect users. Improvements are essential to ensure smooth progress and enhance the outcomes of this project, including conducting physical testing to validate simulation results. As the global vision for deploying 5G worldwide, both technologies can alleviate spectrum congestion in radio frequency (RF) communications. This helps in meeting the growing demand for high-speed communication links between consumer electronics, sensors, and the infrastructure. The commercial potential for this project is significant, especially in the realms of communication and data transmission offering high-speed wireless communication as a complementary solution for overcrowded RF and Wi-Fi systems. Furthermore, this project embodies green technology principles, as the LED components utilized are energy-efficient lighting sources that consume less electricity than traditional fluorescent lighting. Additionally, OWC and UVC systems are compatible with radio-frequency wireless technology across various applications.

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