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Research Article

Is LiFi Technology Ready for Manufacturing and Adoption? An End-user questionnaire-based study

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ABSTRACT

Because of the exponential development of emerging technologies and the increase of devices that use the internet, the wireless fidelity (WiFi) spectrum has been saturated, therefore, the light fidelity (LiFi) has been under development for wireless communication including internet access. LiFi network systems can provide high speed data rates with high security. However, LiFi is still under development and research, and is not yet popular for end-users to be used in homes, companies, and other industries. Therefore, for the first time, this study investigates the adoption probability of LiFi technology by the end-users to anticipate the success rate when launching ready-to-use LiFi devices for end-users by the manufacturer companies. A well-designed questionnaire is used in this study for data collection. A total of 100 participants from around the world have been chosen to fill-up the questionnaire forms including three phases: basic information, preferences, and usage, and LiFi and Pricing. The findings of this study show a high and positive probability for adoption rate of LiFi technology. However, the pricing aspect has a critical impact on the acceptance of using LiFi systems by the end-users.

1. INTRODUCTION

As per the statistical report by the end of 2020, mobile data transmission accounted for 71% of Internet traffic and more than 80% of data transmission in indoor places like homes and offices [1]. Owing to the dense establishment of wireless fidelity (WiFi) hubs and restricted resources of the radio frequency (RF), radio systems encounter difficulty in fulfilling the increasing requirement of mobile Internet. RF spectrum limitation management is supported by light fidelity (LiFi) technology.

LiFi is a short-range wireless communication technology that uses light wave as signal bearers [2]. In contrast to the scarce and regulated RF spectrum, the visible light spectrum is huge (about 300 THz) and unregulated. Other advantages that LiFi offers over WiFi include: i) provision of illumination, ii) availability in RF-restricted areas, and iii) secure communication since light does not penetrate opaque structures [3], [4]. More importantly, LiFi can provide high-speed data transmission to help fulfil the rapidly increasing demand for wireless communications. Recent research shows that with using light-emitting diode (LED), LiFi is able to achieve peak data rates above several Gbps [5], [6]. Compared to WiFi, LiFi supports a relatively small coverage area from a single access point (AP), typically an area 2-3 m in diameter [7]. This enables LiFi APs to be densely deployed. As a result, LiFi can offer very high area spectral efficiency up to 1000 times as much as an RF femtocell.

Relevant research has been studied for LiFi and for hybrid LiFi and RF networks [8]–[12]. WiFi and LiFi networks that have converged provide great coverage and fast data transfer [13]. WiFi and LiFi could be used to compensate for flaws of all these technologies. The hybridized LiFi/WiFi had a superior performance when compared with individual performance of both WiFi and Li-Fi systems. LiFi could be utilized without interfering in some environments that are susceptible to magnetic waves, including aero- planes or clinics. The LiFi technology is still new, unpopular and under development, and has not yet been marketed around the world as WiFi has, therefore, it is important to understand the success rate of adoption of LiFi networks by the end-user as well as the marketing opportunity before launching a wide-range promotion and

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marketing campaigns for LiFi wireless communication systems. This is considered the main motivation for conducting this study.

This study investigates the actual perspective of end-users of using wireless technologies in general, their willingness of using LiFi technology in specific, and to provide real data and opinions that support the adoption and usability of LiFi technology by using questionnaire survey. In this study, a questionnaire-based investigation is proposed focusing on the likelihood of the adoption rate, service purchasing rate including devices. Based on the results of the investigation in this study, the industry and companies will benefit the most in terms of development and marketing.

2. MATERIALS AND METGIDS

A. Scope of the Investigation

The investigation in this study focuses on the adoption probability as an indicator which is specifically designed for targeting real-world opinions. The objective is to come out with findings that could provide clear insights for future marketing opportunities and possibly research directions

B. Study Design, Data, and Research Participants

The process of data collection and analysis for this research consists of few steps. First, a questionnaire is designed which was hosted on Google Forms and distributed online for data collection using various social channels. Moreover, face-to-face interviews were conducted as well for data collection. The questionnaire consists of three sections which are basic information, preferences and usage, and pricing. Figure 1 shows the main elements included in the questionnaire. Data collection consisted of human participants. Figure 2 summarizes the details of all sources of data. As seen in Figure 2, data was collected from around the world including 100 participants from 28 countries. all the questions were written in English. Table 1 show all the phases and questions of the questionnaire.

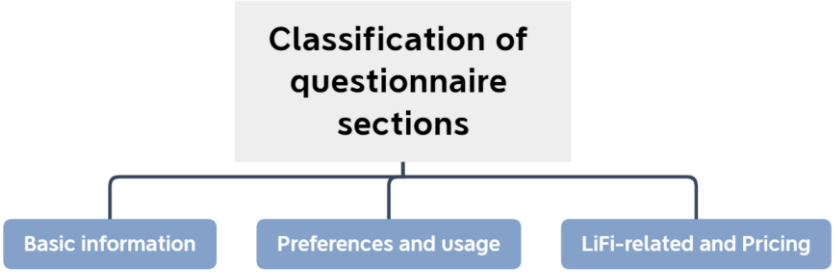

Fig. 1. Sections and classifications of the questionnaire

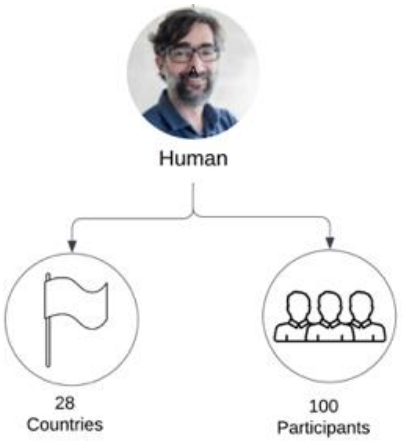

Fig. 2. Data sources

TABLE I. LIST OF THE QUESTIONS FROM THE QUESTIONNAIRE CONDUCTED FOR THE SUBJECTS.

	Questions for Human participants	**Options for answers**
Section 1: Basic information	1-What is your age (years)?	• 10-20 • 20-30 • 30-40 • 40-50 • 50-60
	2-What is your occupation?	• Unemployed • Student (school) • Student (college or university) • Employed (general) • Prefer not to say
	3-Where do you live?	➢ Text input
	4-What is your gender?	• Male • Female • Prefer not to say
Section 2: Preferences and Usage	5-What kind of device do you frequently use?	• Smartphone • Tablet • Laptop • Desktop • Other
	6- How many hours per day do you use the internet (hours)?	• 0-3 • 3-6 • 6-9 • 10 • More than 10 • More than 15
	7- Do you use the internet frequently indoor or outdoor?	• Indoor • Outdoor • Both
	8- What kind of network service do you use?	○ Cellular ○ WiFi ○ Both ○ Other
	9- Do you think your current internet speed is enough?	• Yes • No • Maybe
	10- Do you need higher-speed network?	• Yes • No • Maybe
	11- What do you use the internet for?	○ Gaming ○ Social media (general) ○ Messaging and video calling ○ Video streaming (Netflix or YouTube) ○ Online meetings (conferences or online learning) ○ Browsing and e-mail ○ Other
	12- Do you use the internet for personal use or for work?	• Personal • Work • Both
	13- Do you think current wireless technologies (4G, 5G, cellular or WiFi) affect human health?	• Yes • No • Maybe
Section 3: LiFi and Pricing	14- Have you heard of LiFi?	• Yes • No • Maybe
	15- Are you willing to use LiFi?	• Yes • No • Maybe
	16- Why would you use LiFi?	○ Higher speed ○ Higher security ○ Human safety ○ New technology ○ Other
	17- Will you use LiFi if it functions in the indoor area only?	• Yes • No • Maybe
	18- Do you think LiFi should be used everywhere?	• Yes • No • Maybe
	19- Are you willing to purchase the service at higher costs than your current network service?	• Yes • No • Maybe
	20- Are you willing to use LiFi if it means you need to buy a new phone/device?	• Yes • No • Maybe
	21- Are you willing to use LiFi if it means you need to buy an additional device (USB, dongle)?	• Yes • No • Maybe

Table 1 shows the basic characteristics of the participants including age, gender, occupation, and country. who had access to the internet with an applicable device to fill the questionnaire and could read and understand English language. Participants' privacy and identity were protected and kept confidential. Participants were selected to have a diverse. Participants included in the study were aged from 10 to 60 and divided into 5 groups. The first group was from 10 to 20, the second was from 20 to 30, etc. Figure 3 shows the age and gender groups.

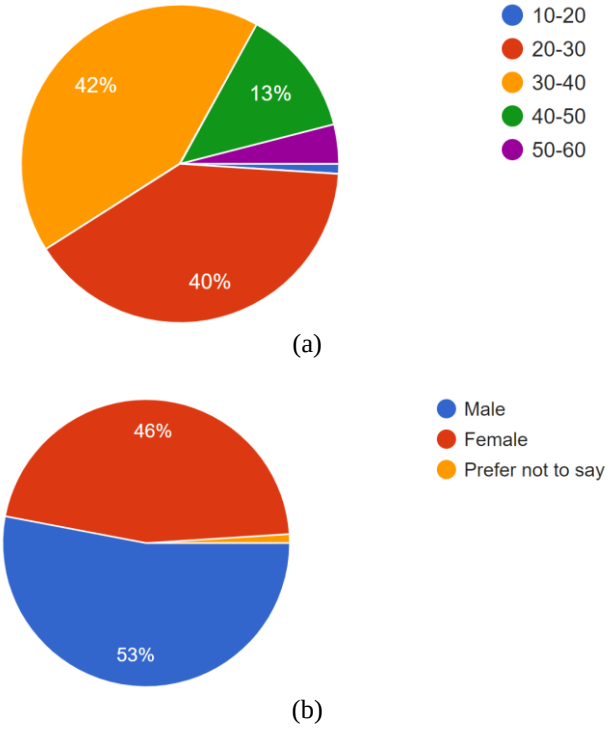

Fig. 3. Age and gender groups including statistics of participants.

as shown in Figure 3(a). People aged 30-40 were 42 (42%) individual and is the highest number among other groups, followed by people aged 20-30 including 40%. People aged 50-60 were 4%, and those who are 10-20 were only 1%. Figure 3(b) shows number of males and females where almost 50/50 rate was included and only 1% chose "prefer not to say". Figure 4 shows the occupation of the participants. Data collection from different countries around the world, as shown in Figure 5, can provide fair judgment for the findings of this study. The highest number of participants come from Malaysia with 10 participants and UK with 9 participants followed by Iraq with 6 participants, and 5 participants for Algeria, Indonesia, Jordan, and Germany. Microsoft Excel was used for data cleaning and screening.

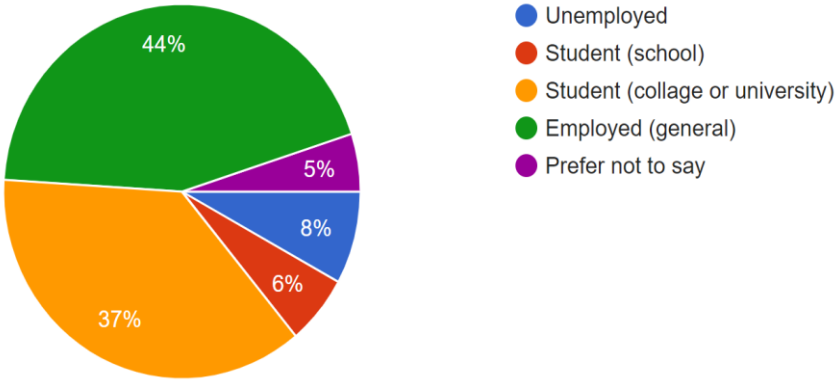

Fig. 4. Occupation groups.

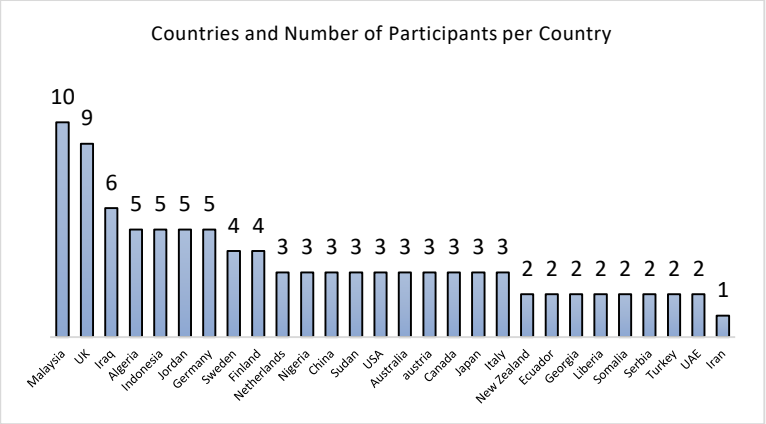

Fig. 5. Numbers of participants from different countries.

3. RESULTS AND DISCUSSION

The results presented includes the preferences and usage responses. It is used to show the types of devices that are used by individuals such as smartphones, tablets, laptops, and/or desktop. It also requires the participants to reveal the time they spend on the internet per day, and where they usually access the internet such as indoor and/or outdoor. Other questions considered for this aspect were targeted for the speed of the internet, the need for higher speed, and what do people use the internet for including gaming, social media, video conferences, etc. Another interesting question consisted of the participants opinions on whether current wireless technologies affect the human health or not. The data collected on the LiFi technology and pricing is also presented to meet the focus of this study. The questions included for this investigated the willingness of using LiFi by the participants. Moreover, other questions were considered such as the reason for using LiFi, and are people willing to use it if it only functions in the indoor area only. The pricing questions investigated the purchase rate of the service if it costs higher than their current service, and will they use LiFi if they must buy additional piece of device such as USB, dongle, or even new smartphone. Below the results of all responses. This section holds the main and most important findings. Many devices including mobile devices have been associated with the use and development of wireless communications [14], [15]. Figure 6 shows the type of devices used by the participants.

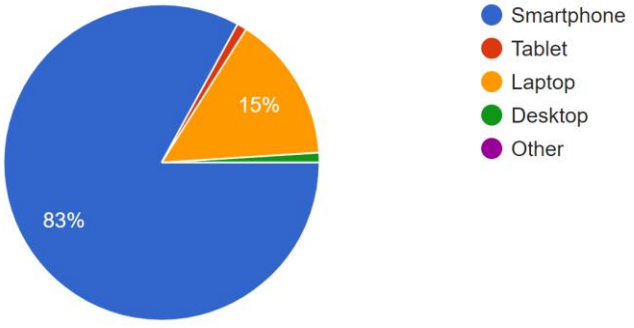

Fig. 6. Types of devices frequently use by the participants.

Smartphone was the most used device by 83% followed by Laptop by 15%, while Table and desktop were 1% each. This supports the adoption of LiFi networks as most of studies considered dynamic environment and mobile users that use cell phone. Figure 7 illustrates the number of hours of using the interne where many people spend from 6 to 9 hours (29%) and 3 to 6 hours (25%), and overall, we can see most people spend from 3 to 10 hours and some people spend even more than that where 13% spend more than 15 hours. This is related to the tons of websites, services and application available on the internet.

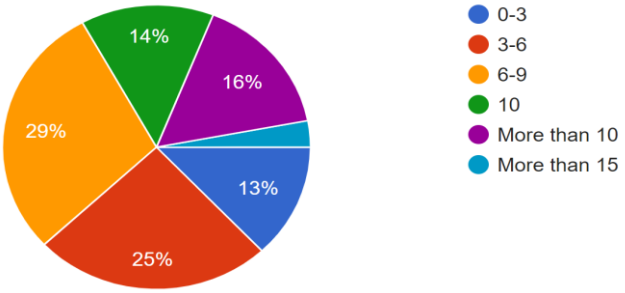

Fig.7. Internet access usage by hours per day.

The indoor and outdoor usage and internet access [16]–[19] is another important aspect investigated recently in many domains and in the wireless communications. In figure 8, we can see 32% of people are using the internet in the indoor area only, and 3% are using it in the outdoor area. On the other hand, 65% are using it both in the indoor and the outdoor. We can conclude from this that most people are using the internet in the indoor at 97% against 68% for the outdoor only. With that being said, using LiFi communication system in the indoor areas [20]–[23] would benefit most people who are interested in LiFi systems.

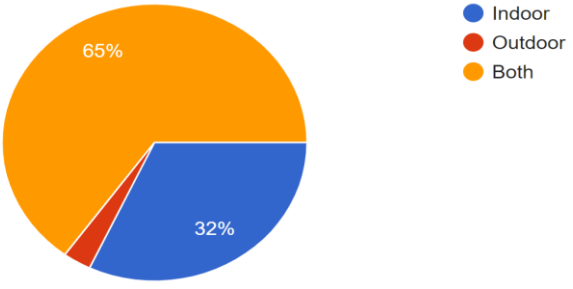

Fig.8. Indoor and outdoor of internet access.

Different radio access technologies (cellular, satellite, WiFi, etc.) or different types of equipment (pico-cells, femto-cells, small-cells, macro-cells, etc.), have the potential to significantly increase network capacity. Indeed, all these technologies focus on the interaction between cellular and WiFi networks. This logical element can be integrated within WiFi Access Points (APs) or into WiFi Access Controllers (ACs). It establishes a connection between the base station and WiFi APs to manage the data aggregation process and exchanges (control/data) between LTE and WiFi devices [24]. One of the main objectives of fifth-generation cellular networks (5G) is to offer a solution to manage a growing number of users [25]. It could be an efficient way to improve cellular networks' scalability and to efficiently share network resources among users [26]. In addition, WiFi networks have been combined with LiFi as hybrid networks for wider coverage and higher speed of data [12], [27]–[29], as well as the cellular networks [30]–[32].

Figure 9 shows the percentage of people using the cellular network against people who use WiFi networks for accessing the internet. Most people are using WiFi at 44% in addition to the 48% for those who chose using both WiFi and cellular. LiFi networks have been combined as hybrid network system with WiFi more than any other network including cellular networks [3], [33]. This number supports the possibility of the adoption of LiFi networks as it also operates in the indoor areas within the same environment where LiFi system can be embedded into the existing light infrastructure [34], [35]. The other option provided in the questionnaire is labelled as "others", where it signifies the cable connection that is linked with the desktop devices where none of the participants is using it as shown in Figure 9 with 0%.

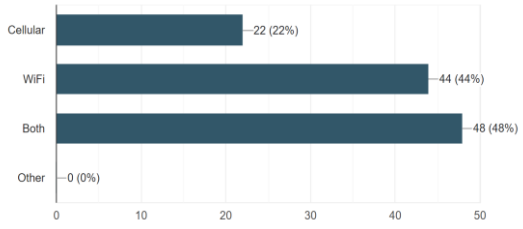

Fig.9. Internet service provider usage statistics by participants.

Given the recent globally changes and difficulties of Internet adoption rates and data usage caused by the COVID19 pandemic, it is worth noting and taking into consideration those factors when investigating the adoption probability of LiFi technology. According to the data presented by [36], little evidence of a faster expansion of access to internet across all country income groups The largest improvement in digitalization during the recent pandemic was the leap in internet speed among existing users [37]. The average mobile-broadband basket price is nine times higher in low-income developing countries than in advanced economies [38], making it even more difficult for low-income developing countries to bridge the gap in internet access. Figure 10 shows the participants' opinions on whether they think the internet speed is enough, this was a general question, where most people think the internet speed is not enough for them at 39% in addition to 23% for those who are not sure or not aware about it.

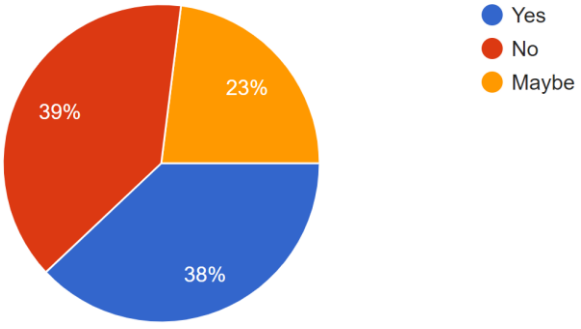

Fig.10. Participants' opinions on the internet speed.

In addition, the percent of people who revealed their need of higher speed networks as shown in Figure 11 where 68% agreed of this need in addition to those who were not sure of it at 19%. Moreover, only 13% of people who said they don't need higher speed.

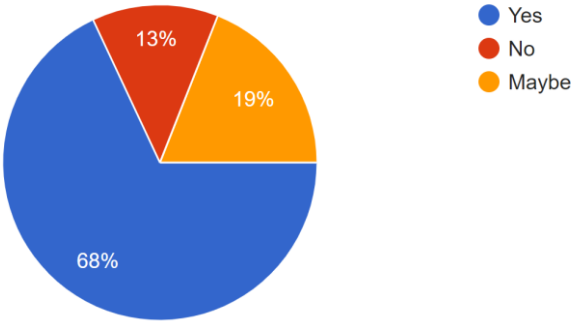

Fig. 11. Participants' need for higher speed networks.

People are using the internet for many reasons, as shown in Figure 12, social media, browsing and email, and messaging were the most services used at 85%, 75% and 71%, respectively. People are using the internet for personal and professional purposes as shown in Figure 13. Moreover, 32% of the participants think the current wireless technologies could affect the human health, in addition to those who responded "Maybe", while only 20% did not think so.

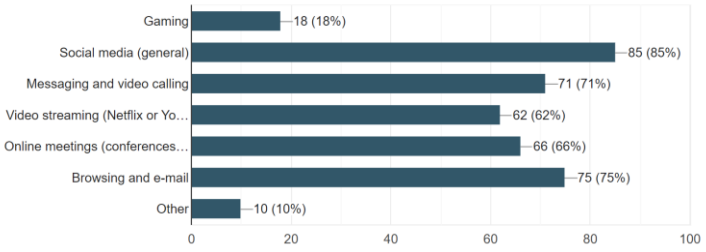

Fig.12. Internet services usage percentage by the participants.

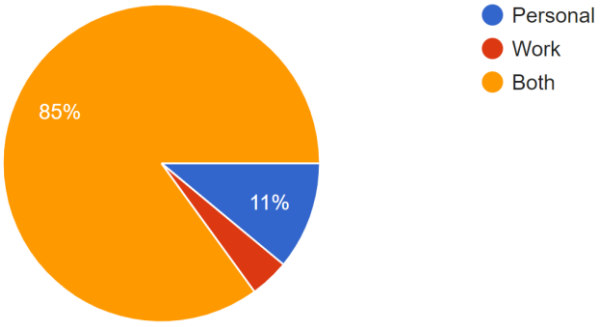

Fig.13. Internet usage preferences.

Since LiFi technology is much safer and has less effect on human health [39], [3], [40], [41], therefore, it is good to understand people's opinions of current wireless technologies (4G, 5G, cellular or WiFi) regarding human health where 39% of the participants believe so and 41% think it could cause bad effects on human, whereas only 20% don't think so as shown in Figure 14.

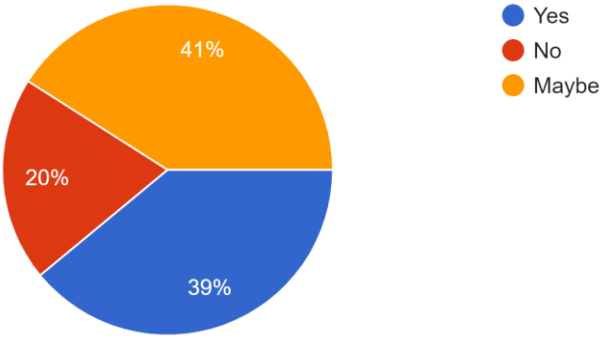

Fig.14. Human health related responses of participants.

After using various wireless technologies in the past decades, people nowadays are aware and used to using all the popular technologies such as WiFi and Bluetooth. Figure 15 shows how many of participants have heard of LiFi before where 68% of them do not know anything and never heard of it, and only 28% who did and the rest 4% responded "Maybe". This means it will be difficult for the end-users to adopt LiFi technology once released in the market either because they are not aware of the benefits and the cost of it.

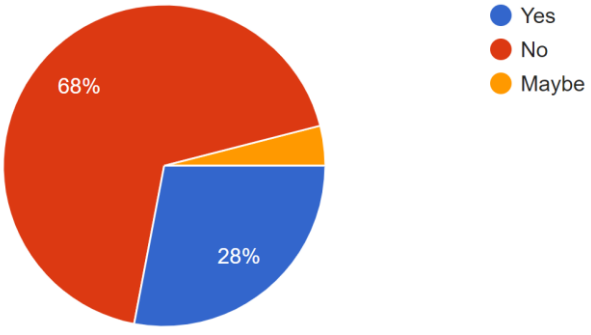

Fig.15. Responses of the participants for prior knowledge of LiFi technology.

In the Figure 16, the responses show the willingness of using LiFi where 45% of the participants responded "Yes" in addition to those who responded "Maybe", while only 7% of them responded "No". This is a positive indication that shows high probability of adoption for the LiFi technology.

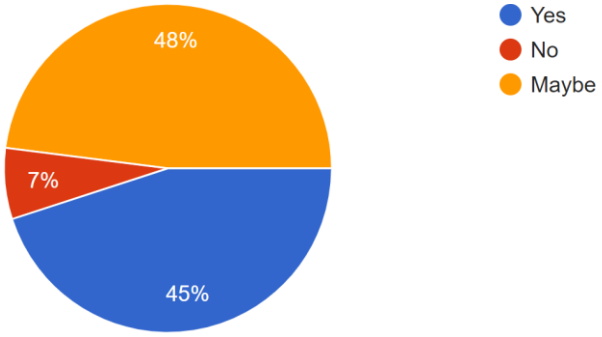

Fig.16. Responses of the participants and their willingness of using LiFi.

Figure 17 is related to the reasons of which why would people use LiFi technology where most responses were related to the higher speed at 53% followed by 39.2% for the human safety, on the other hand, security was weak aspect with 24.7%. Some of the participants chose to use LiFi only because it is a new technology at 26.8% and 18.6% of the responses were classified as "Other" reasons which could be related to those who were unsure of their willingness of using the technology. The responses in Figure 17 are multi choice, this means some participants chose more than one reason.

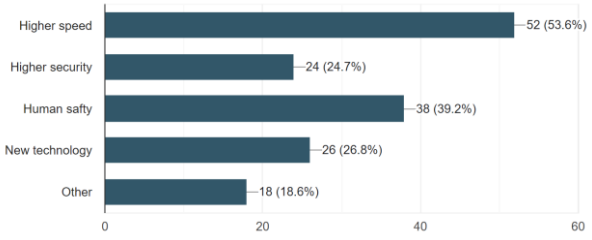

Fig.17. Reasons why people would use LiFi.

After that, the participants were asked a critical question which aims to reveal their willingness of using the LiFi technology if it functions only in the indoor area as shown in Figure 18. Specifically, 35.1% of the participants responded "Yes" and 43.3% responded "Maybe", and only 21.6% were unwilling to use it. In total, 78.4% are willing to use LiFi in the indoor area. The participants were asked whether LiFi should be used everywhere, as shown in Figure 19 where 49% of them said "Yes" and 48% of them said "Maybe", on the other hand, only 3% of them said "No".

Regarding cost of accessing the internet service using LiFi, the participants were asked if they are willing to use it in case it will be available for higher cost than their current network service subscription, as shown in Figure 20, where 18.8% of them responded "Yes" and 36.1% of them responded "Maybe", and 45.4% of them said they would not. This shows the pricing aspect is important for operating and the adoption of LiFi technology.

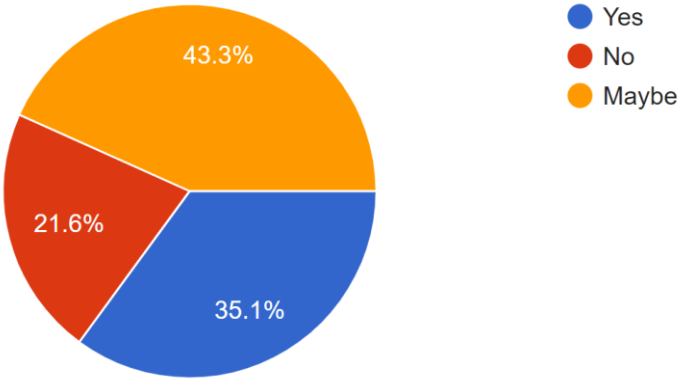

Fig.18. Responses for using LiFi in the indoor area only.

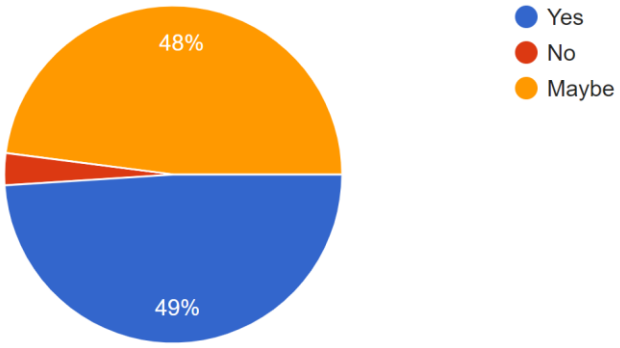

Fig.19. Should LiFi be used everywhere responses.

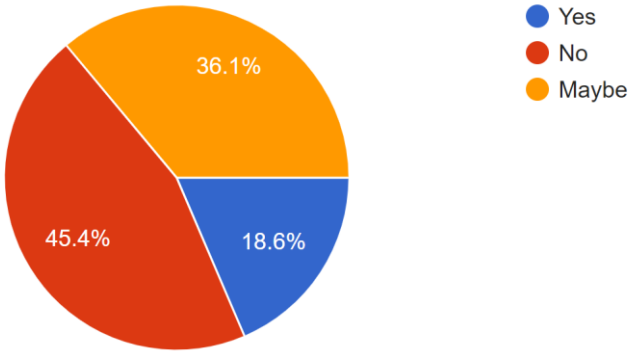

Fig.20. Willingness of using LiFi if it costs more than the current networks.

In addition, Figure 21 shows the responses of how likely LiFi could be adopted if it means the user should buy a new smartphone, and Figure 22 is related to buying new piece of device (including USB or a dongle). In Figure 21, the responses show that users are less likely to use LiFi where 17.3% for "Yes" with 41.8% for "Maybe", in total 59.1% for buying new smartphone, and 40.8% of them said "No".

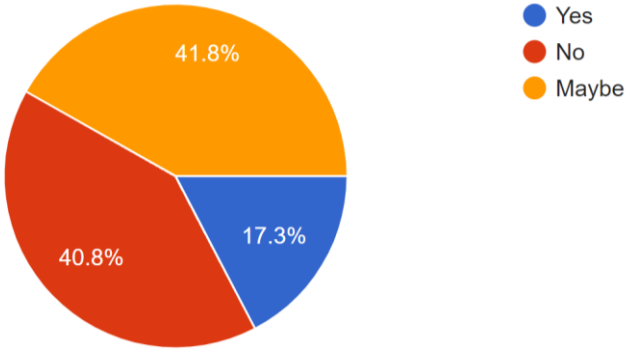

Fig.21. Using LiFi that comes with new smartphone.

In addition, as shown in Figure 22, total of 39.6% said "Yes" and 38.5% for "Maybe" for using LiFi with buying new piece (USB or dongle), and only 21.9% said "No". This variation illustrates how unlikely people will adopt the technology if they need to spend more money until they are able to use the technology. However, more people are willing to use and adopt the technology if it means they should spend less, this increase of 20% shows the technique of embedding LiFi transmitters and receivers in the current smartphones is more important than building new models of smartphones that are dedicated for LiFi only.

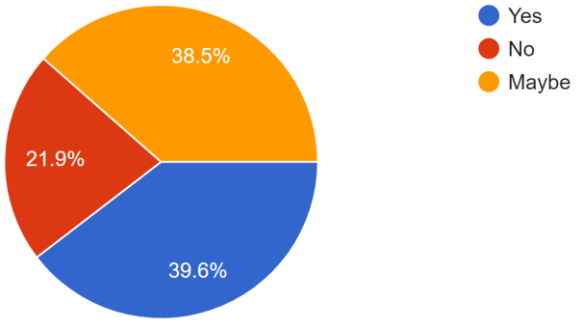

Fig.22. Using LiFi with additional piece (USB or dongle) with the current smartphones.

4. CONCLUSION

This paper aims at investigating the adoption probability of LiFi technology. To achieve this, we first developed a questionnaire that considered usage, preferences, and pricing. This study focused on collecting data from human. A total of 100 participants from around the world with range of ages and genders where the responses to the questions were mainly were done online through google forms. All the responses support the adoption of LiFi technology in terms of speed, security, and safety. The finding of this study will support future researchers and industries for research, manufacturing, and marketing.

Conflicts Of Interest

The paper highlights that there are no conflicts of interest, either personal or professional, that influenced the research process or outcomes.

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