MIMO technology, which supports up to four spatial streams of MIMO; IEEE 802.11ac has been improved by supporting up to eight streams of MIMO, thus increasing the speed of data transmission between sender and receiver [17].

Many researchers have discussed the readiness of universities to implement smart campus initiatives from various perspectives, including digital technologies, concepts and applications and administrative systems [7]–[9]. However, there are limited discussions on the readiness of ICT infrastructure to support the implementation of a smart campus in Malaysian Public HEIs. Therefore, this preliminary study aimed to explore the readiness of WLAN infrastructure at Malaysian Public HEIs to support smart campus initiatives. The study surveyed Malaysian HEIs to investigate WLAN infrastructures and services provided to end users. The findings of this study will serve as a basis for a study to assess the readiness of HEIs to support smart campus initiatives.

## II. Materials and Methods

This study employed a questionnaire survey methodology to determine the readiness of HEIs to support smart campus initiatives. The survey sought to investigate the current WLAN infrastructure available at each HEI. The survey was carried out in October 2021 involving 20 Malaysian Public HEIs, and 19 of the HEIs participated in the survey. In general, this study started by (i) defining the research questions, (ii) creating the research instruments, (iii) choosing the sample size, and (iv) gathering the data from the respondents.

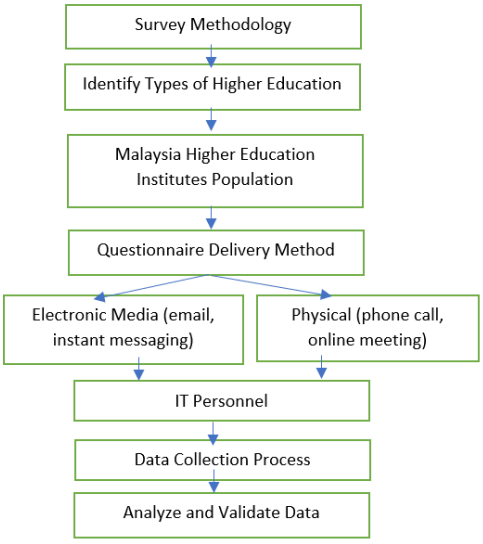


Fig. 1 The data collection and analysis method

The distributed questionnaire consists of five sections: (i) general information; (ii) network infrastructure; (iii) IR4.0 implementation; (iv) WLAN network infrastructure, and (v) WLAN planning method. This paper focuses on selected findings from category (iv), namely WLAN utilization, the adopted network applications, the type of devices for accessing WLAN, WLAN utilization monitoring practices, WLAN topology and the adopted standard, WLAN coverage area, and the average number of users accessing the WLAN service at a particular time.

Fig. 1 presents the data-gathering method and analysis employed in this study. The questionnaire survey was made available to the sample population physically and electronically. The questionnaire was distributed to 20 IT personnel from all Malaysian Higher Education Institutes, and 19 respondents participated in the survey, which spans one month. The collected data were subjected to descriptive analysis.

Table 2 shows the distribution of respondents based on their role in their HEI. Fourteen (74%) respondents are network administrators, three (16%) are network security administrators, and two (10%) are IT executives. The respondents were selected for their role as IT personnel and person-in-charge of implementing and managing the network infrastructure at their higher institution, with a minimum of five years of working experience. It was crucial to select the appropriate respondents because it affected the study outcomes. The respondents provided their insights on the required information for network implementation based on their daily experiences.

TABLE II
Distribution of Respondents Based on Their Role in HEI

| General Information | Frequency (n) | Percentage (%) |
|---|---|---|
| *Position in HEI/ Organization* | | |
| Network Administrator | 14 | 74 |
| Network Security Administrator | 3 | 16 |
| IT Executive | 2 | 10 |

## III. Results and Discussion

The collected data were subjected to descriptive analysis. This study investigated and analysed the readiness of the WLAN infrastructure of Malaysian HEIs to support the implementation of smart campuses. The descriptive analysis was based on the categories described in the methodology section.

### *A. Availability of WLAN Infrastructure*

The questionnaire asked the following questions to investigate the availability of WLAN infrastructure in Malaysia Public HEIs.

*Q1: Does your HEI provide wireless service (WLAN) to the end users?*
*Q2: What is the estimated student population at your HEI?*
*Q3: What is the estimated number of staff (academic and non-academic) at your HEI?*
*Q4: Which types of end devices are connected to your HEI WLAN?*

Malaysian HEIs are the centers that produce the human power that contribute to the nation's development. Each Malaysian HEI has a different number of students in various programs. The survey result showed that 95% of Malaysian HEIs have 4000 active students, and 5% have between 2000 to 3999 active students; all Malaysian HEIs have at least 500 academic and non-academic staff. All Malaysian HEIs have an Internet connection speed of between 1Gbps and 40Gbps to support teaching and learning activities in the new digital era [13].

It is crucial to provide a reliable, flexible, and high-availability network connection to the end users to ensure efficient access to information, online assessments and classes, and other teaching and learning activities [19]. The survey result showed that all Malaysian HEIs provided WLAN access to the on-campus users who use laptops, personal computers, smartphones, computer tablets, CCTV, printers, and photostat machines. Fig. 2 presents the number of Malaysian HEIs providing WLAN services to various end devices on their campuses. Nineteen Malaysian HEIs provided WLAN services to laptops, personal computers, smartphones and computer tablets, and six HEIs provided WLAN service to CCTV.

Campus safety is an essential element of smart campuses [6] and one way to ensure safety on the campus is by installing Close Circuit Camera Videos (CCTVs). A good connection between a laptop or remote monitoring device is essential to obtain high-quality video [20], which requires sufficient network bandwidth. High-quality videos require transmission bandwidths. A successful installation of wireless CCTV involves more than just purchasing the CCTVs in the market; it also requires an appropriate WLAN design and knowledge. The 5GHz frequency is the best option for supporting CCTV deployment on smart campuses because the frequency has less interference and more channels than 2.4GHz [21]. HEIs are encouraged to support smart campuses in the IR4.0 era by connecting CCTV to a WLAN network with 5GHz frequency because of its higher data rates, such as 802.11n and 802.11ax.

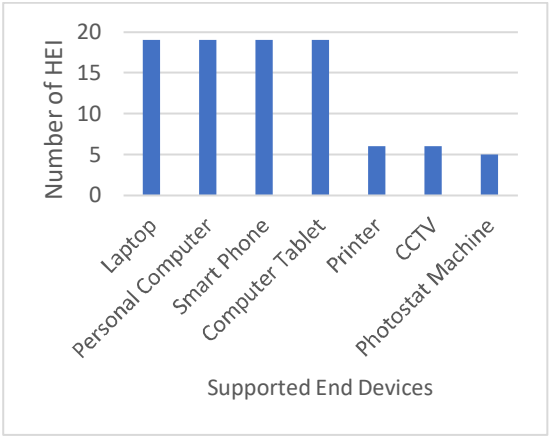


Fig. 2 The number of Malaysian HEIs vs the Supported End Devices

## B. WLAN Logical Architecture

The survey asked the following questions to investigate the logical architecture at Malaysian Public HEIs.

*Q1: Which wireless (WLAN) standard does your HEI use?*
*Q2: Which type of wireless topology (WLAN) does your HEI use?*
*Q3: Which of the following areas have access to WLAN?*
*Q4: What is the average number of wireless users in the following area/space in your HEI? [lecture room]/ [computer lab]/[Admin Office]/[Library]/[Hostel]*

A network's logical architecture consists of the standards and protocols that enable connections between physical objects, or nodes, and regulate the data flow and routing between the nodes [22]. A WLAN design determines the performance of WLAN in an organisation, including Malaysian HEIs. Since WLAN standards and bandwidth are related, it is crucial to deploy appropriate WLAN standards since it will determine the bandwidth received by the end users. Moreover, the applications used in a smart campus environment must be supported by a good WLAN bandwidth [13].

Fig. 3 illustrates the WLAN standards at Malaysian HEIs. The survey showed that Malaysian HEIs deployed various WLAN standards, including 802.11a, 802.11b, 802.11g, 802.11n, 802.11ac and 802.11ax. The highest standard deployed is 802.11n, and five HEIs, which have 26.3% of the population, were already deploying 802.11ax in their networks. However, 11% of the HEIs were still using 802.11a and 802.11b in their network, and surprisingly, one HEI offered up to 802.11g to their end users.

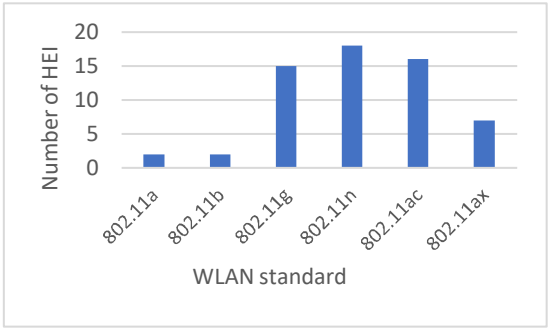


Fig. 3 The number of HEIs vs the WLAN standards Deployed

Table 2 shows the WLAN data rate provided by all 802.11 standards. The speed for 802.11a, 802.11b and 802.11g support a lower data rate than the other standards. Since 802.11a and 802.11b are legacy WLAN, most new access points no longer support these standards. The services are likely to be supported by an old model access point still functioning on the campus. 802.11a and 802.11b are unsuitable for supporting smart campus initiatives because of their low data rate. According to [23], 802.11a and 802.11b use different modulation techniques, OFDM and DSSS. These standards do not have drawback compatibility because they use two different modulation techniques. The performance of a network will be affected when users still using 802.11b connect to the network. Other WLAN standards have drawback compatibility and, therefore, can work with other WLAN devices with different standards and vice versa.

802.11ax or Wifi-6 is a new wireless standard introduced by IEEE and could be the reason for the small number of HEIs that have deployed it [24]. Upgrading the WLAN infrastructure in Malaysian HEIs will take time because of budget constraints. Wifi-6 is capable of handling end devices in high-density areas. As mentioned in section 4.1, 95% of the HEIs have to support 4000 active students at any one time and more than 2000 staff on campus, which resulted in a high-density network. All Malaysian HEIs must deploy Wifi-6 because the next-generation wireless network provides sophisticated applications with predictable performance, such as 4K or 8K video, high-density, high-definition collaborative apps, all-wireless workspaces and the Internet of Things (IoT)[16]. Only seven HEI have deployed Wifi-6 at the time of the survey. Hence, it is crucial for the remaining HEIs to deploy the same WLAN standard on their campuses.

Fig. 4 shows the average number of users accessing WLAN service by area in all Malaysian HEIs. The focus areas were the lecture room, administration office, libraries, and dormitories. Ten HEIs have between 51-100 concurrent users, and five HEIs have more than 101 concurrent users accessing WLAN in the lecture room. The libraries and dormitories have the most connected users, whereas ten HEIs have more than 101 concurrent users connected to the WLAN service in both locations.

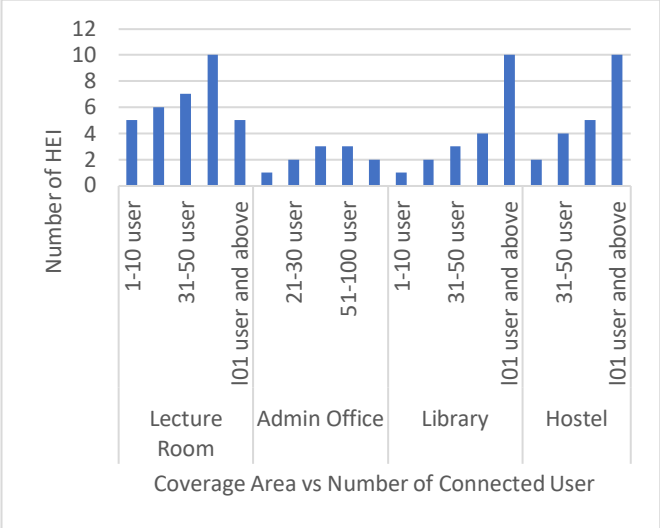


Fig. 4 The Number of HEIs vs the Number of Users by Area

In WLAN technology, the bandwidth is shared by the number of users concurrently connected to the network [25]. A user may experience a slower data rate when more users connect to the WLAN. Therefore, high WLAN bandwidths are necessary to ensure the smooth running of teaching and learning activities using sophisticated tools. In addition, most of the WLAN users at HEIs are the students and staff, who often use laptops and smartphones to access the WLAN. One of the factors determining the WLAN quality of the received signal is the sensitivity of the transmitter and receiver devices [26]. Most new end devices, such as laptops and smartphones, support new WLAN standards such as 802.11ac and 802.11ax. However, since some HEIs still offer the old 802.11 standards such as 802.11a,802.11b, 802.11g, and 802.11n, the user's end device could not receive the high-speed data rate because there is no drawback compatibility between the user devices and the existing access points. In 2011, Craig Mathias [27] stated that the 802.11n introduced in 2009 was almost obsolete with the introduction of the new 802.11ac. 802.11ac and 802.11ax were deployed in 2022. Table 1 shows that 802.11ac and 802.11ax have improved the performance of WLAN technology and solved issues in 802.11n. Malaysian HEIs must deploy more reliable, compatible, updated technology WLAN with less interference. In particular, Malaysian HEIs must deploy 802.11ac as the minimum WLAN standard to support smart campus implementation.

### *C. WLAN Populated Coverage Area*

The survey asked the following questions to investigate the WLAN coverage area at Malaysian Public HEIs.

*Q1: What is the percentage of populated areas covered by WLAN?*
*Q2: What is the average monthly percentage of wireless network bandwidth utilisation by end users at your HEI?*
*Q3: What are the preferred categories of network applications accessed by wireless network end users in your HEI?*
*Q4: Which of the following areas have access to WLAN?*

The survey result showed that the users at HEIs used WLAN to access several categories of network services, web applications, entertainment, finance, businesses and social media. A good network bandwidth provided throughout WLAN coverage must be available to ensure uninterrupted access to network applications [12]. Sufficient WLAN coverage is necessary to ensure the availability of WLAN services at all HEIs.

WLAN is often deployed in a network, including by HEIs, because of its easy installation and flexible access . However, good placement of the access point is crucial to ensure maximum coverage with minimal access points. Wan *et al.* [28] proposed using the Brute Force algorithm to predict the best place for the access point for indoor WLAN. Network implementors often employ heat mapping techniques using the available heat mapper tools on the Internet to indicate the signal strength and coverage planning for some areas [29].

A smart campus must provide access to information throughout the campus [7]. Therefore, WLAN coverage in Malaysian HEIs should be sufficient to support smart campus initiatives and strengthen teaching and learning activities. The readiness of WLAN coverage at HEIs to support smart campuses can be measured based on the area with WLAN coverage over the whole HEI area.

Assuming a wide coverage area, HEIs must be prepared to implement smart campus initiatives. The formula for calculating is as follows.

$$R=C/T*100 \quad (1)$$

Where:
$R$= Readiness
$C$= Total Covered (the total area in HEI with WLAN coverage)
$T$= Area to be covered (the total area in HEI with student population)

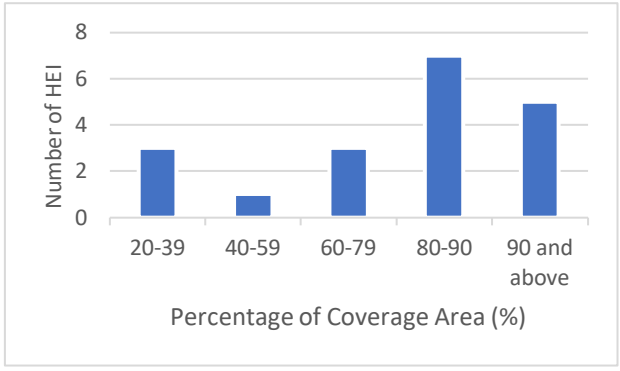


Fig. 5 Percentage of WLAN Coverage Area in the HEIs

This study focused on indoor WLAN deployment. The survey asked about the percentage of WLAN-populated areas to know the status of the WLAN coverage deployment area in

the HEIs. Fig. 5 presents the study result, which shows that five HEIs have less than 60% WLAN coverage over the indoor campus area, ten have between 60-89%, and five HEI have at least 90%.

Based on the results in Figs. 4 and 5, this study concluded that all main areas in the HEIs have WLAN coverage. However, the signal coverage in each main HEI area did not reach 100%. In this case, the areas probably have a dead area zone, which causes the mobility advantage offered by WLAN not to be delivered to the end users because the users roaming within the floor may lose connection to the network. For example, a student downloading or uploading online materials from the HEI's online learning portal while moving on the floor may lose network connection when passing through the dead area zone, causing the downloading and uploading activity to be discarded. It is crucial to ensure there is no gap between the adjacent areas. The areas in HEI must have at least a 10-15% overlapping coverage to allow uninterrupted roaming. Proper signal measurement using WLAN signal strength measurement tools and rearranging the position of the access points can minimize or remove the dead zone areas [30]. HEIs with less than 60% WLAN coverage must re-design the network to avoid too many dead areas in their network since this will disrupt the teaching and learning activities on the campus.

## IV. Conclusion

The Ministry of Higher Education (MOHE) must ensure that Malaysian Public HEIs are ready to adopt smart campus initiatives and IR4.0. The ninth shift outlined in the Malaysia Blueprint 2015-2025 (Higher Education) stated that it is almost impossible to achieve globalised online learning without a good ICT infrastructure, which includes a WLAN infrastructure. This study has achieved its objective of measuring the readiness of WLAN infrastructure to support smart campus initiatives. The discussion in this paper considered several factors, namely the availability of WLAN infrastructure, WLAN logical architecture, and WLAN populated coverage area. All Malaysian HEIs are ready with the availability of WLAN since they have deployed the services to the end users. Concerning WLAN logical architecture, all HEIs deployed mixed WLAN standards. However, three Malaysian HEIs are still not ready to support smart campus initiatives as the WLAN standard deployed in their HEI did not reach the minimum 802.11ac requirement of the WLAN standard and required device upgrading. Finally, four HEIs are not ready in terms of WLAN populated coverage area because their populated indoor areas have less than 50% WLAN coverage. These HEIs must redesign their WLAN to minimize the dead zone before implementing the smart campus initiatives. Malaysian public HEIs would be better prepared to support smart campus initiatives for the factors discussed in this paper if they have an appropriate WLAN network plan. Therefore, we must develop a model for predicting WLAN performance in the planning phase.

## Acknowledgement

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