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Application of an Internet of Medical Things (IoMT) to Communications in a Hospital Environment

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Abstract: IoT technology is used in various industries, including the manufacturing, energy, finance, education, transportation, smart home, and medical fields. In the medical field, IoT applications can provide high-quality medical services through the efficient management of patients and mobile assets in hospitals. In this paper, we introduce an IoT system to the medical field using Sigfox, a low-power communication network for indoor location monitoring used as a hospital network. A proof-of-concept (PoC) was implemented to evaluate the effectiveness of medical device and patient safety management. Specific requirements should be considered when applying the IoMT system in a hospital environment. In this study, the location and temperature of various targets sending signals to the monitoring system using three different networks (Sigfox, Hospital and Non-Hospital) were collected and compared with true data, the average accuracy of which were 69.2%, 72.5%, and 83.3%, respectively. This paper shows the significance in the application of an IoMT using the Sigfox network in a hospital setting in Korea compared with existing hospital networks.

Keywords: IoT; Internet of Medical Things (IoMT); Smart Hospital; Sigfox; LPWAN; LoRa; NB-IoT

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1. Introduction

The use of Internet of Things (IoT) devices and low-power wide area network (LPWAN) communication technology is increasing [1]. LPWAN communication technology has advantages such as high energy efficiency and low cost. However, recent studies have applied only one network, and no study has compared various communication methods in the same environment. Limited studies have applied Sigfox to a hospital environment. This paper introduces the structure of a proposed Internet of Medical Things (IoMT) system for a hospital environment, describes the equipment and data types, and presents the results obtained following the implementation of a location and temperature measurement system with IoT technology according to the network method: Sigfox, Hospital and Non-Hospital Networks.

The significance of this study is in the implementation of three different IoMT system in a hospital environment and the comparison between the accuracy of sending and receiving signals of various targets including infusion pumps, pharmaceutic refrigerators, and people, e.g., patients and nurses). The communication method and architecture for the application of the IoMT system in a hospital environment is described in the following sections. In this study, the communication system was applied to increase the work efficiency of medical staff by allowing the location tracking of patients and medical equipment in a hospital environment.

2. Background

2.1. Type of Communication Methods

Various network technologies can be used for IoT data communication. Table 1 compares the advantages and disadvantages of different communication methods: Sigfox, LoRa, NB-IoT, LTE-M, and 4G/3G.

In the existing 3G/LTE cellular-based system, LPWAN communication technologies such as Sigfox, LoRa, and NB-IoT (LTE Cat NB1) compete for large-scale deployment, which can be used as complementary technologies as shown in Figure 1, which is a graph showing the comparison in date rate vs. coverage of various communication methods. Comparably, Figure 2 illustrates the features of current communication technologies in a diagram to help gain better understanding of the differences between Sigfox, LoRa, NB-IoT, and LTE.

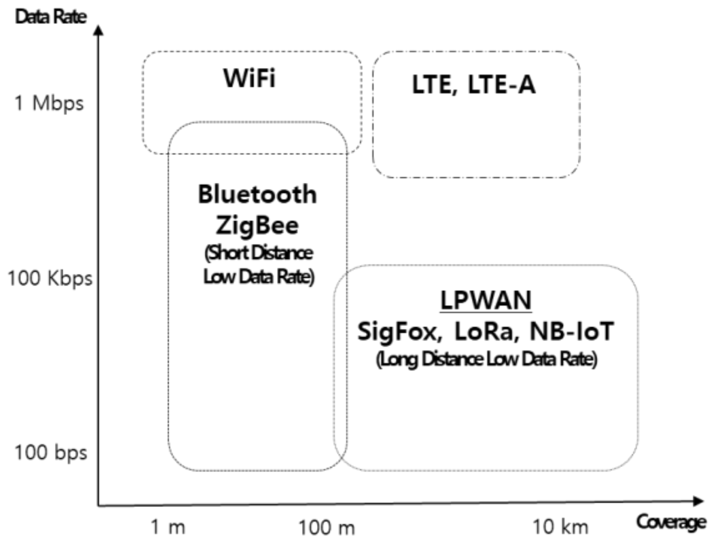

Figure 1. Types of Communication Methods [2].

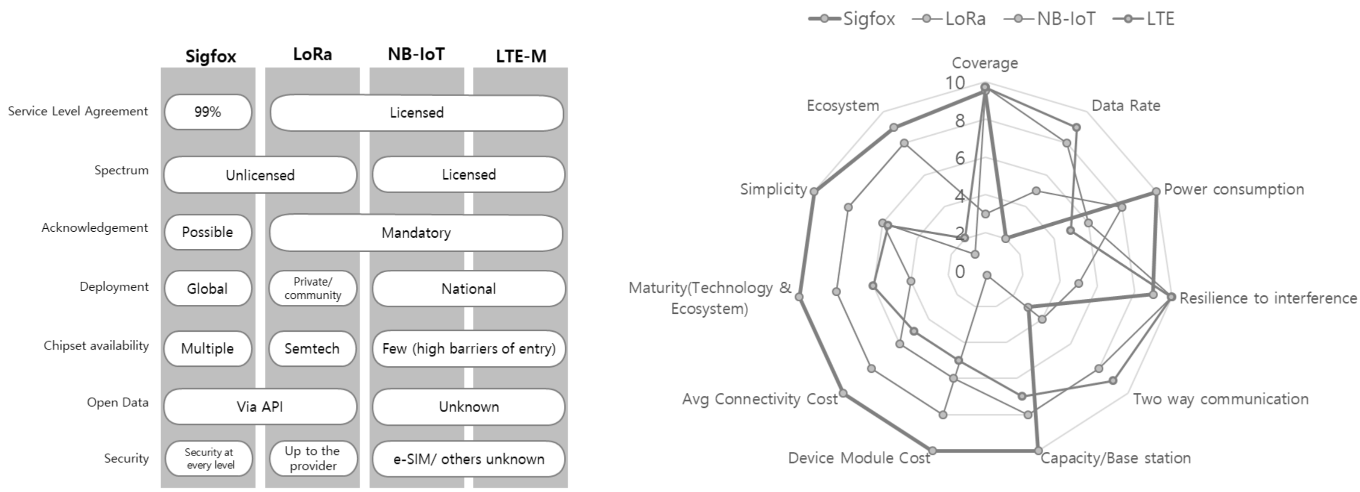

Figure 2. Features of Current Communication Technologies [3].

Table 1. Advantages and Disadvantages of Communication Methods [4–7].

Communication Method	Advantage	Disadvantage
Sigfox Asset location, flood monitoring, water/gas monitoring, preventive maintenance	- Long-range communication - Low cost - Low power - Open backend	- Only small data transmission is possible - Limited downlinks - Unsuitable for real-time monitoring
LoRa Equipment monitoring, valve actuators, water quality monitoring, plug monitoring	- Simple operating procedure with ID-based authentication - Long battery life with low power - Cheap and simple chips, modules	- Narrow chipset ecosystem - Need to build a new network - Concerns about interference with unlicensed band frequencies - Concerns about support service due to non-standard technology
NB-IoT Vending machine, electricity management, parking payments, fleet of cars/trucks	- Transmits large amounts of data - Communication technology suitable for cities	- Concerns over the mobile operator's monopoly in the market - Narrow ecosystem - High cost - Concerns about roaming service disputes between network operators
LTE-M Traffic lights, delivery trucks, blockchain payments	- Secure service quality with licensed band frequencies - Secure service continuity based on standard technology - Provides LTE-level security - Real-time, high mobility	- Expensive and complex chips, modules - Relatively high-power consumption
3G, 4G Video camera, private car	- Expansion of existing national network - Fast data transfer speed - Creates a large-scale ecosystem	- Limited coverage (excluding roads) - Low coverage scalability

2.2. Comparison of LPWAN Communication Methods

Table 2 shows a comparison of the technical specifications of Sigfox, LoRa, and NB-IoT, which are widely used LPWAN technologies.

Founded in France in 2010, Sigfox is a global leader in providing IoT services. It has built a global network that can connect billions of devices at low power and low cost as a complementary technology and is currently being used in 70 countries around the world. As it was the first to provide IoT network services, it currently has the widest coverage and largest number of partners.

The features of Sigfox include low power, low cost, and simplicity (convenience of use) as shown in Figure 3. It can be applied to elderly tracking and protection services, child tracking and protection service, and self-service lockers. In elderly tracking and protection services, an alert or notification is sent to family members as well as service managers. In child tracking and protection services, children carry a small device with a built-in GPS in a bag, which allows parents to track their location during and after school with a smartphone or PC. Self-service lockers integrate Sigfox with the cloud and a smartphone to realize a low-cost, simple transfer-based locker system [4].

Reprinted/adapted with permission from Ref. [4]. 2020, Sigfox.LoRa is a wireless technology that requires low power and exhibits excellent battery performance. It uses an unlicensed band of 1 GHz or less; thus, anyone can use it for free after registration. LoRa has been used for services such as the tracking of missing elderly people with dementia, IoT-based CCTV (CCTV for crime prevention, heatwave warning notification system), and smart water management for waterworks [5].

Table 2. Overview of LPWAN technologies: Sigfox, LoRa, NB-IoT [2].

Division	Sigfox	LoRa	NB-IoT
Frequency	Unlicensed ISM bands (868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia)	Unlicensed ISM bands (868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia)	Licensed LTE frequency bands
Bandwidth	100 Hz	250 kHz, 125 kHz	200 kHz
Maximum date rate	100 bps	50 kbps	200 kbps
Maximum payload length	12 bytes (UL), 8 bytes (DL)	243 bytes	1600 bytes
Range	10 km (urban), 40 km (rural)	5 km (urban), 20 km (rural)	1 km (urban), 10 km (rural)
Interference Immunity	Very high	Very high	Low
Authentication & Encryption	Not supported	Yes (AES 128b)	Yes (LTE encryption)
Allow private network	No	Yes	No
Standardization	ETSI	LoRa-Alliance	3GPP

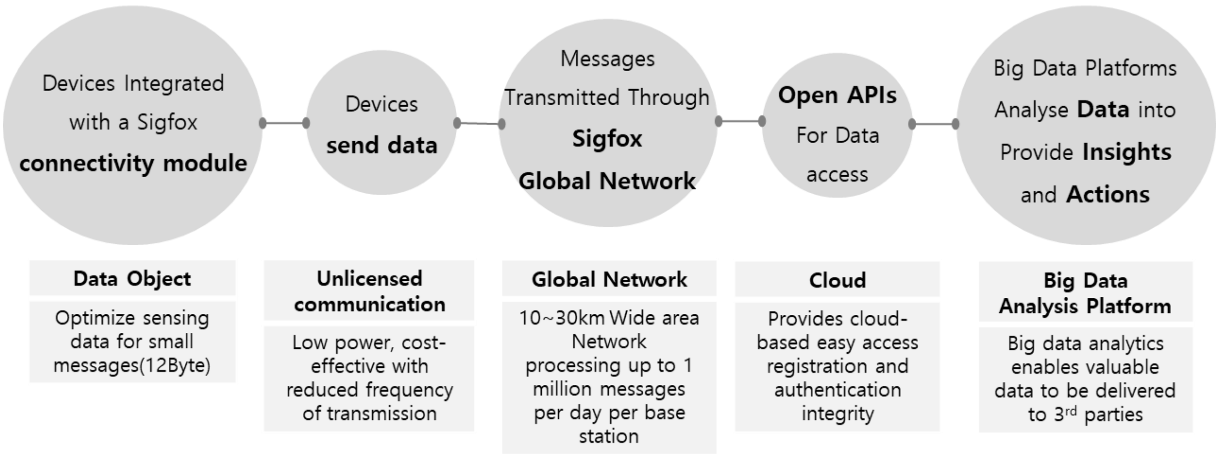

Figure 3. Sigfox Characteristics [4].

NB-IoT is a narrowband-IoT standard that supports a LPWAN through an established mobile communication network. A wide service area of more than 10 km is possible. NB-IoT uses an existing network to cover a large area and consumes less power; thus, it is suitable for an ultra-low-power IoT business model with multiple devices over a wide area, such as water meter reading or location tracking devices [6]. Some NB-IoT applications include smart meters (gas, electricity), asset management (expensive equipment or personal vehicles), protection of the elderly, smart cities (facility management, environment/disaster monitoring), and industrial IoT (security, safety, environment, logistics) [8].

LTE Cat-M1 is a low-power wide-area technology created by 3GPP for applications that require greater bandwidth than what NB-IoT can provide, and its download speeds are approximately five times faster. It is being deployed for applications such as smart metering, intelligent street lighting in smart cities, parking sensors and management, and vehicle management including vehicle tracking, telematics, and asset tracking. However, it is difficult to adopt because the scope of its application is not wide [9].

2.3. IoXT Status and Cases

IoXT refers to IoT technology applied in various industries. When IoT is applied to the automobile field, it is called IoVT (Internet of Vehicle Things), while the medical field uses IoMT (Internet of Medical Things).

Automation services through the IoT can improve the quality of our lives and work. The Korea Intelligent Internet of Things Association divides IoT into 12 service fields, as listed in Table 3 [10]. Table 3 summarizes the main implementation functions for each IoT service field.

Table 3. IoXT Service Fields.

Field	Implementation Feature
Healthcare, medical, welfare	- Health and activity status management and analysis - Parental monitoring and notification - Psychological stability indicator
Energy	- Monitoring and reduction of system power consumption - Battery status monitoring - Energy data visualization
Produce	- Automation of repetitive tasks - Real-time monitoring of industrial environment - Increase equipment operation efficiency
Smart home	- Remote home management - Home security improvement - Systematization of common space in multi-family residential areas
Finance	- Simplification of payment - Biometric authentication security
Education	- Automatic attendance system - Electronic library - Online classes
National defense	- Unmanned systems such as unmanned mobile devices and networks - Advancement of surveillance and reconnaissance technology
Agriculture, forestry, fisheries	- Industrial environment data collection - Remote monitoring/management - Increase production efficiency using big data
Automobile, transportation, aviation, space, shipbuilding	- AI-based video analysis system - Automatic integrated management of parking lots - Real-time traffic relay
Sightseeing and sports	- Recommend customized tour packages - Recommend travel routes based on user location - Provide customized exercise recommendations and activity data
Retail/logistics	- Logistics warehouse management system - Increase transportation and equipment operation efficiency - Unmanned delivery box operation
Construction/facility management/safety/environment	- Building, network security - Remote monitoring of building condition - Increase building energy management efficiency

IoT applications in the energy management field include power plants for energy production and systems for reducing energy use. In energy generation management, IoT technology is used to collect data from devices that generate energy with sensors, send the data to a server, and track real-time power production. In building energy management, sensors placed throughout the building detect the indoor temperature and adjust heating and cooling accordingly or operate by collecting power consumption data [11].

In the manufacturing sector, IoT can be applied to safety systems. It is possible to standardize repetitive field work by collecting and analyzing data from the manufacturing site, monitor temperature, humidity, harmful gases, dust, air pollutants, etc., using IoT sensors, and manage the work environment safely. In addition, it is possible to reliably control the power supply (On/Off) of facilities by identifying the presence of personnel in the field. Energy wasted due to human error, such as leaving work or going out with the lights on, can be reduced; an unmanned surveillance and recording system can apply artificial intelligence technology to identify only moving objects [11].

In the transportation field, IoT can be applied to monitor the surrounding environment and facilitate autonomous driving. An object-based image analysis system can be introduced to the installed CCTV system, which is used to identify the license plate of speed-violating vehicles and to check whether motorcycle riders are wearing a helmet. In particular, the introduction of an 'unmanned parking' system detects the remaining parking spaces on each floor in a parking lot and marks an empty space with a green light and an occupied space with a red light, making it much more visible to drivers [11].

In the field of logistics and distribution, IoT can be applied to automation systems. Once order data are transmitted to the server, products can be moved by an unmanned moving system or a person who recognizes the data. Logistics equipment detects inventory changes based on tags attached to products and updates the logistics management system when products are ready to be delivered. This method is effective because it is possible to check the inventory of each center at the same time when distribution centers are located in several places.

2.4. IoMT

The convergence of medical devices and applications that can be connected to medical information technology systems utilizing networking technology is known as the Medical Internet of Things. The IoMT connects patients with doctors through a secure network and allows for the transmission of medical data, thereby reducing unnecessary hospital visits and burdens on the medical system. The IoMT market involves the production of smart devices such as wearables or medical monitoring devices, which can provide real-time location tracking or telemedicine services in home, community, or hospital environments.

2.5. IoMT Needs: The Healthcare Professional

From the point of view of medical professionals, the IoMT can help diagnose diseases and play a major role in improving the efficiency of medical services in hospitals. As medical staffs monitor patient health information collected through sensors utilizing IoT technology in real time, the accuracy and timeliness of diagnoses can be improved while helping to track and prevent chronic diseases. Medical professionals can focus on the management of patients who need in-person visits/treatments as the condition of patients in daily life can be established, thereby increasing productivity and efficiency [12]. In addition, the development of low-cost, lightweight sensors with low-power integrated circuits (ICs) and wireless communication can accelerate the spread of IoT in the medical field.

The medical service efficiency and productivity of hospitals that provide IoMT services can also be improved, including improvement of hospital operation and clinical processes, simplification of medical information processing processes, improvement of drug management procedures, prediction of maintenance problems, and improvement of healthcare cost effectiveness, thus contributing to the reduction of medical data errors [11]. It is possible to develop an IoMT business model using accumulated data or by linking and utilizing various data sources.

2.6. IoMT Needs: The Patient

From the point of view of patients, IoMT technology provides convenience by reducing the time spent at the hospital. By collecting, analyzing, and transmitting patient data in advance, IoMT devices address the inconvenience of undergoing tests at each hospital visit, thereby reducing the number of unnecessary hospital visits, waiting times, and periods of hospitalization. As a result, financial and time burdens may be reduced.

In the home, IoMT technology can be applied to the personal emergency response system (PERS), remote patient monitoring (RPM), and telemedicine. The PERS integrates wearable devices and relay devices with real-time medical call center services to increase self-reliance for the elderly at home or those with limited mobility, thus allowing healthcare professionals to quickly communicate with patients and provide emergency medical services. RPM utilizes home monitoring devices and sensors used in chronic disease management, which continuously monitor physiological parameters to manage patient disease at home and support long-term care. Consumer health wearables include physical activity trackers or consumer-grade devices for personal health or fitness, such as health bands, bracelets, sports watches, and smart clothing. Although most consumer health wearable devices are not sanctioned by regulatory authorities, they may be approved by experts for specific health applications following informal clinical validation or consumer research. In acute home monitoring, users are provided with medication alerts and dosing information to improve compliance and facilitate medication management, and discharged patients are observed to accelerate recovery and prevent readmission.

Telemedicine includes virtual counseling to help patients manage their condition and obtain a prescription or recommended treatment plan; for example, counseling and evaluation of symptoms and lesions may be conducted through video observation or digital testing [13].

3. Materials and Methods

IoT applications can be found throughout the industry as mentioned above, which includes widely used LPWAN communication methods with Sigfox. To design and apply an IoMT-based health monitoring service in a hospital environment, it is meaningful to verify that the location data and messages transmitted through three networks match the actual hospital site information: the Sigfox network, the in-hospital network, and the out-of-hospital network.

In this study, we confirmed the temperature and location tracking of people and medical assets through the three networks in a hospital environment, shown as target and observation variables in Table 4. The network structure includes data generation, collection, storage, and monitoring. The practically applied devices used in all three networks in the study are shown in Figure 4. Due to the physical difficulties of forming the networks in the same hospital setting at a given time, the data of different targets were collected in different time settings; the locations of infusion pumps monitored using Sigfox network were collected from 6 to 11 July of 2019; the locations of infusion pumps and the temperatures of pharmaceutical refrigerators monitored using the hospital network were collected from 11 to 19 December of 2019; and the temperatures of pharmaceutical refrigerators, locations of patients with infusion pumps, and the body temperatures of nurses were collected using the non-hospital network from 25 to 29 March of 2021. All the data collected and stored, as well as during transition, were monitored, reviewed, and regulated by the medical information department of Severance Hospital within privacy policy and personal information protection guidelines.

Table 4. Monitoring Targets.

Image	Device or Target	Observation Variable
	Infusion pump	Location
	Pharmaceutical refrigerator	Temperature
	Nurse	Body temperature

(**A**) (**B**) (**C**) (**D**)

Figure 4. Practically Applied Devices (**A**) WiFi; (**B**) Location sensor (Yonsei University Health System Badge); (**C**) Patch type temperature sensor; (**D**) Environmental thermometer.

3.1. Monitoring with the Sigfox Network

The diagram in Figure 5 shows the flow of the collection and monitoring of the location data of patients and objects in a hospital using the Sigfox network. The device transmits a Bluetooth Low Energy (BLE) signal every two seconds. The transmitted BLE signal is sent to the Sigfox Cloud through the base station according to the cycle set in the receiver. The Internet platform, which is an IoT platform, receives data from the Sigfox Cloud through API linkage with Sigfox, converts non-standard data into a standard message set, and stores the converted data in a dashboard server for location monitoring. Figure 6 illustrates the setting of the Sigfox network setting with the location of the sensor, the device attached to the patients, and the Sigfox base transceiver station receiving the Sigfox network data that would be used to monitor the location of patient. In this study, a total of 31 infusion pumps installed among 11 hospital rooms were monitored using the Sigfox network for 5 days for their locations instead of actual patients and the collected data was compared to the actual location of the infusion pumps recorded by the nurses.

3.2. Monitoring with the Hospital Network

Location and temperature data can be collected using the hospital network. As shown in Figure 7, the location information of users and medical devices was obtained through the attached sensor, and temperature data were collected through the temperature sensor attached to the pharmaceutical refrigerator. Data were transmitted and stored. Stored data can be checked at any time through a dashboard. The dashboard monitoring system demonstrated in Figure 8 shows the flow of data collection with Gateway, AP and the server which gets displayed to the dashboard. The location of 31 infusion pumps and the temperature of 2 pharmaceutical refrigerators were monitored by the hospital network for 7 days.

3.3. Monitoring with the Non-Hospital Network

As illustrated in Figure 9, workflow of signal that monitoring system received from the target/device, the data transmitted from the temperature and location sensors to the gateway were transferred to the server via a Wi-Fi network and stored, and the IoMT system was implemented through a dashboard using an out-of-home network. The temperature of

2 pharmaceutical refrigerators, the location of 6 patients with their infusion pumps, and the body temperature of 12 nurses were collected using the non-hospital network for 5 days.

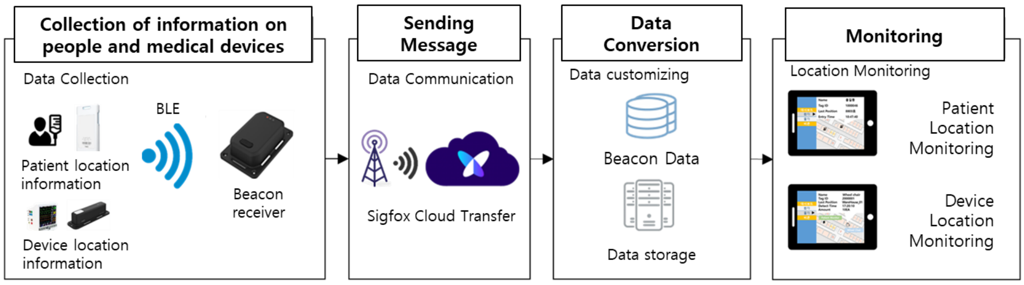

Figure 5. Monitoring System using Sigfox in a Hospital Test setting.

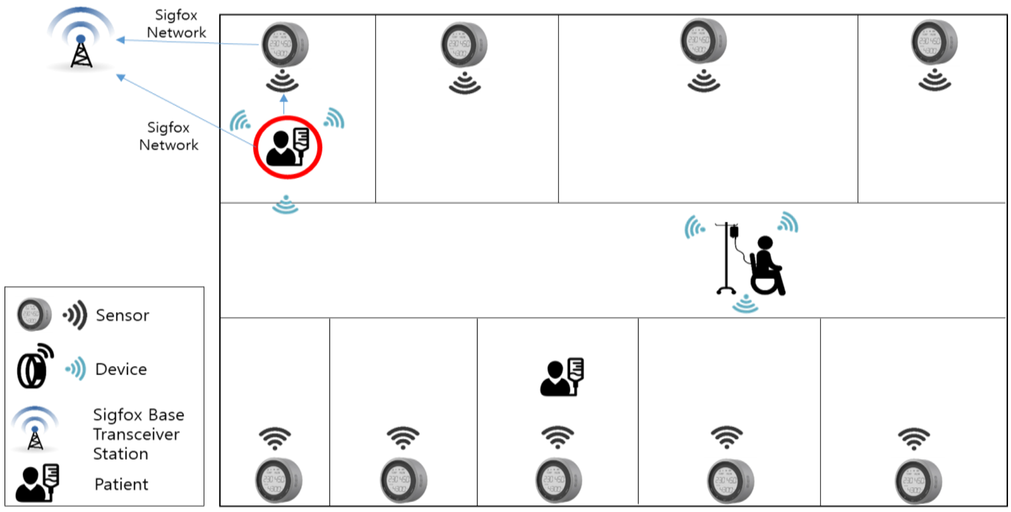

Figure 6. Sigfox Network Field Setting for Monitoring Patient Location.

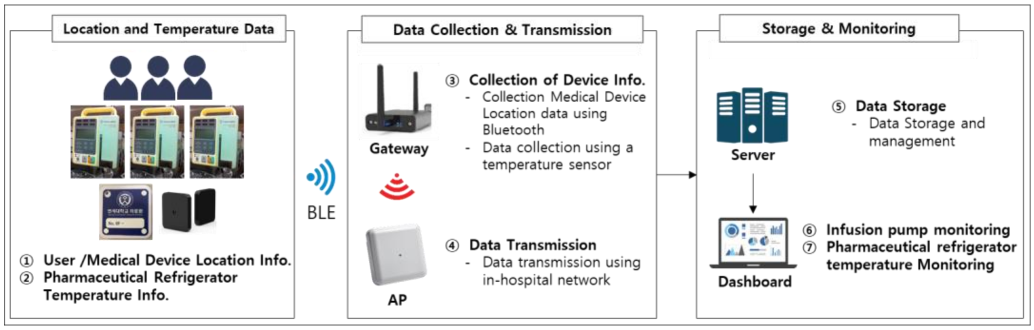

Figure 7. Hospital Monitoring System.

Consents were prepared following the hospital guidelines and signed by the patients and the nurses participating in this research. Figure 10 shows an example of consent collected for the body temperature monitoring using the non-hospital network; this consent included the purpose and methods of the research, the benefits and possible inconvenience of participation, the privacy and security of the information collected, the volitionality of participation and withdrawal, compensation, the point of contact, as well as information on the research.

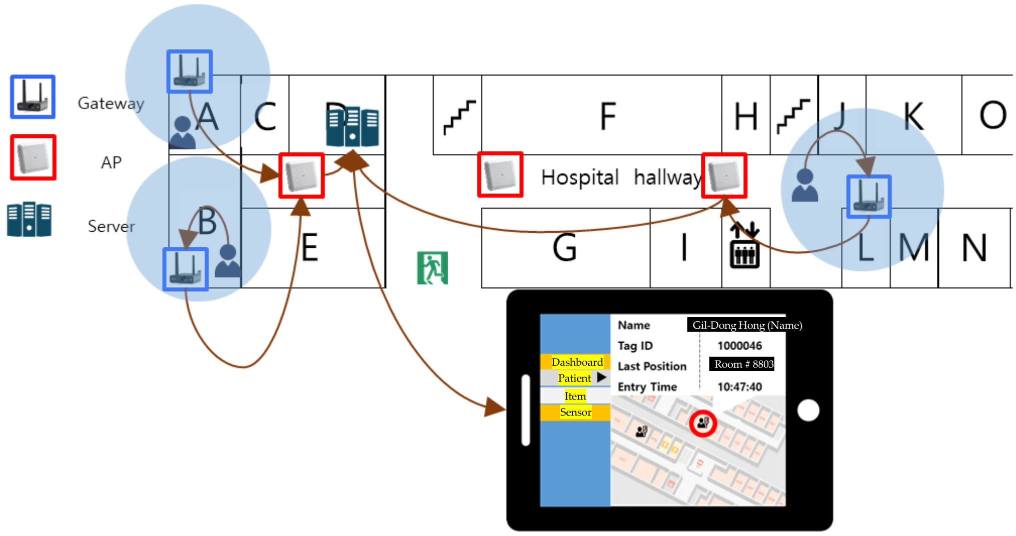

Figure 8. Dashboard Monitoring System.

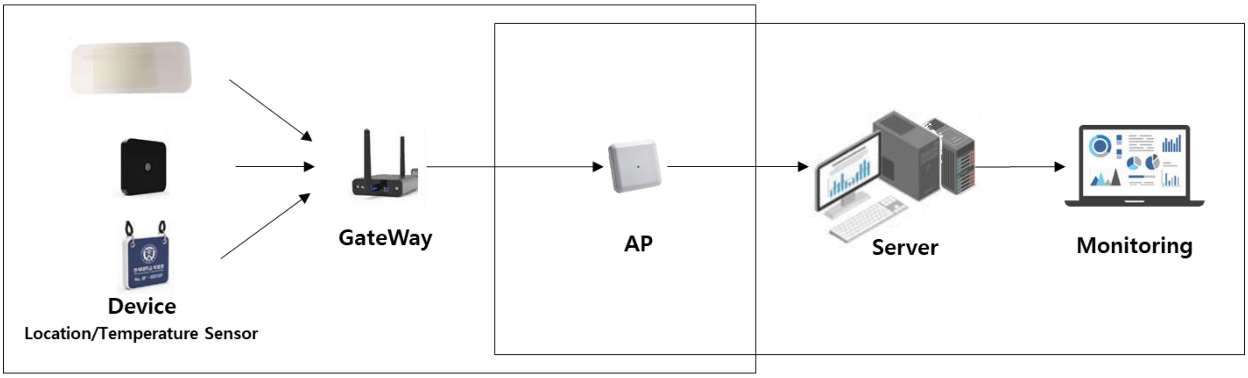

Figure 9. Non-Hospital Network System.

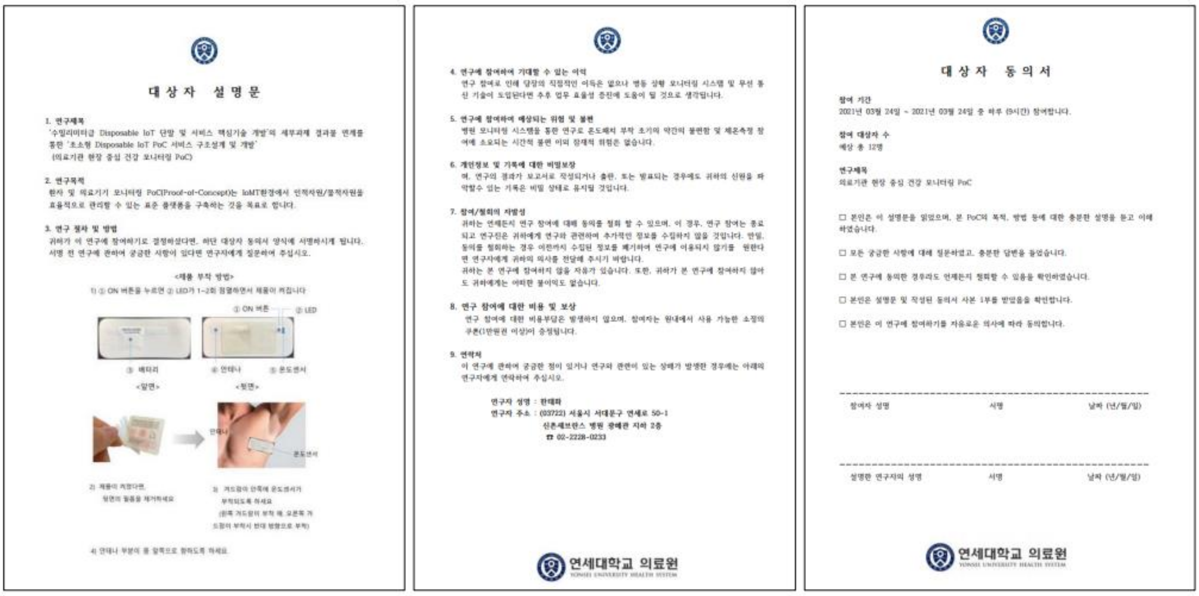

Figure 10. Participant Consent for Body Temperature Collection.

4. Result and Discussion

The collection of the locations of infusion pumps monitored using the Sigfox network was completed from 6 to 11 July of 2019. In the 5 days total, excluding installation and retrieval of the target, sensor, and network, the mean average accuracy of the signal received came out at 69.2%. In total, 31 infusion pumps which sent signals to the monitoring system were in 11 hospital rooms, and the actual locations of the infusion pumps were checked physically by working personnel. The correct location signals received out of 31 infusion pumps came out to be 21 (67%), 28 (90%), 23 (74%), 19 (61%), and 17 (54%), in order of each day. The reasons behind signal failures included signal errors due to superposition signals to the same receiver at the same time, power/battery issues of the devices, dashboard error, and the errors in signals coming from infusion pumps at too close a proximity.

In December 2019, the in-Hospital Network was used to monitor the signals for locations of infusion pumps as we did with Sigfox. The temperatures of pharmaceutical refrigerators were also monitored during this time. In this case, the number of infusion pumps with signal errors were excluded which increased the accuracy of corresponding data. The average was calculated for each day and the average over the total number of days came out at 72.5% as shown in Table 5. The temperatures collected manually of pharmaceutical refrigerators is recorded as ‘real temperature’ in Table 6 and the data collected through the signals using the hospital network is recorded as ‘dashboard’. Figure 11 illustrates the data recorded in Table 6 in a chart format for better visualization. Although the temperature comparison between the real temperature and the dashboard did not correspond 100%, the data was within a reasonable range with a difference within 2 degrees Celsius. With large amounts of data collection happening at the time, the error occurred from superposition signals even with the signal attenuation installed. Some malfunctions of Gateways were also found during the process.

Table 5. Location of Infusion Pumps Using Hospital Network.

Day & Time		Correspondence		Day & Time		Correspondence	
Day 1	10:30	51.7% (15/29)	49.4%	Day 5	10:22	46.7% (7/15)	76.3%
	14:09	41.4% (12/29)			14:30	88.2% (15/17)	
	16:10	55.2% (16/29)			16:20	94.1% (16/17)	
Day 2	10:10	58.6% (17/29)	76.0%	Day 6	10:10	88.2% (15/17)	87.3%
	16:10	93.3% (14/15)			14:25	89.4% (17/19)	
Day 3	10:10	78.6% (11/14)	84.3%		16:37	84.2% (16/19)	
	14:00	90.0% (9/10)		Day 7	10:43	61.1% (11/18)	75.7%
	16:00	Error			14:14	85.0% (17/20)	
Day 4	10:10	61.1% (11/18)	61.3%		16:54	81.0% (17/21)	
	16:00	61.5% (8/13)		AVERAGE			72.5%

Table 6. Temperatures of Pharmaceutical Refrigerators Using Hospital Network.

Date	**Day 1**			**Day 2**			**Day 3**		**Day 4**		
Time	**10:14**	**16:30**	**10:30**	**14:09**	**16:10**	**10:10**		**16:10**	**10:10**	**14:00**	**16:00**
Real Temp 1	4.0	4.0	5.5	5.0	5.0	4.6		6.0	5.0	4.5	4.5
Dashboard 1	4.7	5.8	5.7	4.8	4.8	5.1		6.5	5.9	5.3	6.8
Real Temp 2	6.0	6.0	6.5	6.5	6.5	5.8		6.0	6.0	6.0	6.0
Dashboard 2	6.9	7.1	7.8	7.1	6.8	6.8		6.9	6.9	7.1	6.5
Date	**Day 5**			**Day 6**			**Day 7**		**Day 8**		
Time	**10:10**	**16:00**	**10:22**	**14:30**	**16:20**	**10:10**	**14:25**	**16:37**	**10:43**	**14:14**	**16:54**
Real Temp 1	4.5	6.0	3.0	4.0	4.0	3.0	4.5	4.0	4.5	5.0	4.0
Dashboard 1	4.7	7.0	2.5	4.4	4.9	3.5	5.1	3.9	4.9	5.4	3.7
Real Temp 2	6.0	6.0	6.0	7.0	6.0	7.0	6.0	7.0	6.0	7.0	7.0
Dashboard 2	6.8	6.9	6.8	6.8	7.3	6.7	6.8	6.7	6.6	6.8	6.8

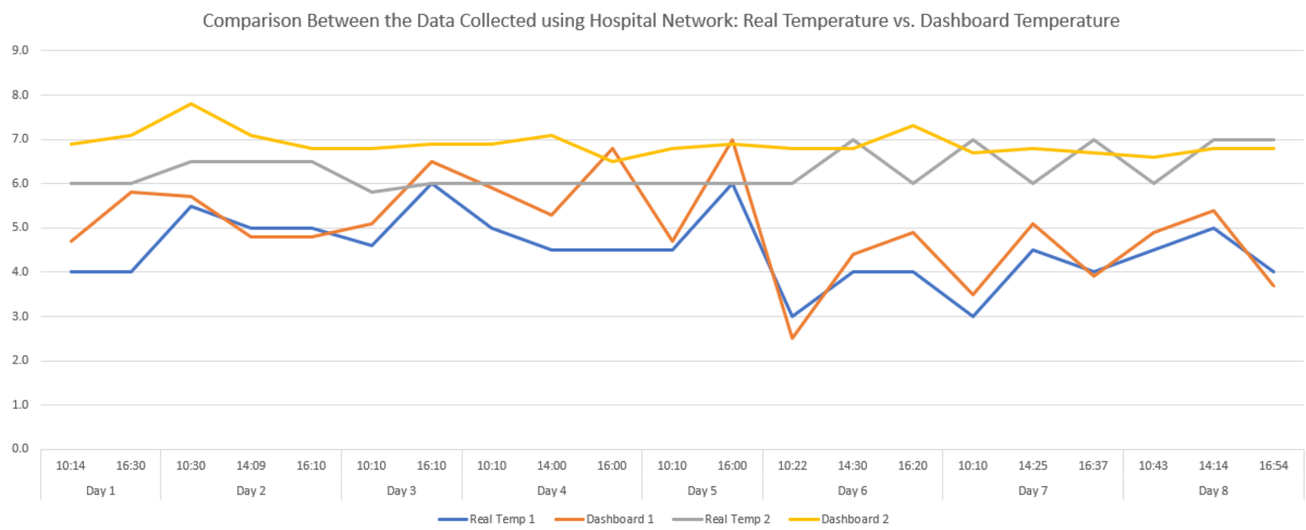

Figure 11. Comparison Between the Data Collected using Hospital Network in Chart.

In the most recent data collection in March 2021, the study included temperatures of pharmaceutical refrigerators, locations of moving patients with infusion pumps, and the body temperature of nurses using the non-hospital network with an average accuracy of 83.3%. The results were recorded in Tables 7–9 in order. Thread superposition occurred within the internal messaging processing and was handled with the use of JMS (Java Message Service) as Queue for a corrective measure. For the location of infusion pumps on the patient, the errors occurred when the patient was in the restroom, due to the restroom not having Wi-Fi installed and when the signal was not accurate due to the doors of patient rooms being left open, possibly interrupting signals. The dashboard monitored multiple signals coming from the same infusion pumps as there was a data update every 4 to 10 s which affected the current signals of moving targets. To increase the accuracy of temperature measurements, the thermal sensor was attached to the underarm and the target was switched from the patients to the nurses due to the effects of the thermal compression packs that some patients were receiving. The monitoring of the dashboards needed to be continuous at a fixed schedule.

Table 7. Temperature of Pharmaceutical Refrigerators Monitored with Non-Hospital Network.

Monitoring Target	Sensor	Comparison	Trial Number 1	2	3	4	5	6
		Time	**8:10**	**8:20**	**8:11**	**8:40**	**9:10**	**8:22**
Pharmaceutical Refrigerators 1	PR1	Real Temp	7	6	6	6	5	6
		Sensor Temp	7.1	7	6.3	6.5	6.4	6.7
Pharmaceutical Refrigerators 2	PR2	Real Temp	5	6	6	6	6	6
		Sensor Temp	6.1	6.2	6.2	6.3	6.4	6.1

Table 8. Location of Infusion Pumps on the Patient Monitored Using the Non-Hospital Network.

Monitoring Target	Sensor	Comparison	Trial Number 1	2	3	4	5	6
Same-Day Admitted Patient	A	Location Read	Same-day Ward	Hallway	Treat-ment Room	Hallway	Same-day Ward	
		Time	14:12	14:25	14:31	14:36	14:45	15:10
		Correspondence	O	O	O	O	O	O
Admitted Patient	B	Location Read	Patient's Room	Hallway	Treat-ment Room	Hallway	Patient's Room	
		Time	14:13	14:26	14:24	14:37	14:46	15:11
		Correspondence	O	O	O	O	O	O
Admitted Patient Taking a Walk	C	Location Read	Patient's Room	Hallway	Rest Area	Hallway	Patient's Room	
		Time	14:14	14:27	14:24	14:38	14:47	15:12
		Correspondence	O	O	O	O	O	O
Patient with Slow Movement	D	Location Read	Hallway	Hallway	Treat-ment Room	Treat-ment Room	Rest Area	
		Time	14:15	14:28	14:24	14:39	14:48	15:13
		Correspondence	O	O	O	O	O	X
Same-Day Admitted Patient + Restroom	E	Location Read	Treatment Room	Restroom	Treat-ment Room	Same-day Ward	Restroom	
		Time	14:16	14:29	14:24	14:40	14:49	15:14
		Correspondence	O	X	O	O	X	X
Patient Leaving the Patient Room with Certain Range	F	Location Read	Hallway	Leaving the Room	1 m	3 m	5 m	7 m
		Time	14:17	14:18	14:19	14:20	14:50	14:52
		Correspondence	O	X	O	O	O	O

Table 9. Body Temperature Monitored of Nurses Using the Non-Hospital Network.

Monitoring Target	Sensor	Comparison	Trial Number 1	2	3	4	5
Nurse 1	BT1	Time	7:06	9:25	11:12	12:00	14:30
		Tympanic Temp	36.7	36.5	37.0	36.9	37.1
		Sensor Temp	35.2	35.1	36.3	35.8	36.3

Table 9. *Cont.*

Monitoring Target	Sensor	Comparison	Trial Number				
			1	2	3	4	5
Nurse 2	BT2	Time	7:07	9:24	11:21	13:37	14:09
		Tympanic Temp	37.2	37.6	37.0	37.6	37.4
		Sensor Temp	34.3	34.5	34.2	34.5	34.6
Nurse 3	BT3	Time	7:17	9:27	11:22	13:35	14:29
		Tympanic Temp	36.3	37.3	37.4	37.3	37.3
		Sensor Temp	33.5	34.6	33.3	33.6	33.4
Nurse 4	BT4	Time	7:18	8:15	12:36	13:32	14:31
		Tympanic Temp	36.2	36.4	36.7	36.9	36.7
		Sensor Temp	32.6	32.6	32.8	33.1	32.9
Nurse 5	BT5	Time	7:24	9:24	11:22	12:47	13:31
		Tympanic Temp	36.0	36.9	37.0	37.5	37.2
		Sensor Temp	33.1	33.2	33.3	33.6	33.4
Nurse 6	BT6	Time	7:28	11:08	12:51	13:41	14:23
		Tympanic Temp	36.5	36.7	36.8	37.2	37.2
		Sensor Temp	33.3	33.4	32.5	33.8	33.9
Nurse 7	BT7	Time	7:33	9:22	11:24	12:48	13:40
		Tympanic Temp	36.3	36.4	37.1	37.3	37.4
		Sensor Temp	33.5	33.6	33.7	33.8	33.7
Nurse 8	BT8	Time	7:41	11:08	13:37	14:14	15:36
		Tympanic Temp	36.2	36.9	37.1	36.9	37.1
		Sensor Temp	33.3	33.8	33.6	33.3	33.8
Nurse 9	BT9	Time	8:02	10:01	13:41	14:32	15:24
		Tympanic Temp	36.4	36.5	37.0	37.0	37.1
		Sensor Temp	35.7	35.6	35.9	36.0	35.8
Nurse 10	BT10	Time	8:04	10:02	11:25	12:48	12:51
		Tympanic Temp	36.2	37.1	37.1	37.0	37.3
		Sensor Temp	33.4	33.7	33.6	33.9	34.1
Nurse 11	BT11	Time	11:10	12:49	13:38	14:35	15:36
		Tympanic Temp	37.0	37.2	37.4	37.2	37.4
		Sensor Temp	34.1	34.0	34.2	34.4	34.6
Nurse 12	BT12	Time	11:24	14:25	15:34	14:04	17:12
		Tympanic Temp	37.4	37.3	37.4	37.4	37.4
		Sensor Temp	35.1	35.2	35.2	35.3	35.6

Table 10 summarizes the results of the data collection of location tracking according to the three network methods, which suggests the difference between three network methods range from 14.1% to 10.76% compared to Sigfox.

Table 10. Summary of Results According to the Network Method.

Network	Sigfox	Hospital Network	Non-Hospital Network
Accuracy	69.2%	72.5%	83.3%
Target (count)	Infusion pump (31)	Infusion pump (31), pharmaceutical refrigerator (2)	Infusion pump (6), Pharmaceutical refrigerator (2), Nurse (12)
Sensor	Location	Location, Temperature	Location, Temperature
Sensing cycle	Within 1 s	Within 1 s	Within 1 s
Communication method		BLE to Wi-Fi	

Limitations of this study incorporate the security and privacy of the data collection, physical errors due to the materials used such as sensors and targets, and the errors occurred with the signals' superposition and interruption. This study obtained the signatures and agreements from the participants with created consents for the patients and nurses when collecting the data of their location and temperature, strictly following the hospital's manual, as well as the management of personnel governing the IoMT devices to follow the devices' security within Self-Security Inspection Guidelines. However, it is suggested that in further research, a security manual designed solely for IoMT should be established rather than using those designed for medical devices. Furthermore, a study of work personnel other than nurses, who are specifically related to the management of the devices would increase the efficiency and effectiveness of the study's regulation and establishment.

5. Conclusions

This study explains the importance of utilizing IoMT systems when monitoring patient information in a hospital setting, while collecting and comparing the data of different target variables using three different networks, which are the Sigfox, Hospital, and Non-Hospital networks, whilst monitoring the locations of infusion pumps, the temperatures of pharmaceutical refrigerators, and the body temperatures of nurses. Based on the findings drawn from an examination of the implementation of the IoMT system in the hospital, specific data, measurement, and user requirements should be taken into account when using the system for patient monitoring in the future.

(1) Data requirements: The system must be able to accurately obtain temperature, acceleration, and gyro data. The gateway must comply with medical standards (HL7 and IEEE11073), and the reliability and security of the wireless network must be ensured when transmitting the measured patient's data.
(2) Measurement requirements: When measuring body temperature, as the measurement cycle and set temperature value are different for each patient, it is necessary to ensure that the environment is appropriate for the patient and the ward condition and to make changes in cases of error. In addition, it is necessary to increase the reliability of the device by using a suitable battery in consideration of the average hospital stay (7 days) and the patient's biometric profile.
(3) User requirements: Users of the IoMT system can improve the efficiency of service provision only when they understand the inconvenience of wearing a device, as well as the surgical and treatment schedule of each patient, the ward condition, and asset movement.

A Design of Technology Element-based Evaluation Model and its Application on Checklist for the IoT Device Security Evaluation; Seul-Ki Han, Myuhng-Joo Kim, published in 2018 was written in the position of developer and service proposer and covers inclusive and generalized security rather than that specific to each IoT, which makes it hard to identify the security of IoT for particular IoT, as a general user [14]. This study proposes a security evaluation model, based on the existing guidelines and related documents, for more specific IoT devices and proves that this approach is more convenient to ordinary users by creating checklists via the use of smart watch.

IoMT amid the COVID-19 pandemic: Application, architecture, technology, and security; Azana Hafizah Mohd Aman et al., published in 2021, suggests that the Internet of Medical Things (IoMT) has been deployed in tandem with other strategies to curb the spread of COVID-19, improve the safety of front-line personnel, increase efficacy by lessening the severity of the disease on human lives, and decrease mortality rates [15]. A number of on-going studies show that the adoption of secure IoMT applications is possible by incorporating security measures with the technology. The development of new IoMT technologies which merge with Artificial Intelligence, Big Data, and Blockchain offers more viable solutions. This study highlights the IoMT architecture, applications, technologies, and security developments that have been made with respect to the IoMT in combating COVID-19. Additionally, this study provides useful insights into specific IoMT architecture models, emerging IoMT applications, IoMT security measurements, and technology direction that apply to many IoMT systems within the medical environment to combat COVID-19.

Along with these two studies, previous research related to the IoMT introduces the IoT models for the evaluation of security or proposes the requirements for medical/healthcare application. However, this study has significance for its application of IoMT technology through three various network methods in specific hospital settings and demonstrates the accuracy of data collection in a medical environment. Although the data was collected in the limited location of a hospital with a small number of targets, with the development of an IoMT system and its implementation, we would expect to have an increase in the number of possible targets/devices detailing multiple and different variables including, but not limited to, patients' health data, locations, and physical conditions moving forward. With the listed requirements stated above, this study suggests a better and more stable IoMT system to be established in hospitals for more effective and efficient patient management and care in the future.

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