Implementation of IoT and Blockchain for Temperature Monitoring in Covid19 Vaccine Cold Chain Logistics

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Abstract

The current COVID-19 pandemic impacted globally and resulted one hundred million cases with almost two and half million death to-date. The concerns of further spread of the virus has caused the global economy to a halt when most countries globally implementing movement control. Recent approved vaccines developed by multiple fronts has shed some hoped for the recovery of the human activities back to pre-pandemic state. For Malaysia, the government has procured the vaccine from six suppliers and each vaccine require proper temperature monitoring to ensure the safety and the efficacy of the vaccines during transportation and distribution process. Effective vaccine Cold Chain Logistics (CCL) management will be required precise coordination and cooperation across multiple parties to ensure the quality of the vaccines which require temperature monitoring, distribution of records for traceability. Furthermore, the CCL process continuity is becoming critical from the handover point at Malaysia point of receipt from the manufacturer and further distribution from central storage to the two hundred vaccination center across the country. Key concerns will be the vaccines' CCL process for remote areas in Malaysia. This paper will describe the architecture required to integrate IoT and Blockchain into the CCL management system to monitor the temperature of insulated container or cooler box. In this study, it shows that promising system of integrating IoT and Blockchain for COVID-19 vaccine CCL management.

Keywords: *COVID19, vaccine, ColdChain Logistics management, IoT, Bockchain*

1. Introduction

In general, cold-chain is defined as the process used to maintain optimal conditions during the transport, storage, and handling of cold chain products, from the point of manufacturer to the point of use [1]. Referring to [2], cold chain is defined as maintaining the fresh food and frozen foods such as the quality of the products from the initial process. Cold Chain Logistics (CCL) management, in general, is the management of necessary refrigeration level for temperature sensitive product. The scope of the CCL including agricultural products, processed foods and special products (such as drugs and vaccine). CCL consisting of low-temperature processing, low-temperature transport and distribution, low temperature storage and low-temperature for aspects of marketing [2]. Using ISM, analysis of cold chain

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development has been investigated in [3] and analysis of risk factor of medical CCL has been investigated in [4]. Several studies have investigated the application of wireless sensor network and Internet of Things (IoT) in CCL [5-8] while others investigated the data security issues that arose in CCL [2,9-10].

One of the most critical issues, currently not fully managed in CCL, is the safe transportation of temperature sensitive medicines, vaccines, and biological samples. The diffusion of emerging technologies enabling the Internet of Things such as embedded systems, mobile Apps and Cloud services, it is possible to obtain continuous monitoring of sensitive substances and environments. Previous work by [11] proposed a system called SensIC for monitoring the refrigerated storage of drugs, vaccines, medical devices and any biological samples (blood and its derivatives, saliva, urine, cells of various types and classification). The proposed system offers immediate alarm tools in case of malfunction of the refrigeration systems (fridge and/or freezers) using implementation of smart device called SensBox and a cloud infrastructure dedicated to device management.

Previous study by [12] proposed a Blockchain solution for secure IoT data acquisition used for weather monitoring. In their study, a system consisting of ESP8266 microchip and temperature and pressure sensor of GY-BMP280 has been developed. The data collected from the system displayed on the web interface of Grafana to thoroughly view over the weather. Data collected then sent to Raspberry Pi gateway for further processed and will make up for the transactions inside the chain.

Vaccine management and monitoring, cold chain management, and immunization safety are the key areas of logistics support. Logistics ensures that vaccines are available at the right time, in the correct amount, and in the correct condition. The cold chain refers to the storage and transportation of vaccines at recommended temperatures from the manufacturing location to where they will be used. An effective cold chain ensures that vaccines will remain effective and usable when they are administered [13]. It has been established that any breach in temperature control can degrade a vaccine, making it lose its full potency. An unbroken cold chain with temperatures below the required storage temperature has to be maintained, or it will risk defrosting and losing its efficacy within a day of temperature breach above the required storage temperature. Hence, a good temperature monitoring and control is required throughout the transport process to ensure vaccine quality and safety.

IoT is an encouraging model that integrates several communication and technical solutions. The IoT is defined as a field in which each physical object is to be connected at any time and at any place with the help of internet and to be able in identifying these devices to other devices [14]. The objective of this project is to setup a temperature monitoring prototype based on IoT & Blockchain system to collect store critical data, such as temperature breach, for COVID-19 vaccine CCL. The IoT system to continuously monitor the inside of an insulated container or cooler box to ensure the integrity of the vaccine storage during transport and transit to the remote vaccination centers. The introduction of the IoT system in the CCL will enable 'in-situ' temperature while in transit. The data collected will assist the

CCL process managers to track and trace the process. The integrity of the data collected will be protected by the Blockchain system established.

2. Methodology

The IoT-Blockchain setup to monitor the temperature of the CCL process as shown in Figure 1.

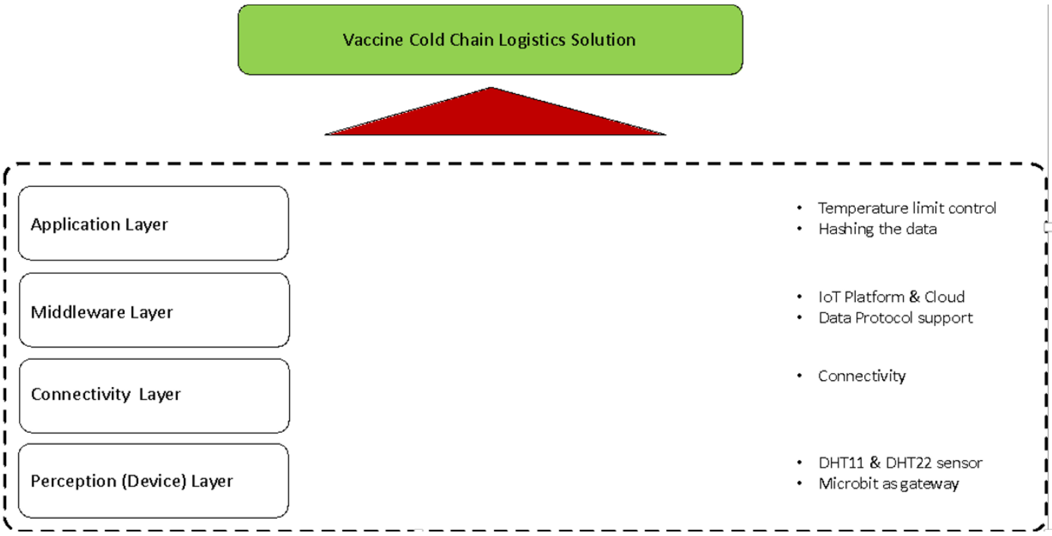

Figure 1. Temperature Monitoring System based on IoT-Blockchain environment

2.1. Device Layer

The objective of the device layer is to collect the temperature data within cooler box (insulated container). The temperature sensor for this project prototype will utilising DHT-11 sensors and this sensor has been chosen mainly due to the consideration of characteristics as in Table 1.

Table 1. DHT-11 Sensor Specification

Parameter	Specification
Measurement range	20 – 90% RH 0 – 50°C
Humidity accuracy	±5% RH
Temperature accuracy	±2°C
Response time	10sec

The sensors connected to the Micro:bit board for data processing as the signal generated is in electrical pulse to be translated by Micro:bit based on the driver program, obtained from the manufacturer, combined into the ‘coldbox.py’ program written inside the board. The ‘colbox.py’ program is a set C codes and command to measure the temperature inside the cooler box every 5 minutes; to translate the electrical signal to temperature; and to push the data to the IoT Platform in the Middleware. The data obtained is then wrapped in mosquito (MQTT) data exchange protocol, which was then tagged with JSON service discovery protocol for northbound communication to the IoT Platform.

2.2. Communication Layer

The wrapped data from the device layer is then transported through the communication layer via 4G using TCP/IP. For security purpose, a pre-set API key and Channel ID was assigned to the system. This information is embedded into the 'coldbox.py' program together with authentication details to sign on process to the IoT Platform.

2.3. Middleware Layer

The middleware is the service management layer for the IoT system as it is the layer that process received data, make decision delivers required services. In general middleware functions are for Service Discovery; Data Exchange; and Data Processing. For this project, the system is connected to 'ThingSpeaks' (www.thingspeak.com) as the middleware for service discovery and dashboard and storage. The collected data are stored in database setup in ThingSpeak (Matlab) cloud. Previous work by [15] proposed a system for monitoring heart rate and temperature data with the application of IoT using the similar system propose in this study.

2.4. Application Layer

The application is defined as the layer to process the data. In this layer, the 'business logic' where the temperature breaches are calculated. For the purpose, the project utilised the embedded features of Matlab. The code will check for the temperature breach and send in the email to the admin of the CCL process. At this layer also where the data will be to create the blockchain for data integrity. Duly noted that the IoT system is resource constraint. Hence, the project must choose the most suitable platform for the project. Each platform tabulated as in Table 2 referring to previous research [16].

Previous research by [17] investigated a model with IOTA/Tangle network which received data from wireless multi-sensor device, Bosch XDK110. Motivated from study by [17], for this project, IOTA was selected as the Blockchain platform. This is due to the fact it is much easier to setup and scalable with the increase of the size of the network if compare to the other platform. Furthermore, the IOTA offers a hashing option between SHA3 and SHA256. With a lighter option, it will reduce the needs for higher processing at the IoT system.

For the deployment, Figure 2 illustrate the flow for block creation from data acquisition to Smart Contract creation.

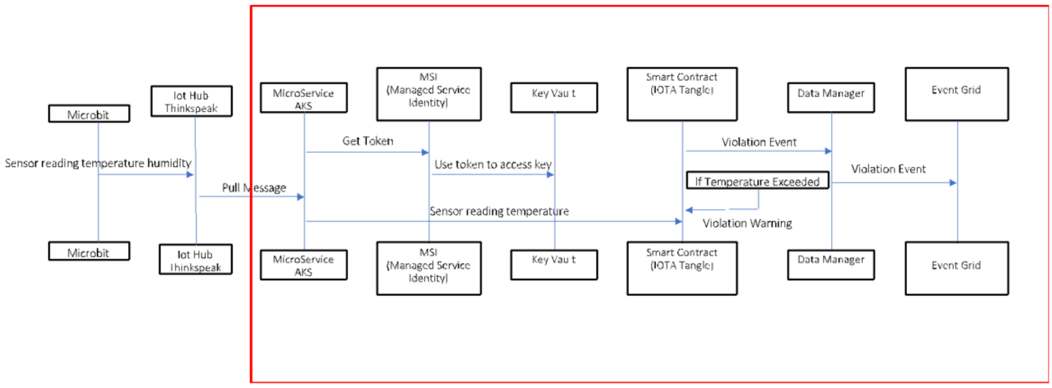

Figure 2. Block creation Process Flow using IOTA Tangle

2.5. Setup Consideration

As an overview, IoT is an integrated system comprised of devices to collect the data, connectivity, storage, data processing and visualization applications. However, the fidelity of the information generated and the autonomous process from the innovative applications created concerns of security and privacy that may hampered further progress of IoT. While Blockchain is a technology that warrant the data integrity by using the immutable ledger in a distributed network. The ledger is connected with has value of each previous block, and the ledger, including all of the information about the transaction is stored in each node of the distributed network. The distributed ledger is maintained by making consensus using define consensus algorithm to achieve same data blocks across all nodes in the network.

Table 2. Several platform for Blockchain (Source from [16])

Features	Bitcoin	Ethereum	Hyperledger	IOTA
Fully developed	✓	✓	✓	In transition
Miner participation	Public	Public, Private, Hybrid	Private	Public
Trustless operation	✓	✓	Trusted validator nodes	✓
Multiple applications	Financial only	✓	✓	Currently financial only
Consensus	PoW	PoW, PoS (“Casper”)	PBFT	Currently a coordinator approves the TXs through a Tip Selection Algorithm
Consensus finality	X	X	✓	X

Table 2. Several platform for Blockchain (Source from [16]) (continued)

Blockchain forks	✓	✓	X	Not exactly forks, but a tangle can be faded out later
Fee less	X	X	Optional	✓
Run smart contracts	X	✓	✓	X (Currently)
TX integrity and authentication	✓	✓	✓	✓
Data Confidentiality	X	X	✓	X
ID management	X	X	✓	X
Key management	X	X	✓ (through CA)	X
User authentication	Digital Signatures	Digital Signatures	Based on enrolment certificates	Digital Signatures
Device authentication	X	X	X	X
Vulnerability to attacks	51%, linking attacks	51%	> 1=3 faulty nodes	34% attack
TX throughput	7 TPS	8-9 TPS	Can achieve thousands TPS (depending upon number of endorsers, orderers and committers)	Currently, the coordinator being the bottleneck, the throughput varies between 7- 12 TPS
Latency in single confirmation for a TX	10 mins (60 mins for a confirmed TX)	15-20 secs	Less than Bitcoin and Ethereum	Being in transition phase the TX confirmation time varies from minutes to hours
Is it Scalable?	X	X	X	Yes (Scalability improves with the increase in the size of the network)

Nevertheless, the three biggest challenges for implementing Blockchain in IoT system are:

i. Scalability, whenever the transaction grows may lead to centralisation for the administration of registries. Consequently, one of the feature of Blockchain of distributed network will be eliminated.

ii. Computing power and time, IoT devices is known to have very small computing power which insufficient to run a complex encryption algorithm.

iii. Storage, IoT devices may not have storage capacity to store the copy of all the transaction all nodes keep a copy of all transactions that ever occurred in the blockchain since its creation. The size will increase as time goes by and IoT devices might not be able to store it.

2.6. Data Collection Strategies

The data gathered is in 15 minutes time intervals by the sensor. This is to ensure conservation of the battery. The breached data send by email is then processed by IOTA/Tangle Platform.

3. Result & Discussion

The proposed prototype produced the following results as shown in Figure 3 and Figure 4. Figure 3 shows the data from the ThingSpeak and then the data will collected and gathered for further analysis as shown in Figure 4.

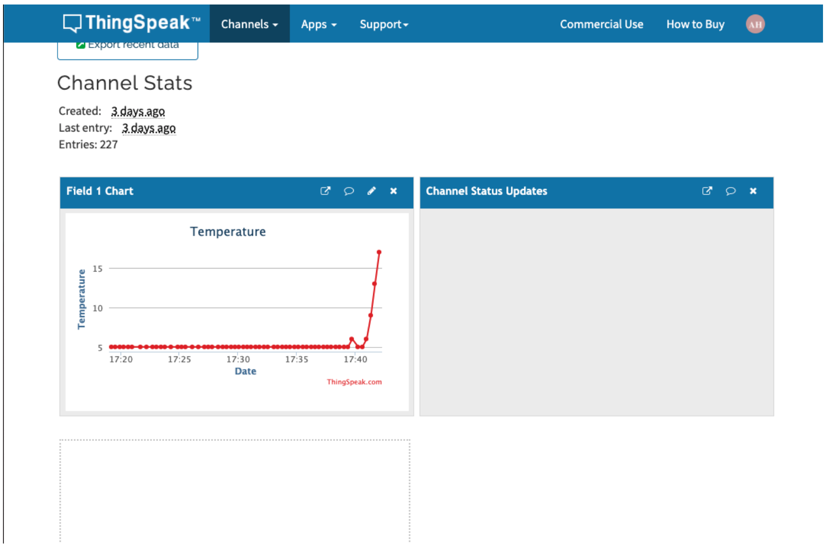

Figure 3. Temperature Data Collected from Cooler Box

{"channel":{"id":1306440,"name":"Temperature","description":"Monitor the Temperature inside cooler
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Figure 4. Gathered data in JSON format for further analysis

Using the prototype system, we have added another DHT-11 to understand the impact of external temperature to the inside temperature of the cooler for the characterisation of the temperature rise while in transit. For comparison of internal and external temperature of the cooler box as shown in Figure 5. For the difference of internal and external temperature of the cooler box as shown in Figure 6.

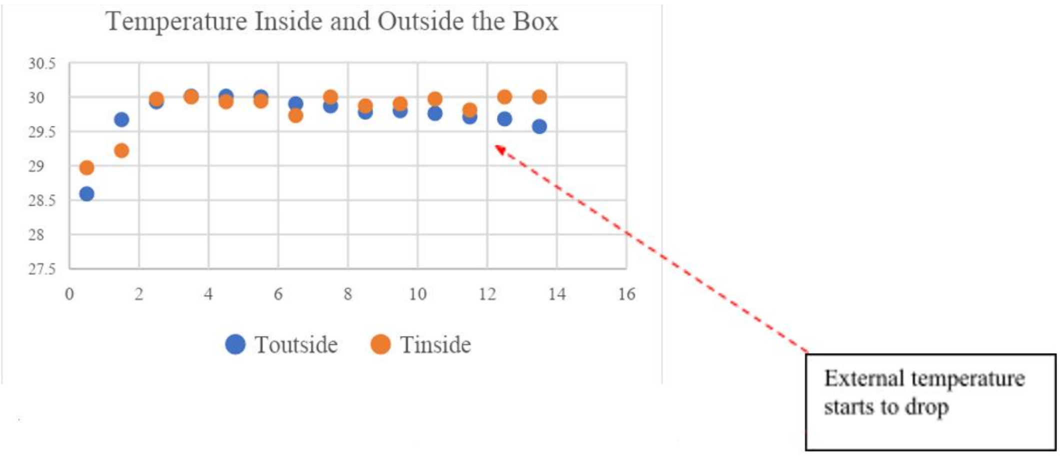

Figure 5. Temperature Inside vs Outside Cooler Box

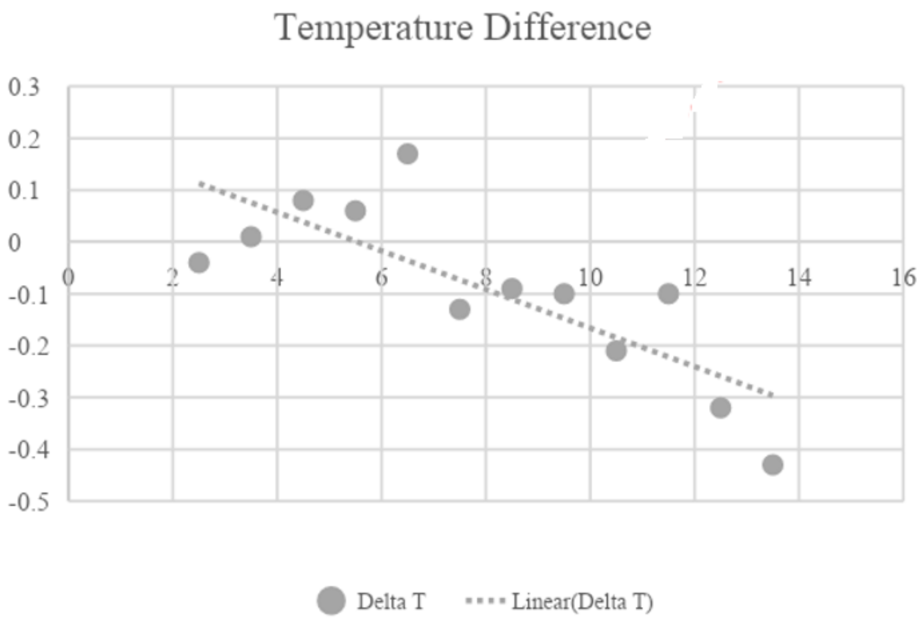

Figure 6. Temperature difference between inside vs Outside Cooler Box

Based on the Figure 5 and Figure 6, there a noticeable difference between internal and external temperature to the cooler box. The difference is evident as the external temperature starts to cool down while internal temperature remains the same from the start of the monitoring as shown in Figure 6. General observation, using continuous temperature monitoring enables CCL manager to effectively estimate the insulation capability of the vaccine storage. Hence, CCL manager will be able to forecast the temperature rise during storage and in transit

4. Conclusion

This project has presented a way to integrate IoT and Blockchain system to continuously monitor temperature for vaccine CCL processes. The project took the liberty to conduct an experiment to understand the effect of external temperature to the inside temperature of the cooler box to demonstrate the utility of the data gathered for the CCL process manager to design the insulation of the storage container CCL. The project also demonstrated on the method to protect the data integrity of the CCL process. For future work, research to consider the inclusion of controlling temperature of the container by turning on the refrigeration unit once the temperature to be 10% form the limit and the transit time to limit before it reached the maximum allowable storage temperature using the data acquired from IoT system

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