Intelligent Medicine Kit for Healthcare Monitoring, An IOT Based Solution

Shailja Gupta[1*], Sameer Gupta[2]

[1]*Manav Rachna University, Faridabad, India.*

[2]*Loadshare Networks Pvt. Ltd., Bengaluru, India.*

Abstract

Increase in chronic diseases worldwide demands efficient healthcare solutions for maintaining well-being of people. Treatment requires timely in-take of medicines and strict adherence to routine. This lack of adherence is estimated to cause many deaths and hospitalizations. If we can get people to take their medications regularly, they won't develop complications. In addition to improving patient outcomes, medication adherence will reduce health care costs associated with these conditions. Healthcare monitoring solutions based on Internet of Things (IoT) technology has drawn significant research attention. This paper proposes an IoT based user configurable customized intelligent medicine kit augmented with Wi-Fi and Bluetooth Low Energy technologies. It has capability to detect whether patient is taking all prescribed medicines on fix schedule and intelligently communicates the same to patient and their close relatives using uniquely created Four Tier Notification System (FTNS), thus helping patient to live a healthy life. The paper discusses a novel theme on the functioning of a medical grade device which would consume information from sensor and send it to the central server with a maximum possibility of success using Four Tier Notification System (FTNS). This novel approach discusses handshaking of connection to the central serve with a fallback mechanism to achieve maximum success of data synchronization. This paper also discusses how this useful data from medicine kit can help healthcare sector to closely track patient's physical activities and helps to influence the way healthcare sector operates in future.

Keywords: Healthcare, Internet of Things, Medicine, Health Monitoring System, Bluetooth Low Energy (BLE), Health Cloud, Medicine Kit, Four Tier Notification System (FTNS).

*Corresponding author Email: shailjaguptaymca@gmail.com

1. Introduction

Prescription drugs can work miracles, it can cure severe diseases and help to improve lives of patients with chronic conditions. A major factor that contributes to this miracle is adherence to the prescribed schedule of the medication. Patients are not following doctors orders and the number worldwide are alarming. Research shows that nearly 25 percent of patients who are prescribed medications for a newly diagnosed chronic illness do not fill their initial prescription. Additionally, half of patients taking maintenance medications for chronic conditions will stop taking them within the first year of starting therapy. The situation puts patients at risk and puts pressure on the health care system costing billions of dollars in unnecessary care. While abuse of prescription drug often make the headlines, a recent survey shows that nearly two-thirds of Americans are non-adherent to follow their medication schedule and do not take their medication properly.Whether intentional or not, the problem is rampant and causes an estimated 125,000 needless deaths every year. A major push for medication adherence could turn that around.

If technology can make people take their prescribed medicines on schedule, they will have less chance of developing complications associated with chronic diseases like diabetes, they will have significantly reduced the risk of a heart attack and won't have to visit the emergency department with asthma. Medication adherence not only improves patient outcomes but also significantly reduces their expenditure on healthcare. For every patient with heart failure who fails to comply with his or her medication schedule, the U.S health care system spends an average of $8000 annually. A study by the Brigham and Women's team, published in the January 2014 American Heart Journal adds evidence to the fact that medication adherence improves outcomes. During six months of follow-up, heart attack survivors who followed their medication strictly were less likely to suffer another heart attack, or unstable angina, stroke, or congestive heart failure than other patients.

Our collective goal as a nation should be to achieve a higher standard of fitness and health which will help us to prevent poor health outcomes. Technology can help us achieve this by preventing serious health complications and even death, a simple way to do that is to remind people to take their medicines on time and as per the directed dosage. This can especially help people who suffer from multiple chronic conditions and have to manage multiple medicine routines. Involvement of the healthcare community and patients is pivotal to address the serious public health issue of medication adherence. Some common barriers which lead to poor medication adherence are difficulty in remembering or managing multiple medications or complex regimens by the patient, prescribed to them by multiple doctors. Patients fail to understand the importance of the medicine therapy and the regularity of the drug routine.

With a projection of the connected healthcare sector as a Multi-billion dollar sector in the future, the need is to reinvent it as a structurally different kind, that is more strategically aligned with the future of healthcare and not held by past with conventional practices. A more radical vision would be to make information available to the insurer at a much larger scale which has never been seen in the past. This will give insurance companies a much deeper understanding of their customers and could help implement a new data-centric, technology-enabled model.

One of the use cases is collaboration of Insurance companies in Healthcare sector with technology giants which are helping them to provide IOT based solutions for local customers in thecountry. There are already some insurance companies that have adopted IoT and Insurance Tech such as AXA Life Insurance, ICICI Lombard, and HDFC life.

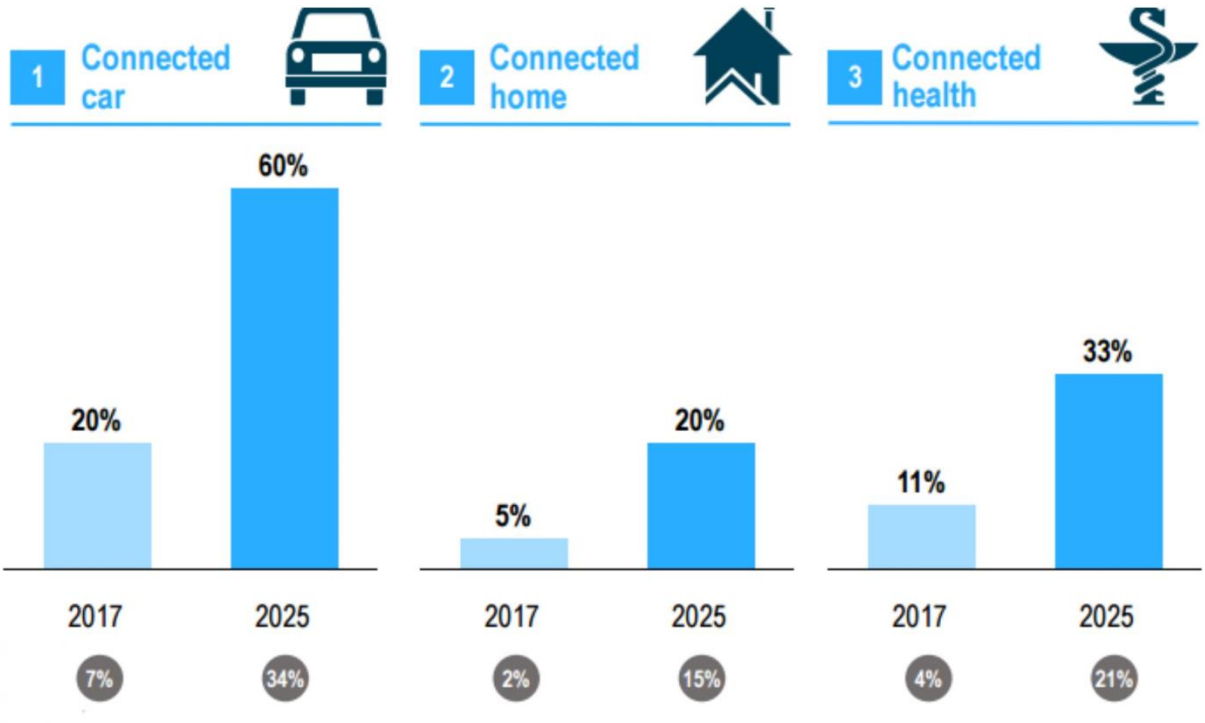

Fig. 1: Trend of IOT devices

Treatment of chronic diseases requires timely in-take of medicines and strict adherence to routine. There are chances of medicine doses being missed due to patient's busy schedule or lack of proper communication. Here technology can play a major role in bridging this gap and to provide effective communication. Fig 1 shows trends of various IOT devices from year 2017-25.

Currently, there is a nursing system that is based on RFID[1] (Radio Frequency Identification) wireless technology. Based on RFID tags the nursing staff ensures the identities of patients and their medical order. These tags help to improve the accuracy of medical order execution but have an underlying limitation that every patient should be equipped with an RFID tag which is difficult. Another shortcoming of this model is to ensure the real-time execution of reminders[2].

2. Design of Intelligent Medicine Kit

The user centric design of smart medicine kit incorporates several features providing a complete solution to support everyday medicine intake of the user. The core motivation of design is building a user-friendly smart medicine kit that is easily configurable and operable by user[3]. One of the objectives of the proposed solution is to extract user data from the kit, which includes user behavior toward his/her medicine intake. The extracted data is processed by applying relevant data analysis techniques upon which it can be provided to various Healthcaresectors like medical research, Insurance firms etc. Fig. 2 illustrated the architecture of intelligent medicine Kit and its interaction with other subsystems. Intelligent medicine kit is a handy device augmented with Wi-Fi and Bluetooth technologies. Along with the device itself two external support systems namely Health Cloud and User Application Suit work in unison to fulfil its intended purpose. The Health cloud holds the user information sent from medicine kit which is later used to generate user patterns. The User application suit is a collection of applications for user’s mobile devices and smart watch that can interact with medicine kit.

2.1. Structure of Medicine Kit

The physical structure of smart medicine kit resembles to a normal medicine kit with 28 Small Medicine Compartment. These compartments can hold seven days of medicine taken 4 times a day at max. Medicine kit has two microcontrollers along with Wi-Fi and Bluetooth Low Energy Module attached to the primary Microcontroller. These peripherals enable exchange of information and commands between medicine kit, user and health cloud.

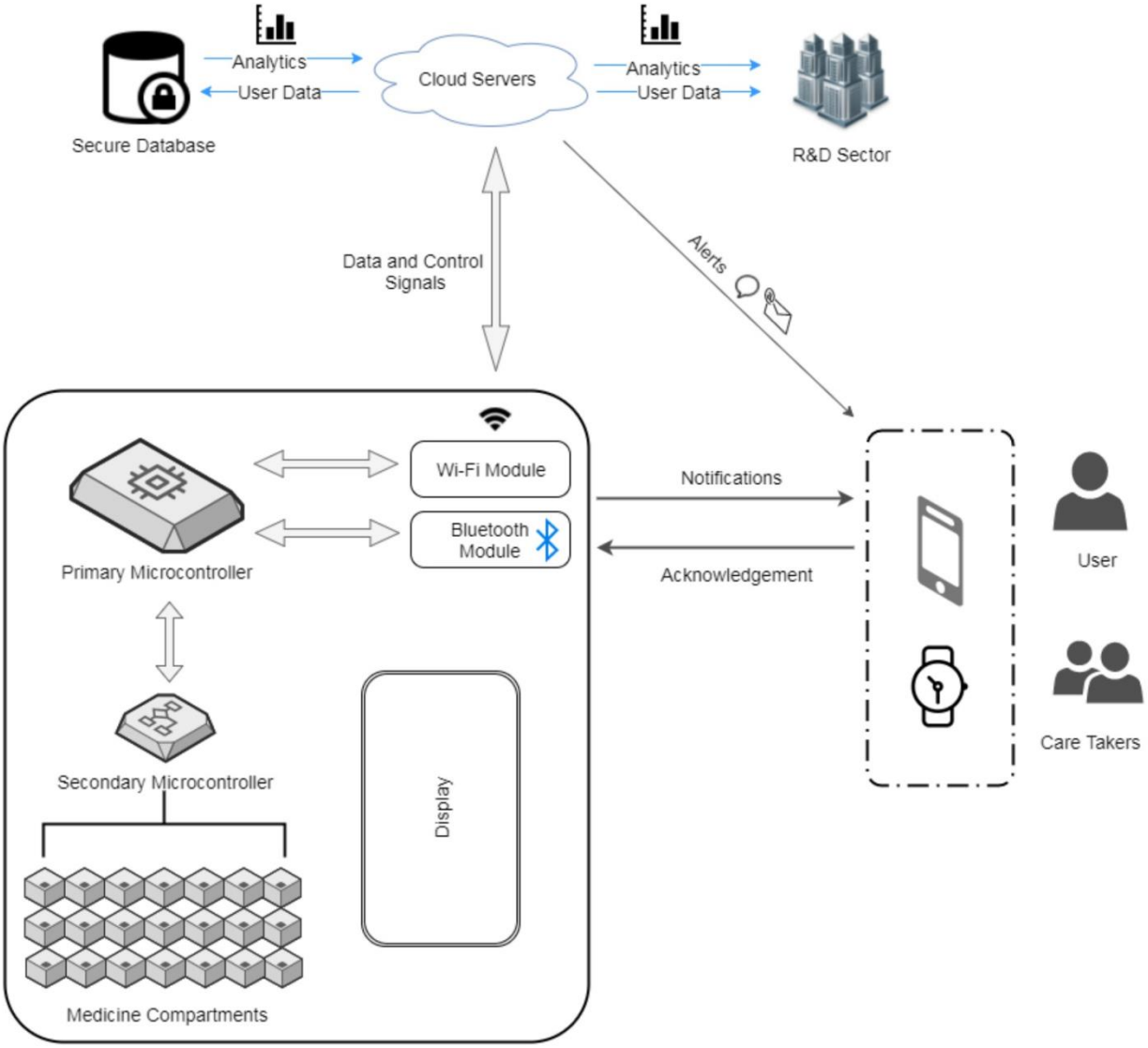

Fig. 2: Architecture of Intelligent Medicine Kit

The primary microcontroller is high performance microcontroller with enough memory to store all the user data locally. It controls the overall exchange of information between user, medicine kit and health cloud. The initial setup require user to connect medicine kit to internet via Local Wi-Fi. The medicine kit performs sync

operation to download previously configured data, if any. This process send/receive information related to any change in user information. The User then initiates a request to configure medicine box via Bluetooth. Since the communication is carried over Bluetooth low energy[4] there is very little energy spent in the communication.

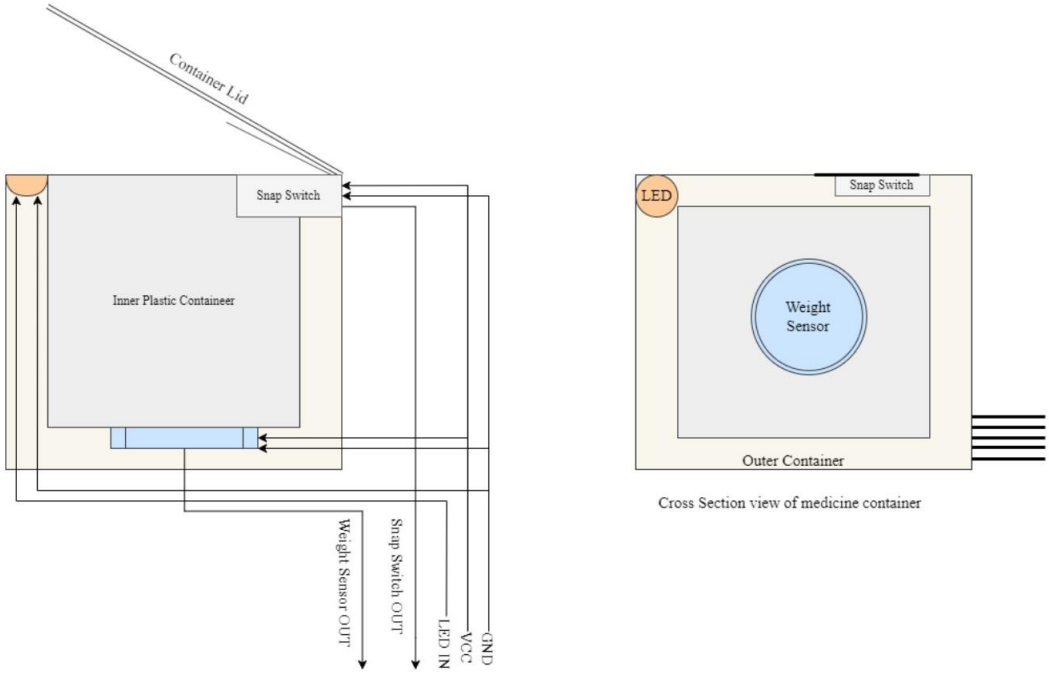

Fig 3: Structure of Medicine Compartment

Another important task of primary microcontroller is to coordinate with secondary microcontroller to get updates on the medicine intake. Secondary microcontroller has large number of I/O pins to be directly connected to all 28 medicine compartments placed in an orderly fashion on the medicine box.

Each compartment is equipped with a multi-color LED, weight sensor and a snap switch. Fig. 3 illustrate the structure of a single medicine compartments. Each medicine container have five terminals namely Voltage Common Collector (VCC), Ground (GND), LED input, Weight

Sensor Output, Snap switch Output. Two sensor terminals and LED input terminal are unique to each compartment, this gives secondary microcontroller ability control individual medicine compartments separately. At the time of medicine intake the primary microcontroller signals the secondary microcontroller to light the compartment from which pills are to be taken. The snap switch detects the opening/closing of the medicine compartment, weight sensor confirms if the medicine is taken out of the compartment. Notification for refilling the compartment is also generated with the help of weight sensor.Fig. 4explains the initial setup sequence of Medicine box. The user sends medicine kit information packets this information include the user contact information, information of care takers, if any and medicine schedule. The information is stored locally and send to Health cloud to be maintained for Third party research firms to access.

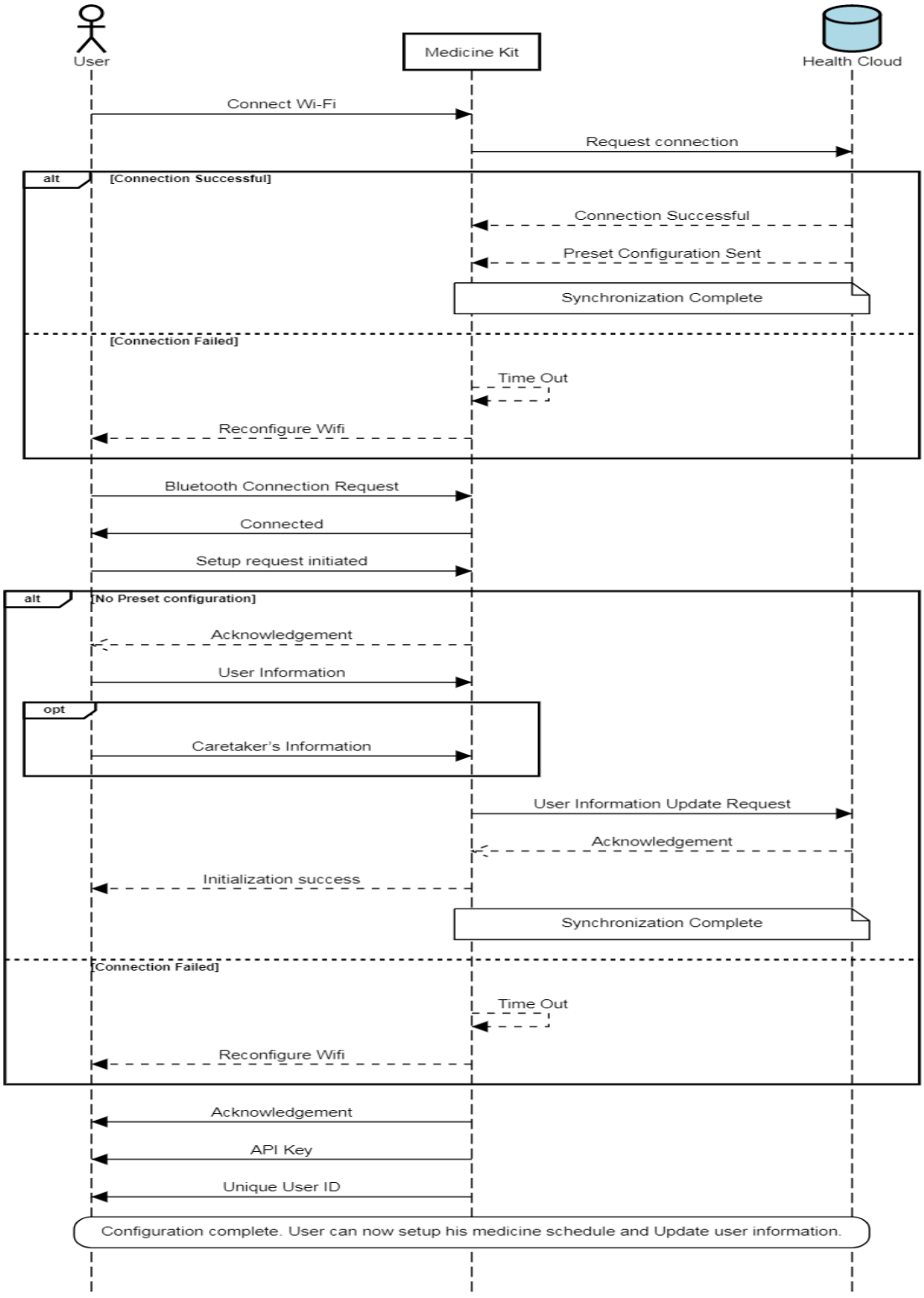

Fig 4: Initialization Sequence

User inputs the medicine schedule into the kit as prescribed by doctor via a simple, user friendly mobile application, User then places medicine pills in the designated compartment according to the prescribed time. The medicine schedule is maintained by primary microcontroller and Health cloud. The medicine box has 28 medicine compartments, in a grid of 7X4 where each column signifies time of the day namely morning, noon, evening, night and each row designated to a day of week. If the user takes certain medicine in morning and before sleep. The first and fourth column will be filled by the medicines for the number of days in the week for he/she take the prescribed medicine. This user-friendly setup allows user to follow multiple medicine course within the same setup.

Four Tier Notification System (FTNS) is used by medicine kit at the time of medicine dosage. The system consists of four levels of notifications sequences. Each level has a minimum coverage area, which increases with progression of each level. FTNS ensures that notifications form medicine box reaches the user irrespective of his/her location with respect to medicine box. Each level has a set of sequence which is carried out to produce and deliver notifications. These sequences are carried out at each level for a Minimum Wait Time (MWT), after which operations of current level are suspended and action sequence of next level is initiated. User can comply with these notifications anytime until the end of final tier of notification, this is done by simply opening the medicine compartment and taking the medicine pill. This action is detected by secondary microcontroller with the help of snap switch and reading from weight sensor. Secondary microcontroller creates an acknowledgement packet (Fig. 5) which contains timing information and data from sensors, this packet is sent to primary microcontroller which confirms that the medicine is being taken. Primary microcontroller upon receiving the acknowledgment packet marks the current dosage as "TAKEN" and suspend all further action of FTNS.


```
"Kit_id": "<kit_id>",
"version": 1,
"User_id": "<user_id>",
"name": "John Doe",
"API_Key": "XXXXXX2SJ8RHD",
"Timestamp": "2017-12-25T00:00:00.000Z",
"Packet_ID": "<p_id>",
"Acknowledgement_Satus": true,
"Medicine_Status": "TAKEN",
"Data_packet":
  "Snap_Switch": 1,
  "Weight_Sensor": 58
```


Fig. 5: Acknowledgement Package

The acknowledgement packet is also uploaded to cloud for maintaining the schedule. After each dose schedule a notification is send to user from cloud of TAKEN/MISSED dose. Relevant information is extracted from acknowledgement packet to detect events of over dosage or an irregular intake of medicine, in such cases the user will be alerted and health cloud will keep a record of such events for analysis of user behavior. Four Tier Notification System utilizes different convergence technologies embed in the system itself. Each level is described as follows:

Level I: The primary microcontroller starts Bluetooth Low Energy advertisement to be received on user's mobile phone and smart watch. Bluetooth Low Energy advertisement [4] is a type of connectionless broadcast which can be received by multiple devices at the same time. Bluetooth continues to advertise till Minimum Wait Time (MWT), if the user complies within this period the advertisement is stopped and acknowledgment is sent to primary microcontroller, else second tier notification sequence is executed. This tier of notification targets user present within 10 meters range. Fig.6 illustrates the sequence diagram for Level I notifications.

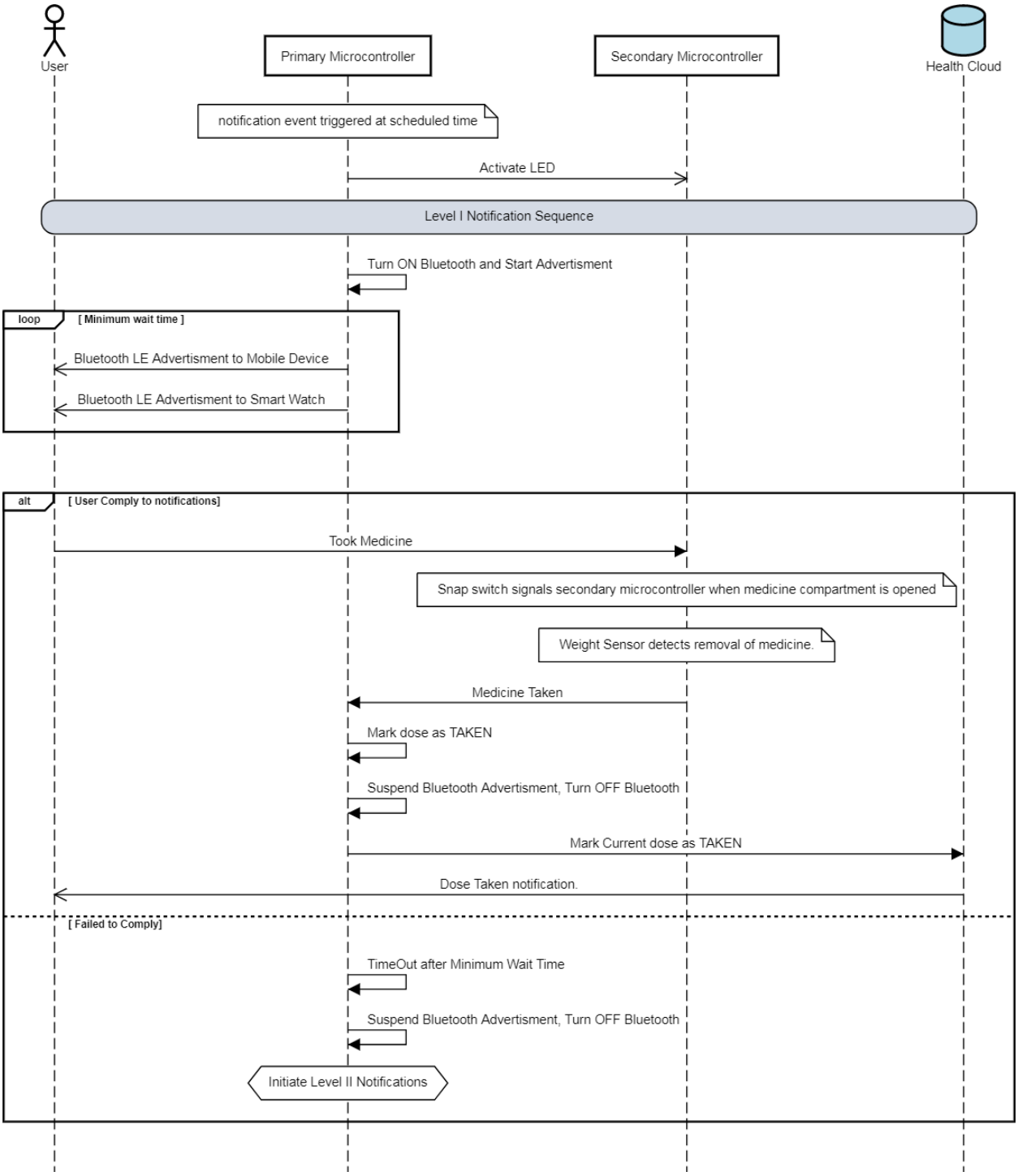

Fig. 6: Level I Notification Sequence

Level II: Notifications in this tier are sending to user's mobile via local Wi-Fi network unlike level I, Wi-Fi notification is not executed in a loop rather send once. The primary microcontroller waits till MWT for acknowledgment and then switched to level III. The rangeof notification in this tier increases to 40-50 meters. Fig. 7 illustrates the sequence diagram for Level II notifications.

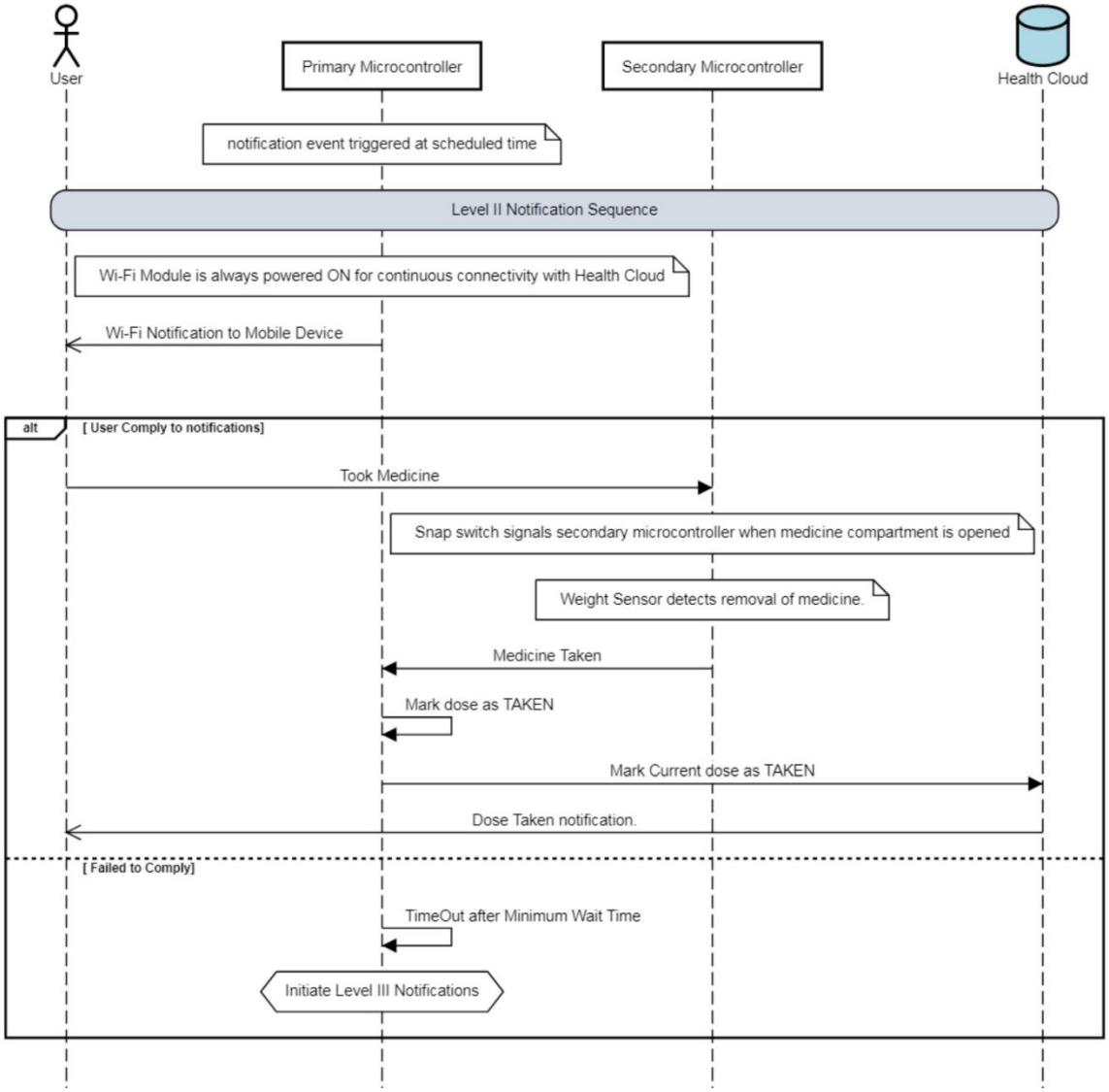

Fig. 7: Level II Notification Sequence.

Level III: In case user fails to comply with second tier notifications, primary microcontroller connects to health cloud and initiates a process of notifications to be sent via cloud. These notifications are in the form of SMS and email send to user's mobile phone and email account.

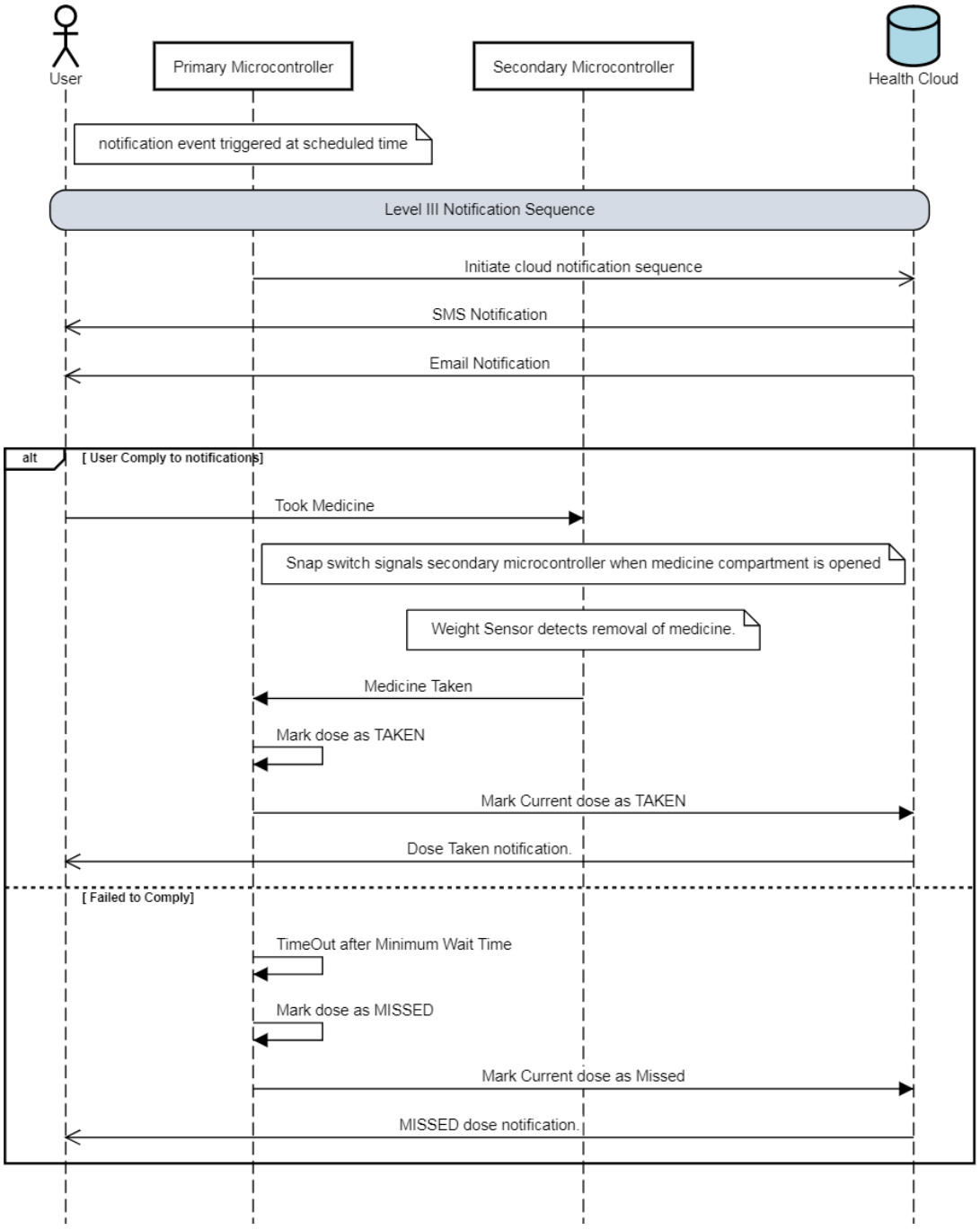

Fig. 8: Level III Notification Sequence.

These notifications will reach user regardless of its distance from medicine box. The primary microcontroller again waits till MWT. If the user fails to comply with this tier notification the dosage is marked as "MISSED". Fig. 8 illustrates the sequence diagram for Level III notifications.

Level IV: This is a special tier of notification which is useful when the user is unable to take the medicine by himself i.e., bedridden or sick enough to comply with the notifications. These notifications are targeted to caretakers along with the user. The caretaker's information is entered at the time of initiation and can be updated anytime via user's mobile device. The notifications include Bluetooth Low Energy alert [4], Wi-Fi notification, SMS and emailto caretaker's devices. Unlike others, notifications of this tier are not triggered automatically, rather they are enabled by either user or care takers. Notifications in this tier follows the same sequence as the previous 3 levels i.e., 1) Bluetooth Low Energy Advertisement, 2) Wi-Fi Notification, 3) SMS and Email Notification. After MWT the dosage is marked as "MISSED". Fig.9 illustrates the sequence diagram for Level IV notifications.

2.2. User Application Suit

User Application Suit is a collection of user-friendly application for user to interact with medicine box and Health Cloud. This application span to various platforms like android, IOS, Smart watches. The prime function of application include:

1)User Profile Setup and Update: Users have to setup their profile prior to using the medicine box. It includes information like contact information of user, contact information of caretakers and medicine course, these information can be updated any time via mobile application provide in application suit. Fig. 10 illustrates thesequence in with this operation is performed using mobile application.

2)Receive Notifications: There are different types of notifications that medicine box sends to user. These notifications include timely alerts for medicine intake, over dosage, under dosage, missed dosage notifications, these are segregated and ranked based on their severity by Mobile application and provided to user.

3)Monitoring User Behavior: User can keep track of his/her daily usage and observe intake pattern behavior. With the help of the application suit user can also query health cloud for past medicine schedules.

2.3. Health Cloud

Health Cloud is an essential part of intelligent medicine system. Health cloud hold all the information related to user, caretakers, medicine schedule and other sensor data from medicine box in a secure database. Applying relevant data analytics techniques user patterns and other useful trend across different gender, age group, geographical area can be generated. As stated as one of the use cases of medicine kit this data from user can be made available to Healthcare research facilities, insurance firms, government bodies etc. only after consent from user. Health cloud serves as a medium by which user can enter into agreement institutions that could benefit society or user itself. Health cloud is also an essential component to carry out four tier notification sequence successfully. It initiates Level III and level IV notification upon receiving signal from primary microcontroller; these notifications include SMS and Email to user or caretakers.

3. Capabilities and Analysis

A Medicine Kit discussed here are provided with some major enhancement that makes it an intelligent machine. These features widen the scope and improves efficiency of the solution. The intelligent medicine kit has capability overcome the below stated hardware limitations and has resistance to some human errors, making it a much effective solution to patients, who are the intended users of this medicine kit. Some of the key to capabilities of this device are highlighted below.

1)The medicine kit uses four tier notification system (FTNS) created specially to ensure that notification reaches the user regardless of the distance between the user and the kit. The automatic switching mechanism ensures minimal energy expenditure and simpler usage of resources. Level of notification are switched to increase the range only when needed, rather than using more energy consuming process directly.

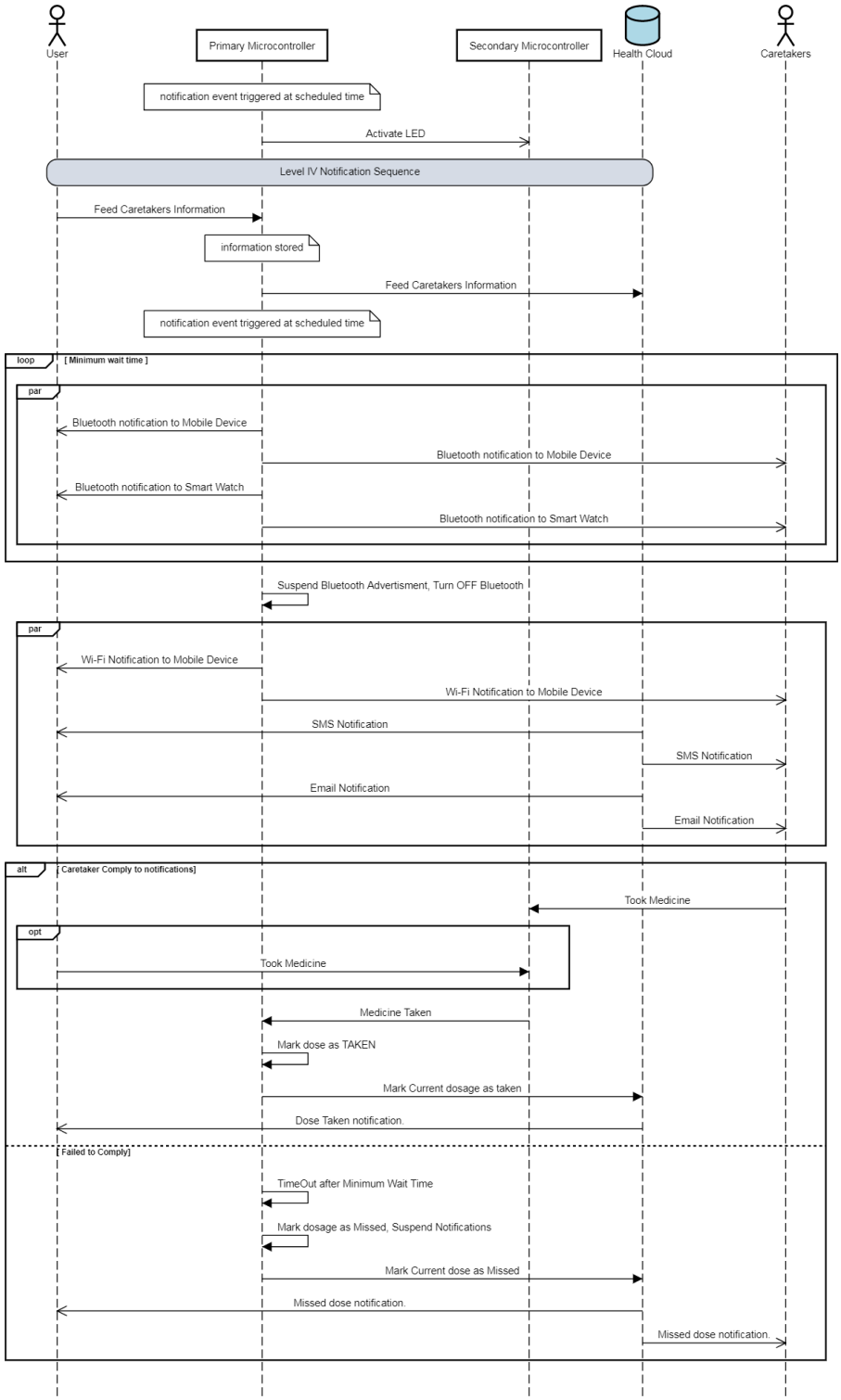

Fig. 9: VI Notification Sequence

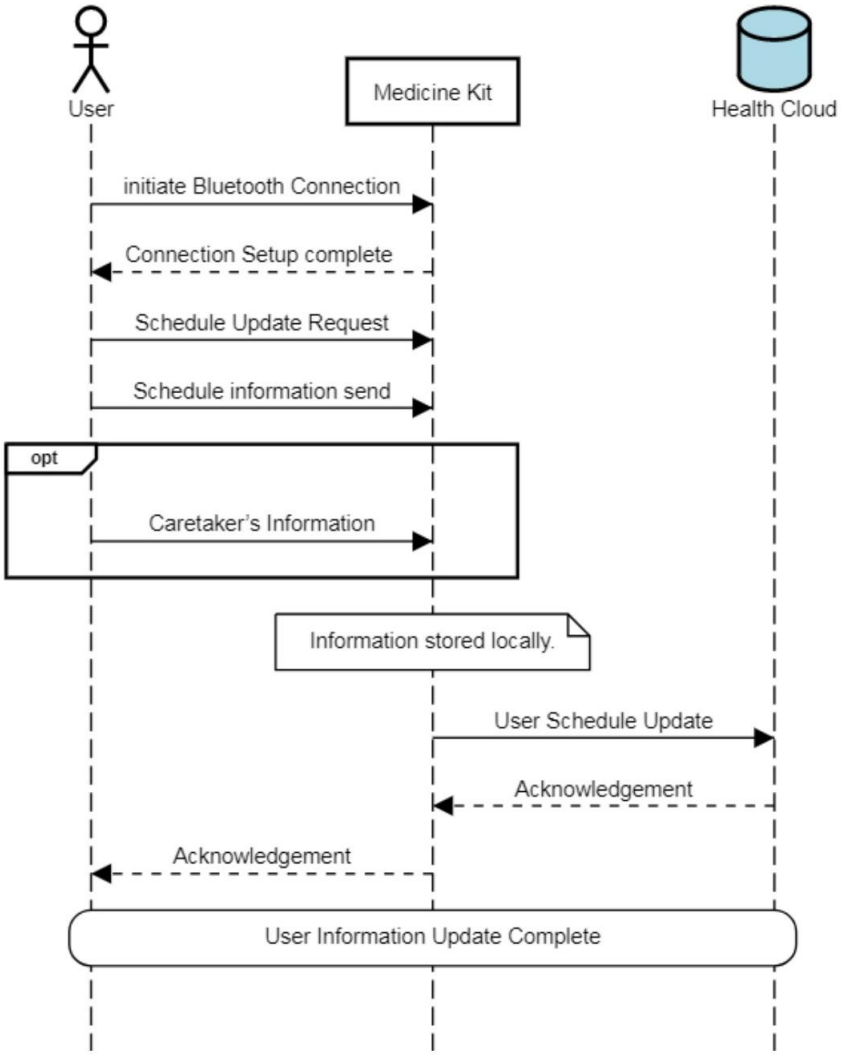

Fig. 10: Update Profile Sequence

2)Health Cloud provides addition computation capabilities to the medicine kit. The initial configuration reloads all preset setting into medicine kit again. So medicine kit once configured will not lose the user settings. This also ensure that no other person can configure the medicine kit while being used by another user. This security measure is very necessary to avoid confusion and misuse of the device.

3)Health Cloud is the core component of this intelligent system. Some microcontrollers are unable to maintain the real-world time or switch time zones automatically. In such cases Medicine kit can ping heath cloud for timing related information. Heath cloud will analyze the IP of the request to provide real time according to the time zone.

4) Data from Sensor embedded in Kit is analyzed by heath cloud to detect events of over dosage or an irregular intake of medicine. These results become very important to patient andcaretakers especially when the patient is on medication with higher potency. Analysis for this data plays very important role in some industries like Medicine Research and Healthcare Insurances.

5) Intelligent medicine kit has the ability download any new update in hardware and firmware automatically. As soon as medicine kit connects to the cloud it will check for update. In case of new update, instructions from cloud are downloaded by medicine kit and changes take effect in the device. The device backups all the user information on the cloud, so that the upgrading process doesn't cause any loss of data.

Analysis of data collected for medicine kit is another major capability of the proposed technology. Large number of results can be deduced from the data which help to project trends and user behavior. These behaviors can then be rectified in case of negligence from user. Medicine intake trend combined with health report would serve as an important resource for research in medicine field. Some of the results extracted from the data is discussed below.

1) **Number of Missed Doses vs Days**: When graph of number of missed doses is plotted against days, we can observe that the events of dose miss increases during weekends (i.e. Friday, Saturday, and Sunday). Fig. 11 illustrates that the user becomes negligent and shirks his/her schedule on weekend.

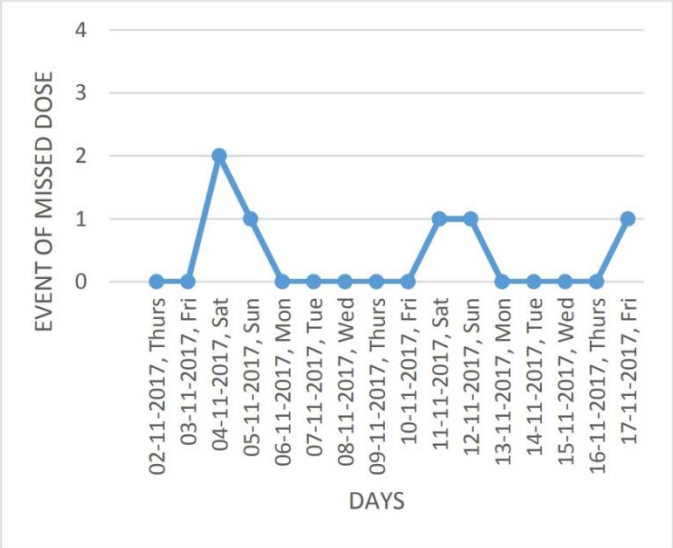

Fig. 11: Events of Missed Dose as a Function of Days of Week

2)**Time vs Missed Dose Events**: Fig. 12 shows the trend of Event of missed doses against the time of the day. This data reveal that the person has a habit of getting up late and thus missing early morning doses. This behavior causes the person to miss the most important dose of the day. This can be corrected by taking appropriate measure to wake up in the morning and take the medicine.

3)**Average difference in weight sensor vs Date**: Graph in Fig. 13 illustrates data from weight sensor plotted against days. The difference in weight signifies the removal of pills from medicine compartment, i.e., lesser difference indicates fewer medicine are taken than prescribed amount, and higher difference indicate more medicine intake than prescribed amount. With help of Fig. 13events of overdoes (marked in red) can be pinpointed. Coupled with the data from Fig.11 we reveal a very interesting pattern, the event of overdose is preceded by event of missed dose, this clearly means that user overdose pills to compensate the missed doses. This behavior is very hazardous and can have adverse effects on health. In such cases user's caretaker/doctor can be informed about this behavior to prevent such actions further.

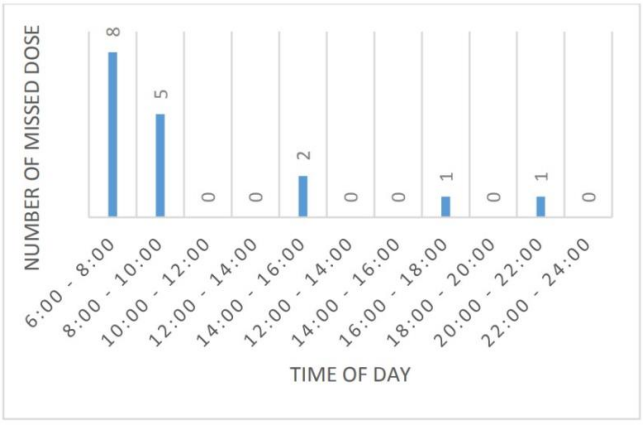

Fig 12: Number of Missed Dose as a Function of Time of Day

Fig 13: Weight Difference as a Function of Date

4)**Average response time vs Date**: Average response time is the difference between the scheduled medicine timing and the time user takes to intake the medicine. Low response time indicate quick response of the user, and higher response indicates missed does or longer time taken by user to take the medicine. Fig. 14 is marked with minimum wait time of different level of four tier notification system (FTNS). It illustrates that the user almost every time fails to comply with Bluetooth notification (Level I), this can be due to placement of medicine kit very far from the user. User can then be notified to properly place the medicine kit. If the behavior continuous the caretaker can be notified about deliberate procrastination from user.

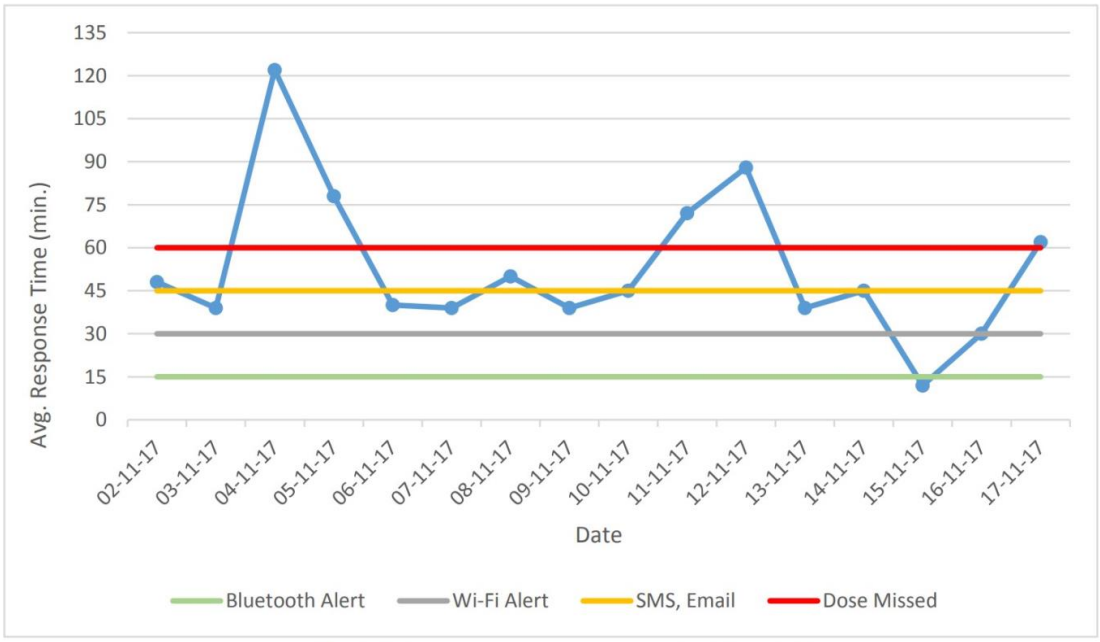

Fig. 14: Average Response Time as a Function of Date

4. Conclusion

With growing concern for health among people of all ages and gender they are gradually becoming more aware of their medication and careful of their work-life balance. Especially patients and their family are paying more attention to the accurate and real-time implementation of medical orders during the time of treatment. So the accuracy and timely use of medication significantly reduces doctor-patient complication and increases effectiveness of the treatment. Research firms closely monitor the implementation of these medical orders to study and evaluate results of various treatments. In this paper, the automatic reminder system of medicine intake based on four tier notification system for users and caretakers has been proposed, thus realizing the growing scope of IoT based device in healthcare sector. Further the intelligent medicine kit will broaden the scope of such IoT solution to play a central role in field of medicine research, healthcare insurance and many other institutions which affect and are affected by health of people. The limitation of our work is that the medicine kit cannot support any divisible medicine like portions or powdered drugs. The data graph shows the data for the usage of pills by few diabetic patients and we plan to further conduct our experiment large number of patients.

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