Development of Space-based IOT terminal for Nanosatellite UiTMSAT-1

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Abstract. This paper presents the development of space-based IOT terminal for Store and Forward (S&F) mission of nanosatellite UiTMSAT-1. The function of this ground terminal is to collect data from the sensor and send the data to the satellites over VHF amateur radio frequency band. In this case, the satellite is replaced by dummy S&F payload. To send the data from the terminal to satellite, a concept of communication in an amateur radio network is adapted. In an amateur radio network, the communication is done by a special microprocessor system called Terminal Node Controller (TNC) which implement a special protocol called AX.25 protocol. The hardware involves the development of the terminal are Control and Communication Unit (CCU) and Very High Frequency (VHF) Transceiver. CCU function as a device that collects the data from the sensor and sends the data to the VHF Transceiver, while VHF Transceiver function as a device that does the data processing before sending them to the satellites. The VHF Transceiver is built-in with TNC, AFSK Modulator, and FM transmitter. With the current setting, the total bytes allowed for sending the data packet to the satellite are 175 bytes with speed of 1200 bits per second. The data packet that was successfully received by the dummy S&F payload can be validated by using terminal emulator communication program such as real-term, here the data packet that is received by the dummy S&F payload will display on the real-term display terminal. The transmitting data from the proposed ground terminal that are successfully received by the dummy S&F payload can be seen at terminal emulator program (Real-Term).

Keywords— Store and Forward; AX.25 Protocol, nanosatellite

1. Introduction
The research on nanosatellite has moved to the fore, the construction of nanosatellite that made up of commercial off the shelf (COTS) device has cut the cost and reduce the development time due to this the research on high institute level can be done [1]. In satellite communication, there are three important elements which are the space segment, the ground segment and the mission control segment [2]. The proposed space-based IOT terminal is located in ground segment, where its roles are to collect the data from the sensor and be ready to communicate with satellite once the satellite approaches the location where the space-based IOT terminal lies. The function of space-based IOT terminal is to transmit or receive the information to/from the satellites in most reliable manner while maintaining the desired

signal quality. The link for the process of data transmission from the space-based IOT terminal to the satellites is called an uplink, while the link for the process of data transmission from satellites to space-based IOT terminal is called downlink [3].

UiTMSAT-1 is a BIRDS-2 nanosatellite project involving Japan, Malaysia, Philippines, and Bhutan. There are six missions involved in this project, one of the mission is Store and Forward (S&F). The objective of this mission is to collect sensor data from space-based IOT terminal through the UiTMSAT-1, store them on-boards and download the sensor data to the Mission Control Centre (MCC) located at Kyushu Institute of Technology (Kyutech) in Japan or any BIRDS member ground station by using satellite's ultra-high frequency (UHF) antenna for the downlink [4]. Generally, S&F mission can be described as to receive and store message/data from one part of the earth and download them later over another part of the globe. Figure 1 shows the illustration of communication between S&F mission with space-based IOT terminal and MCC respectively.

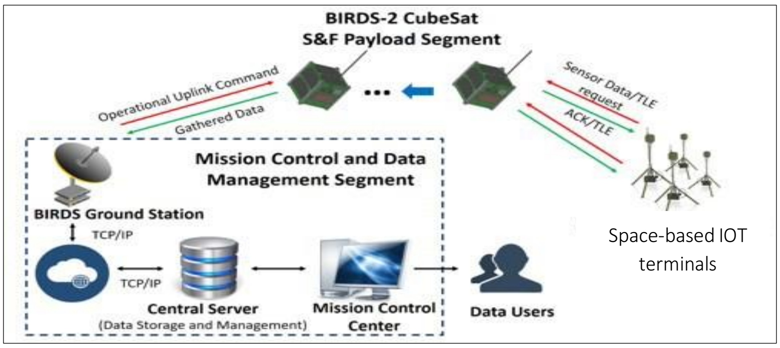

Figure 1. The System architecture of BIRDS-2 S&F nanosatellite-based remote data collection system [4].

To send the sensor data from the terminals to the BIRDS-2 CubeSat S&F Payload Segment, there are several communication layers involved, such as a physical layer, data link layer, and application layer. Figure 2 shows the communication layer for the space-based IOT terminal to communicate with S&F payload [3].

Application layer	Store & Forward data
Data link layer	AX.25 protocol
Physical layer	UART, NRZI, 1200bps AFSK Modem Radio & VHF transceiver

Figure 2. Communication Layer.

In application layer, CCU in the terminal will collect S&F data. The AX.25 protocol is used in data link layer, to accept and deliver the packet sensor data over a communication link. This protocol is a family of High Data Link Control (HDLC) protocol and modification result of radio amateur operation. The AX.25 protocol is arranged in a frame; each frame contains an individual datagram as given in Figure 3. The AX.25 protocol is a sophisticated protocol, that control and managing the data and build establish connection [5]. In the physical layer, the VHF antenna will be used to send the data to the satellites [6].

	START	DESTINATION CALL SIGN	SOURCE CALL SIGN	CONTROL	PID	INFORMATION FIELD	FCS	END
BYTES	1	2-8	9-15	16	17	18-172	173-174	175

Figure 3. AX.25 protocol format.

In this paper, we present the developed space-based IOT terminal for Store & Forward mission of UiTMSAT-1. This module was built by using COTS components. An experimental test was carried out in order to verify the end-to-end transmission, in which dummy S&F payload and dummy data were used. The hardware development consists of several devices, such as real-time clock (RTC), sensor, control, and a communication unit (CCU), SD card, VHF transceiver and an antenna. The real-time clock provides the facilities of real-time information to the microcontroller (MCU) and assists the MCU to manage the flow of data that involve a specific time. The sensor can be any sensor that is used as an input to the CCU. The SD card is used to keep the sensor data in the CCU and later the data will be sent to the VHF transceiver. From the VHF transceiver, the data packet will be transmitted to the satellite.

2. Methodology

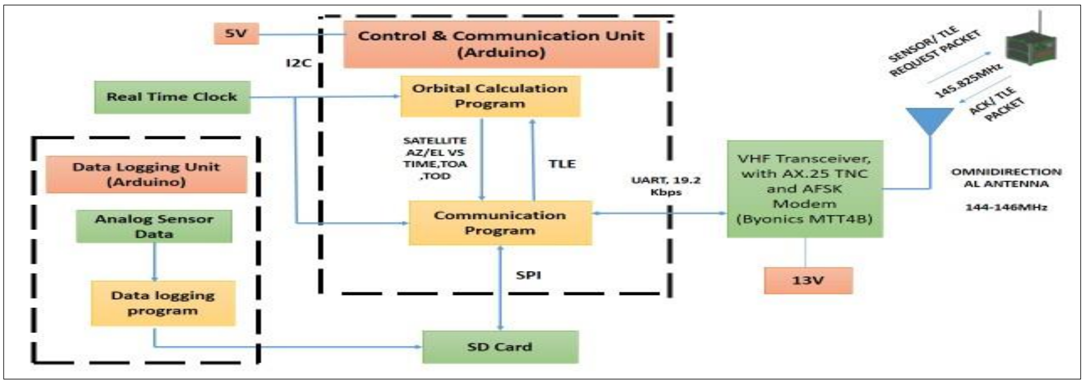

Figure 4. Space-based IOT terminal block diagram.

The block diagram of the developed space-based IOT terminal is illustrated in Figure 4. The terminal consists of 3 blocks which are Data Logging Unit with sensor integration, control, and communication unit and VHF transceiver [7]. However, in this work, we focus only on CCU and VHF transceiver. In this project, Arduino is used as CCU, where it contains the orbital calculation program and a communication program. The orbital calculation unit and communication will interact with RTC, for utility both unit to keep track with the real time. In the data logging unit, the analog sensor will transfer the output data to the SD card and later be used as data sensor for the CCU. The data sensor will be programmed according to the AX.25 protocol in the CCU. After the programming is done in the CCU, it will be sent to the VHF transceiver and transmitted to the payload.

2.1 Space-based IOT terminal operation.

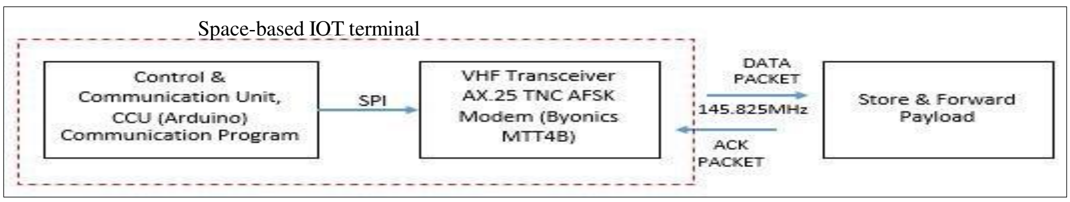

Figure 5. Block diagram of sending communication program to the payload

In Figure 5 the block diagram of communication between the space-based IOT terminal and S&F payload is given, which consists of CCU, VHF transceiver, and a dummy S&F payload. The transmission process from the terminal to the dummy payload is illustrated in the flowchart in Figure 6.

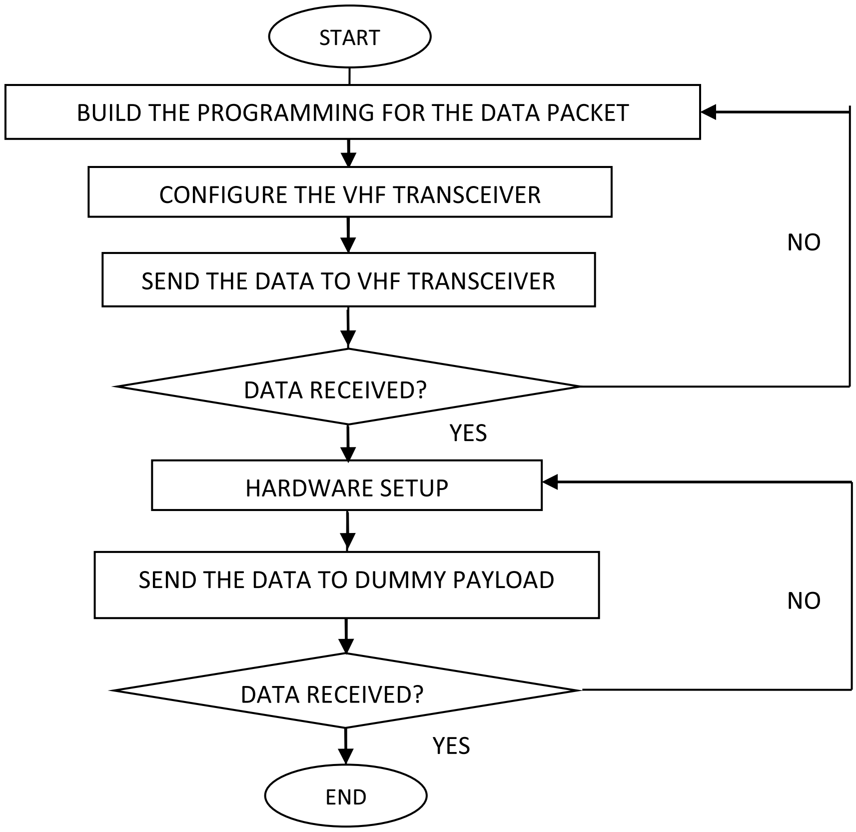

Figure 6. The flowchart for sending communication program to the payload.

2.2 AX.25 protocol

In transmitting the packet data to the satellite, several constraint factors need to be considered such as such as the size of bytes that allowed to be sent to the payload. By referring to the Table 1, the total bytes that are available for sending data packet for each time packet data is transferred to the payload is 175 bytes [8]. Although the available size of bytes is 175 in total, only 122 bytes are available for sensor data [3].

Table 1. Format of sensor data packet.

	Start	Destination Callsign	Source Callsign	Control	PID	Information Field				FCS	End
Byte #	1	2-8	9-15	16	17	18	19-20	21-50	51-172 (up to 122 bytes)	173-174	175
Content	Start flag	Satellite callsign	GST callsign or ID	Control (0x3E)	PID (0xF0)	Packet type (0x01)	Data Packet sequence #	Time packet transmitted, time packet generated, AZ and EL during packet transmission	Time data logged, sensor data, etc.	FCS	End flag
Format	HEX	ASCII string	ASCII string	HEX	HEX	HEX	HEX	ASCII string	ASCII string	HEX	HEX

The data packet was programmed in the CCU. The information in the data packet should include start, destination call sign, source call sign, control, PID, information field, FCS, and END.

2.3 CCU

In this work, Arduino is used as the CCU. For the purpose of testing, the data from the sensor is replaced by number 0 to 9. Data that was intended to send to the satellite is program comply with the AX.25 protocol by using C+ language. The programming is done in Arduino software ide and is called the data packet. It is called the data packet because it follows the AX.25 protocol which is in the form of the datagram, where each datagram contains a frame and each frame consists of a specific function. Fig. 7 shows the programming of the data packet which data sensor is replaced by number 0 to 9.

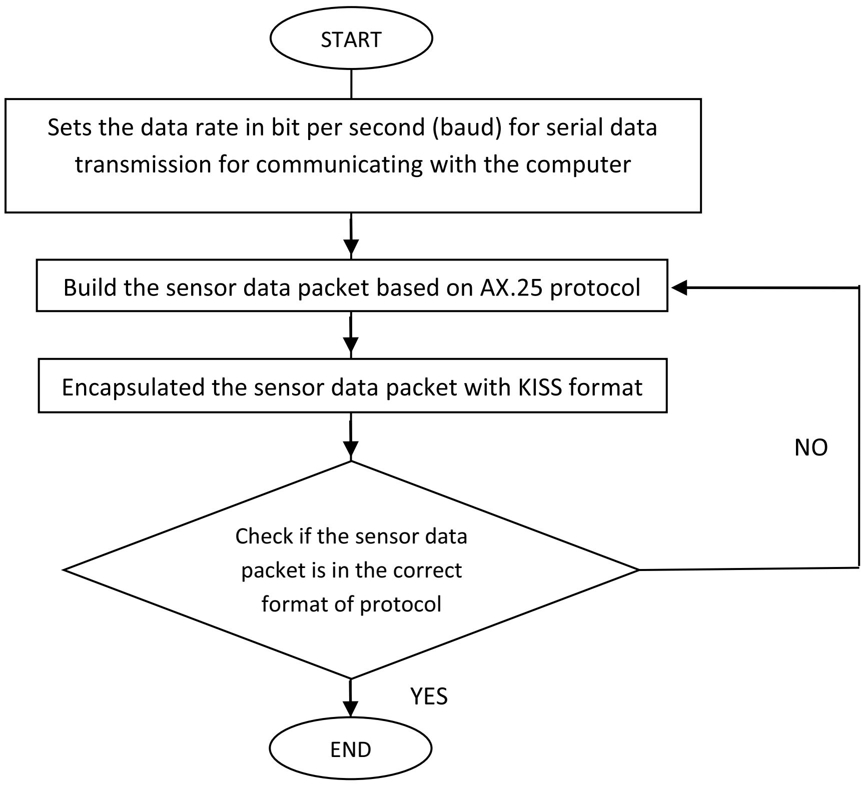

Figure 7. Flowchart for data packet programming

The data packet that was successfully constructed by can be seen on the serial monitor of Arduino ide software environment. The result will be shown in the result section. Next, data packet will be sent to the VHF transceiver

2.4 VHF transceiver

In this work, MTT4B is using as the VHF transceiver. The VHF transceiver must first be configured to the appropriate setting by using terminal emulator communication program such as Real Term. Figure

8 shows the terminal emulator communication program that is used for the configuration of VHF transceiver.

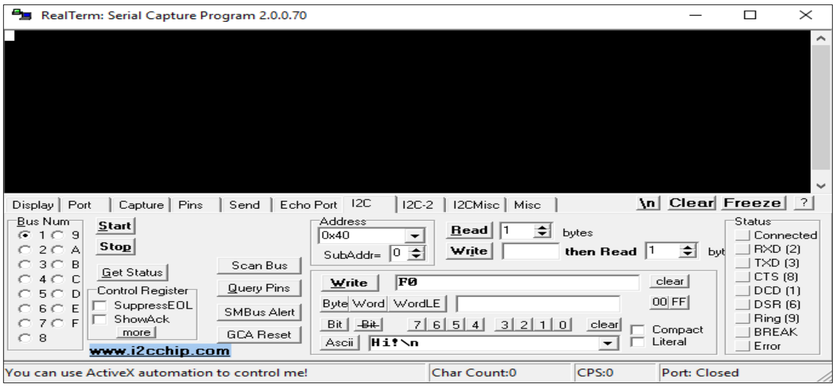

Figure 8. Terminal emulator communication program (Real-term.)

The VHF transceiver uses 13 volts power supply and 2 Amperes current and it is connected to the computer by using the DB9 connector. The communication between the transceiver and the computer is done through UART. To right port selection for configuring the VHF transceiver, can be check in the device manager.

Next, the baud rate is set to the suitable value, such in this case, the baud rate is set to 19200. In this project, the Byonics MTT4B is using as the VHF transceiver.This baud rate is set according to the Byonics MTT4B manual description. After setting the port and the baud rate. The configuration mode is entered by clicking the ESC button on the computer for three times and the programming for setting the VHF transceiver is made. Figure 9 shows the hardware required in configuring the VHF transceiver.

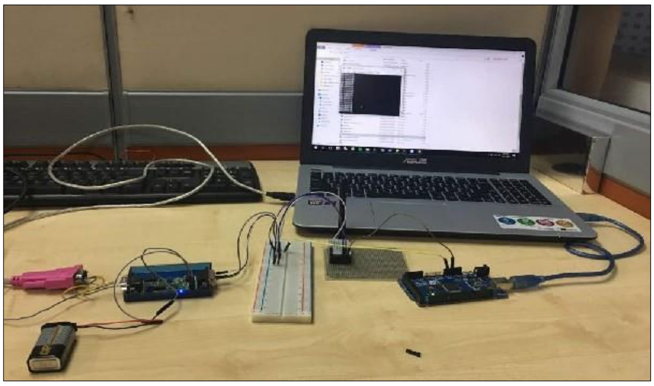

Figure 9. The hardware required for the configuration of VHF Transceiver.

In the VHF transceiver, the signal will be processed by the TNC, AFSK modem and later be transmitted by the FM transmitter to the payload. Figure 10 shows the block diagram of data processing in the VHF Transceiver.

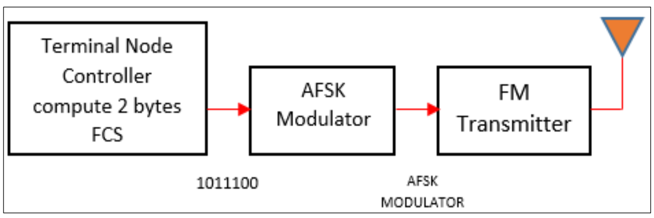

Figure 10. Block diagram of data processing in the VHF Transceiver

The data packet from the CCU is in the format according to the AX.25 protocol, but it is encapsulated in KISS frame, in order to ensure that the data packet can be transferred to the TNC over a serial link of the VHF transceiver. Besides, it allows the TNC to have a complete control and access to the data packet. Before sending the sensor data packet to the VHF transceiver, the connection between CCU and VHF transceiver is made. Figure 11 shows the connection between CCU and the VHF transceiver

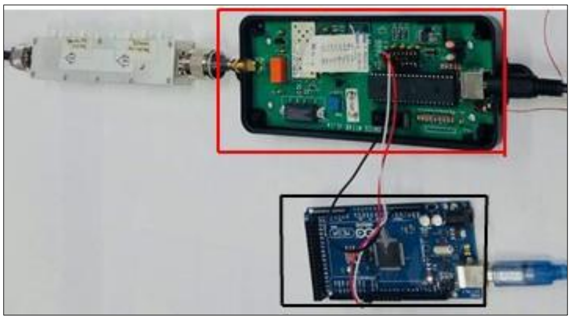

Figure 11. The connection between CCU and VHF transceiver.

After the data is received by the VHF transceiver, the TNC will perform frame check sequence calculation (FCS) to detect if there is an error in the data packet. Next, the AFSK modulator will modulate the data packet in which the digital data will be translated to the changes of frequency that make the encoded signal is suitable to transmit via the FM transmitter and later sent to the dummy payload via an internal antenna for short-range testing.

2.5 Sending the sensor data from terminal to the dummy payload

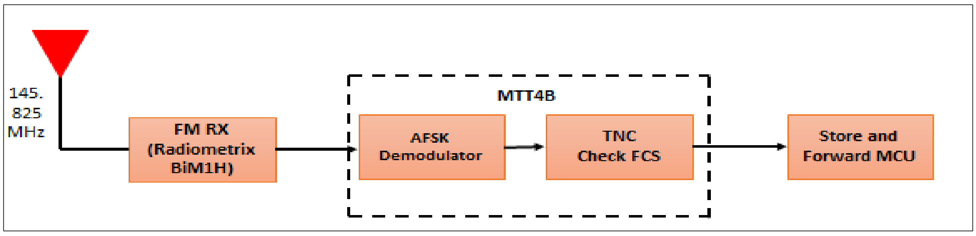

Figure 12. Block diagram of S&F payload

Figure 12 shows the block diagram of S&F payload. In fact, in S&F payload, the process of data received is the reverse process of what happens in the VHF transceiver in the terminal. The antenna receives the data packet, then the data packet goes through the FM receiver. Next, in the VHF transceiver of S&F payload, the data packet is demodulated by the Audio Frequency Shift Keying (AFSK) demodulator and sent to the Terminal Node Controller (TNC) for the process of Frame Check Sequence (FCS). When the process is completed, the data will be transferred to the S&F MCU.

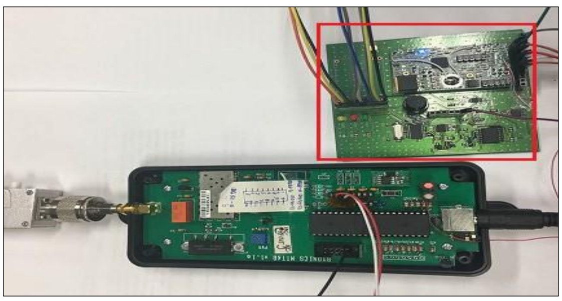

Figure 13. VHF transceiver is sending the data wirelessly to the dummy S&F payload.

Figure 13 shows the dummy S&F payload that represents the actual payload. The received data packet from the payload can be monitor through the Terminal emulator communication program by connecting the payload to the computer by UART. The VHF transceiver transmits the data wirelessly to the dummy S&F payload via the frequency 145.825 MHz.

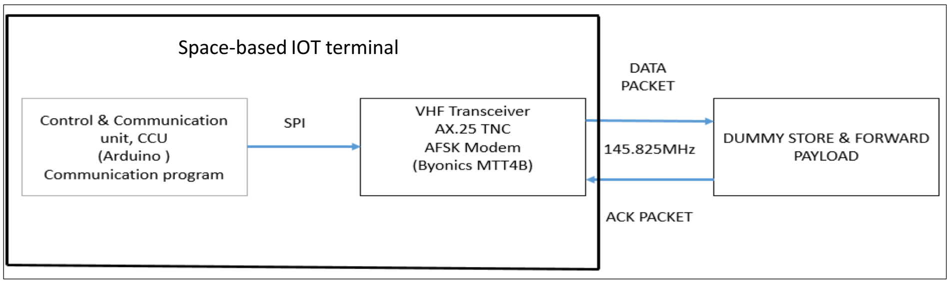

Figure 14. The Block diagram of transmission.

Before sending the data packet to the payload, the hardware setup required for this process must first be established based on block diagram on Figure 14.

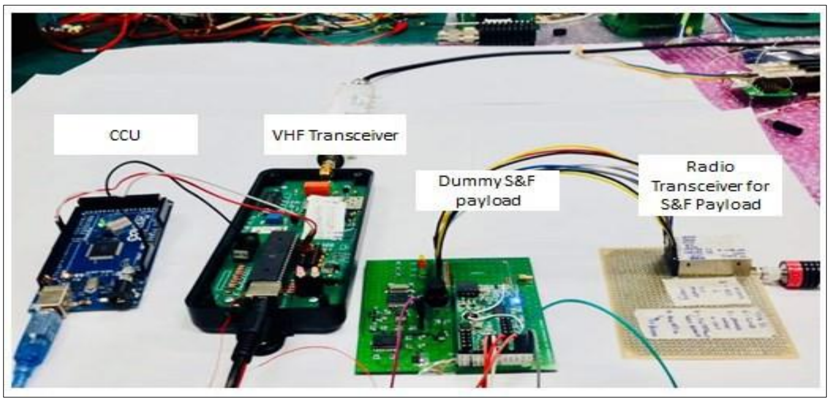

Figure 15. Complete connection to hardware system

Figure 15 shows the complete connection of the hardware system. In this work, the Arduino is supplying with 3v and 1ampere current, MTT4B is supplying with 13v and 5 amperes current while dummy payload is supplied with 5v and 2 amperes current.

In this testing, internal antenna from the MTT4B is used for the process of data packet transmission. The testing was done in short distance, and the main objective is to validate the data packet format that can be accepted by the payload.

For the installation of this space-based IOT terminal in the rural area, the data that will be collected is the Earth magnetic field. Power transmit for the MTT4B is set to 5 watts. To test either the MTT4B can have a variety of power transmission, the blue pin located on the board of MTT4B that is shown in Figure 16 is turned around, the MTT4B is connected to the spectrum analyzer to see the output power of the VHF transceiver.

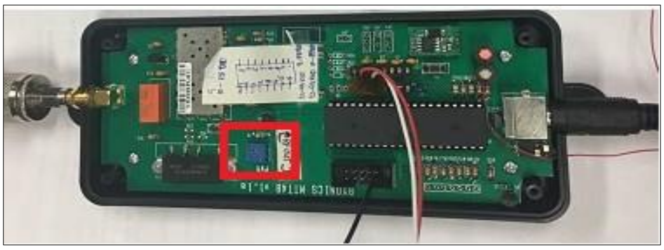

Figure 16. VHF transceiver (MTT4B)

Figure 17 shows the testing done by check the power transmit by the MTT4B.

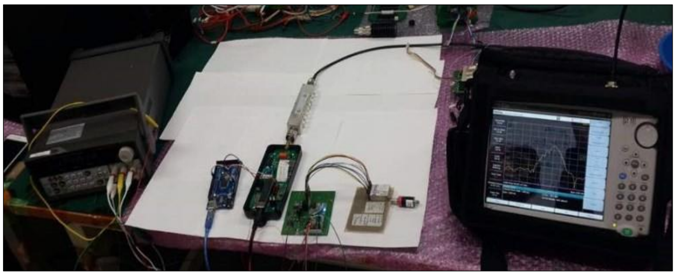

Figure 17. The hardware setup for testing the output power by the MTT4B.

3. Result and discussion

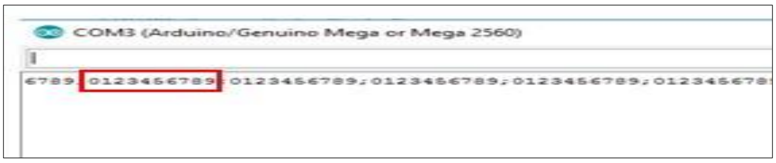

Figure 18. The serial monitor's output of the Arduino software ide

Figure 18 shows the result of the programming for a data packet in communication program that is built in Arduino software IDE, it shows that number 0 to 9 is displayed on the serial monitor.

Next, after programming was able to construct in Arduino software IDE, it was later sent to the VHF transceiver through UART by connected the CCU to the VHF transceiver, to validate if the data packet is according to the right format. The data packet will be displayed on the terminal emulator program.

Figure 19. The data packet from MCU

In Figure 19 the number 0 to 9 was displayed at the terminal emulator program. When a data packet is transmitted to the VHF transceiver, the digital signal will be modulated by AFSK modulator. The spectrum of the modulated signal was verified by using a spectrum analyzer. Two signals with a different frequency are formed after modulation process is happening. The frequency of the signal will be 1200Hz and 2200Hz.

Figure 20. Signal spectrum of spectrum analyzer

In Figure 20 the amplitude of the spectrum is maximum at frequency 145.825MHz every time the data packet was sent to the VHF transceiver.

After sending the data packet to the VHF transceiver, the data was sent wirelessly to the dummy payload at frequency 145.825MHz. The data received by the dummy payload was observed at the terminal emulator program in order to verify if the transmitted data was successfully received.

Figure 21. The data packet received by the payload

Figure 21 shows the result at the payload where the numbers 0 to 9 was displayed at terminal emulator program. It shows that the data is successfully received by the payload.

Next, the transmission signal was tested with different power level supply by the VHF transceiver and signal wave of the data packet transmission to the payload is observed using a spectrum analyzer. A fixed attenuator of 40 dBm was connected to the VHF Transceiver. This testing was done to observe the signal power strength by using a variety of power level from the VHF transceiver. Channel power width value represents the signal power strength of the signal wave.

Table 2. Channel power width of the transmitted signal at different power level

Attenuator value (dBm)	Power level supply at VHF Transceiver(dBm) & (watts)	Channel power width at spectrum analyzer(dBm)
40 dBm	30.6 dBm / 1.14 watts	10.6 dBm
40 dBm	35.3 dBm/ 3.38 watts	4.7 dBm
40 dBm	38.4 dBm/ 6.91 watts	1.3 dBm

Table 2 shows the calculated channel power width value that should be achieved when testing with the different power level.

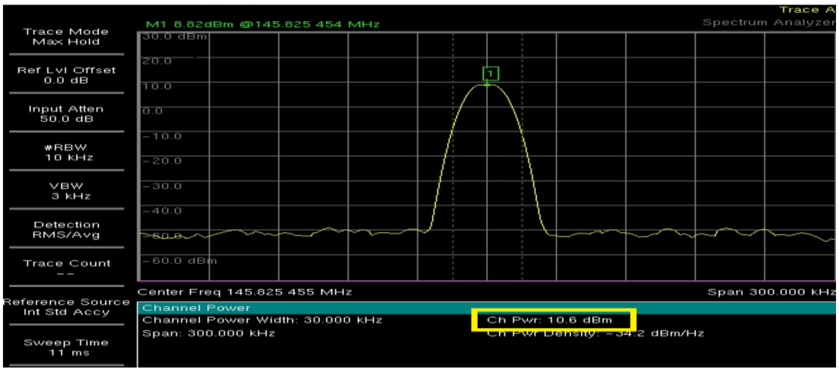

Figure 22. The spectrum with 1.14 watts power supply

Figure 22 the power supply is set to 1.14 watts, the channel power width of the signal shows the value of 10.6 dBm.

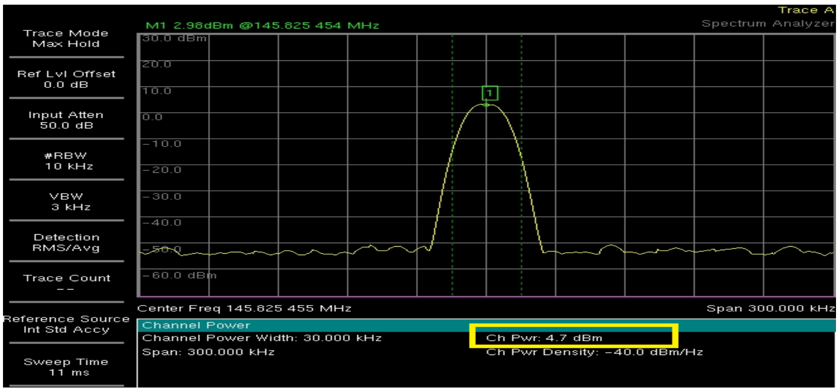

Figure 23. The spectrum with 3.38 watts power supply

Figure 23 shows when the power supply is set to 3.38 watts, the channel power width of the signal shows the value of 4.7dBm.

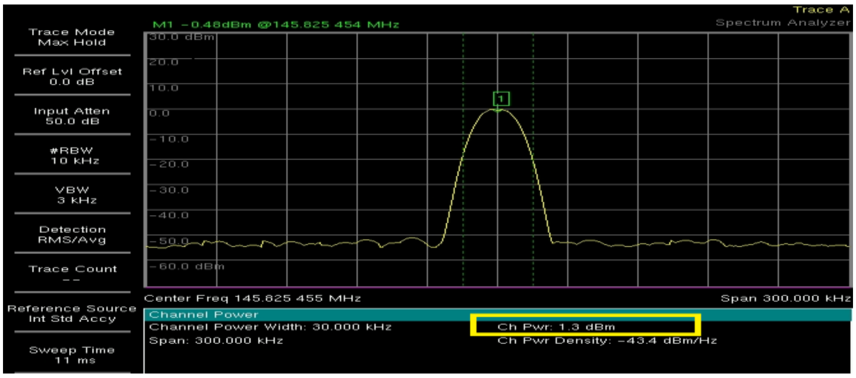

Figure 24. The spectrum with 6.91 watts power supply

Figure 24 shows when the power supply is set to 6.91 watts, the channel power width of the signal shows the value of 1.3 dBm.

From the result obtained in Figure 22 to 24, when VHF Transceiver is supplied with different power level, it shows that the spectrum analyzer can detect the signal wave produced by the packet data that was transmitted by the CCU.

4. Conclusion

This project is to shows the process of transmission of the data packet from the space-based IOT terminal to the dummy payload. By using COTS components, low-cost space-based IOT terminal can be built. The development of the proposed terminal at current stage has been tested and it shows a good agreement between the terminal as transmitter and dummy payload as a receiver. The data packet that was intended send to the payload, is successfully received. However, to show the overall project is successful several elements for the improvement of hardware and software should be added. The future recommendation such as orbital calculation and data logging should be added in software programming while instalment of VHF antenna for the hardware improvement can be added.

Acknowledgment

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