Mahanakorn Satellite Receiving Station
Part I : System Architecture and Preliminary Results

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Manuscript received March 30, 2019
Revised June 1, 2019

ABSTRACT

This paper presents the Mahanakorn Satellite Receiving Station (MARS). The requirements on downstream applications are proposed to select the type of sensors on-boarded the direct broadcast satellites. The communication concern and link budget are taken into account for choosing the suitable COTS (commercial-off-the-shelf) RF module for setting up ground receiving station. The MARS architecture consists of three major subsystems; antenna subsystem, acquisition subsystem, and data processing & solution subsystem. In the antenna subsystem, the dedicated X/L band 2.4 metre parabolic antenna mounted on 3-axis positioner is performed to track and receive satellite signals. The COTS of RF feeder, LNA (Low Noise Amplifier) and RF downconverter is performed for providing IF (Intermedia Frequency) signal. The COTS DSP (Digital Signal Processing) based digital receivers are used in the acquisition subsystem. The operational aim of MARS is to receive the direct broadcast signal from Earth Observing Satellites (EOS) which are orbiting in LEO (Low Earth Orbit). The MARS has capability to track and receive the series of NASA's EOS and NOAA's EOS. Preliminary testing of satellite signal tracking and satellite images production are performed for verifying the system capabilities.

Keyword : *satellite receiving station, signal acquisition, receiving satellite images from direct broadcast EOS.*

1. INTRODUCTION

Mahanakorn University of Technology (MUT), a private university was established in 1990. At the beginning of establishment, MUT aimed and focused on high quality teaching in engineering field due to the demanding of industry in Thailand. However, MUT gradually expanded to open other three faculties; information technology (IT), business administration and veterinary medicine. Currently, MUT has more than 30 curriculums which offer bachelor degree, master degree and Doctor of Philosophy.

In 1996, MUT has starting involved in space program. MUT and former mobile phone operator, UCOM, (United Communication Industrial Ltd.) collaborated with University of Surrey for first Thai MicroSATellite (TMSAT) program. The objective of TMSAT mission was for education, research purposes, and made use of satellite images for various GIS (Geographic Information System) applications. There were 12 Thai engineers (11 from MUT and 1 from UCOM) participated in technology transfer program at Surrey Space Centre (former CSER : Centre for Satellite Engineering Research), University of Surrey [1].

The 50 kg class micro-satellite carried the multi-spectral cameras and digital store & forward communications payloads for education and technology transfer proposes. It was a medium resolution (15 metre) of multi-spectral (MS) optical system carried onboard. The satellite images were used in agriculture applications and disaster monitoring. The onboard DSP (digital signal processing) was used to experiment the digital communications [2].

TMSAT was launched into SSO (Sun synchronous orbit), 815 km altitude and 98.64 degrees inclination, on 10 July 1998 by Zenith-II launcher from Baikanur, Kazakstan. Later on, in October 1998, TMSAT was renamed as ThaiPaht given by the King Rama 9.

Fig. 1 *ThaiPaht first Thai microsatellite and Team*

Since 2014, MUT and GISTDA (Geo-Informatics and Space Technology Development Agency) has collaboration for mutual research in space program. The

MUTT and GISTDA researchers have developed several crucial elements for satellite engineering such as orbit propagator for THEOS, multi-mode downlink communication and camera subsystem for cubesat [3] – [5].

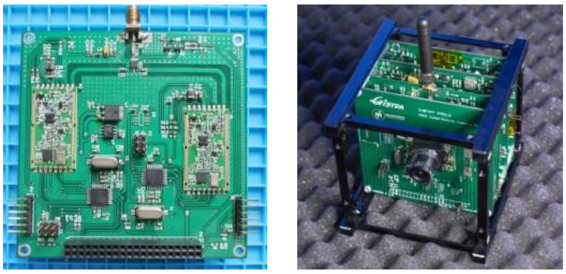


Fig. 2 *Communication subsystem for Cubesat*

Over past years the global technology has rapidly developed. In 2017, MUT has established a flagship unit, Mahanakorn Institute of Innovation (MII) in order to develop engineering curriculums and setup new research laboratory that emphasise innovation and disruptive technology. To serve the digital and space economy, MUT designs three curriculum groups. The first group is MII courses which include computer engineering, control and instrumentation engineering, mechatronics engineering, innovation and business management, and a bilingual program in engineering. The second group is the conventional engineering courses which cover electrical engineering, mechanical engineering, civil engineering, chemical engineering, industrial engineering, and telecommunications engineering. The last group is courses in other fields including information science and technology, business administration, and veterinary science [6].

Under the MOU between MUT and GISTDA, the MARS installation commenced in April 2018. The first objective was to provide real practical opportunity to university researchers and postgraduate students for gaining their knowledge and hand-on expertise in satellite engineering and GIS applications. The second objective was to make use of satellite images for developing GIS solutions demanded by private and industrial sectors, particularly for agriculture farming, water management, weather and disaster monitoring.

Nowadays, several universities around the world have developed the satellite ground segment for receiving the Earth observation satellites, and providing the satellite data. The Space Science and Engineering Center (SSEC) at the University of Wisconsin-Madison is the most internationally well known. The SSEC provides data from polar-orbiting and geostationary meteorological satellites operated by the U.S., and other meteorological agencies around the world [7]. In Europe, the ICARE Data and Services Center, the University of Lille and its partners (CNES, CNRS, and the Nord-Pas-De-Calais Regional Council) provides various services to support the research community in fields related to atmospheric research, such as aerosols, clouds, radiation, water cycle, and their interactions [8]. In China, the Wuhan University (WHU) is the top university in remote sensing technology and applications. The IGS center of (WHU) provides satellite data from Earth observation satellites operated by China [9].

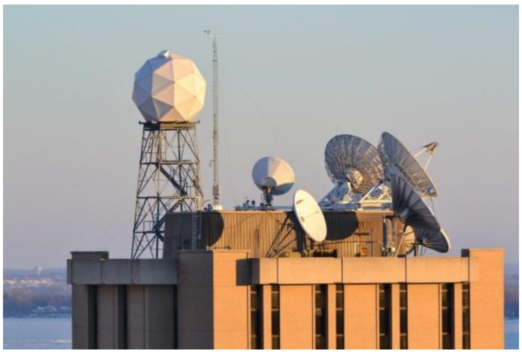


Fig. 3. *The Space Science and Engineering Center (SSEC) at the University of Wisconsin-Madison*

2 THE REQUIREMENT INFORMATION FOR SETUP SATELLITE RECEIVING STATION

MUT researchers and postgraduate students have experienced in specific research areas which relate to satellite engineering such as satellite communications, digital signal processing, image classifications and recognitions. In addition, MII plays a role of research unit for developing the essential technology and applications as required by private and industrial sectors.

MUT intend to expand the research capability and facility in satellite engineering by setting up MARS and making use of the satellite images for the downstream applications, particularly in agriculture farming, water management, weather and disaster monitoring. Therefore, in order to serve these wide area applications, the medium resolution of image (resolution from hundred metre to less than one kilometre) is the most suitable for practical operation. Moreover, there are several free-accessible EOS in space. The conceptual requirements are shown in Fig. 4.

The selected direct broadcasting missions are listed in Table 1 [10 – 13]. The interesting instruments (payloads) onboard those missions which can be used for target applications are listed in Table 2 [14] – [17].

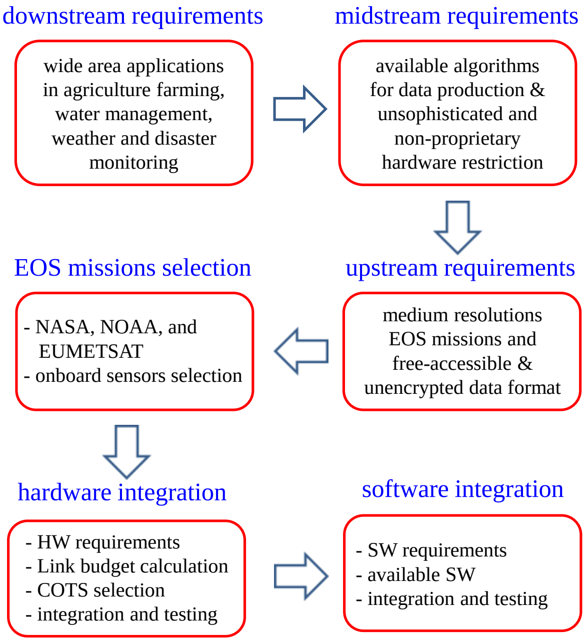


Fig. 4 *Conceptual Requirements for MARS*

Table 1 *Selected Missions for Preliminary Setup*

Mission	Orbit Type	Altitude (km)	Inclination (degree)	Orbital Period (minute)	Equator Crossing Times
Aqua	SSO	700	98.2	98.8	13.30 (A)
Terra	SSO	700	98.5	99.0	10.30 (D)
MetOp	SSO	817	98.7	101.0	9.30 (D)
NOAA15	SSO	793	98.8	101.0	6.30 (D)
NOAA18	SSO	855	99.2	101.9	7.40 (D)
NOAA19	SSO	850	98.9	101.9	15.44 (A)

SSO : Sun Synchronous Orbit
(A) : Ascending Node (D) : Descending Node

Table 2 *List of interesting instruments (payloads) (Cont.)*

Instrument	Full Name	Application
Mission :	Aqua and Terra	
MODIS	Moderate-resolution Imaging Spectro-radiometer (36-channel VIS/IR spectro-radiomete)	agriculture, hot spots (bushfires), phytoplankton bloom, disaster monitoring (e.g. typhoon)
Mission :	MetOp (B) 0	
AVHRR/3	Advanced Very High Resolution Radiometer / 3	Global sounding, atmospheric minor constituents, (ozone)

Table 2 *List of interesting instruments (payloads) (Cont.)*

Mission :	NOAA (15, 18, 19)	
AVHRR/3	Advanced Very High Resolution Radiometer / 3	daytime and night cloud and surface mapping, Land-water boundaries, Snow and ice detection, sea surface temperature
HIRS/3 (NOAA15) HIRS/4 (NOAA19)	High-resolution Infra Red Sounder / 3	temperature sounding, surface temperature and cloud detection, total ozone retrieval

For the selected direct broadcasting satellites, the communication parameters are listed in Table 3.

Table 3 *Communication Parameters of Selected Satellites*

Mission	EIPR dBm	Frequency MHz	IF MHz	Modulation Scheme	Data Rate	Protocol
Aqua	44.0	8160.0	720.0	SQPSK	15 Mbit/s	CCSDS
Terra	42.0	8212.5	720.0	OQPSK	13 Mbit/s	CCSDS
MetOp B	36.0	1701.3	137.5	QPSK	3.5 Mbit/s	CCSDS
NOAA 15	35.0	1702.5	137.5	split phase PSK	665.4 kbit/s	CCSDS
NOAA 18	35.0	1707.0	137.5			
NOAA 19	35.0	1698.0	137.5			

3 SYSTEM ARCHITECTURE

The system architecture of MARS consists of three subsystems; antenna subsystem, acquisition subsystem, and data processing and solution subsystem as shown in Fig. 5. The inter-connection diagram between antenna and acquisition subsystems is shown in Fig. 6.

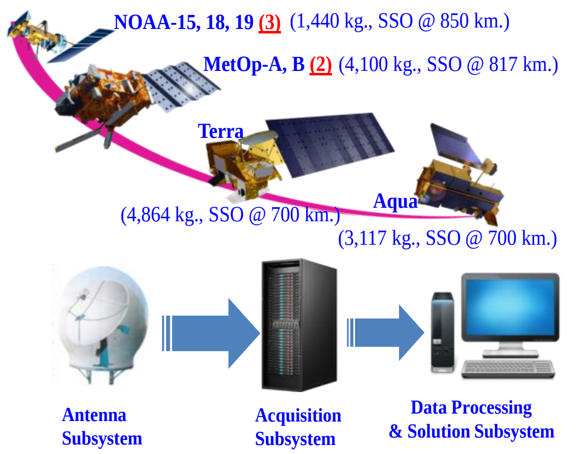


Fig. 5 *Mahanakorn Satellite Receiving Station (MARS)*

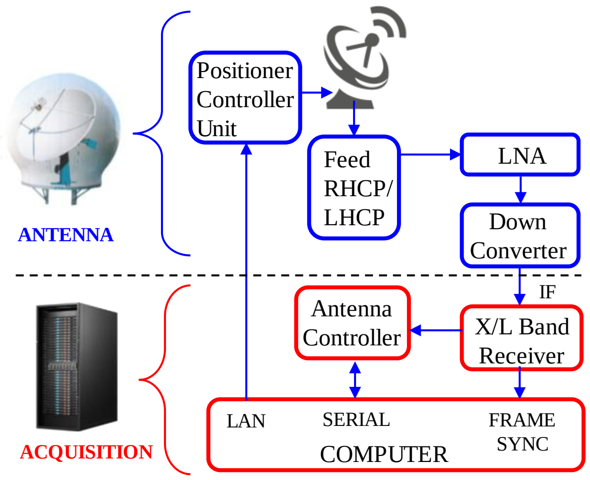


Fig. 6 *Diagram of Antenna and Acquisition Subsystems*

In this paper, we focus and describe the detail of antenna subsystem and acquisition subsystem. The X/L band antenna subsystem makes use of a 2.4 metre parabolic reflector mounted on a three-axis positioner. The 3.2 metre radom with air conditioners is used to protect the antenna, RF feeder and RF electronics devices, and three-axis positioner from hot-humidity environments.

From the satellite EIRP and data rate as shown in Table 3, the estimated link budget of Earth station (antenna diameter 2.4 metre) for X/L band at 5 degrees elevation angle is summarised as shown in Table 4 [18].

Table 4 *Link budget for receiving signal for X/L band*

parameter	X band @ 8.2GHz	L band @ 1.7GHz		unit
		NOAA	MetOp	
radom noise temperature	12.62	14.0	14.0	K
antenna gain	43.7	30.1	30.1	dBic
antenna noise temperature	63.9	30.0	30.0	K
RF front end noise temperature	56.84	44.1	44.1	K
total system noise temperature (Tsys)	141.3	144.0	144.0	K
system G/T	22.8	12.2	12.2	dB/K
C/No	77.39	71.27	72.31	dB Hz
Eb/No	6.25	13.04	6.87	dB

The 2.4 metre reflector made from solid aluminum is designed with 0.375 F/D ratio. The three-axis controlled positioner has capability tracking in elevation, azimuth and cross-elevation direction. The range of azimuth is unlimited, while the range of elevation is ± 90 degrees. The range of active tracking axis, cross-elevation, is ± 20 degrees.

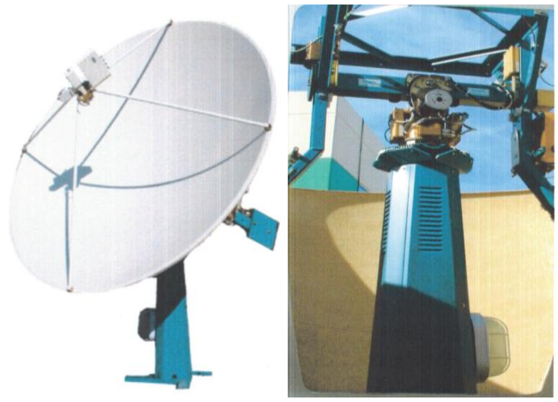


Fig. 7 *Antenna Reflector and Positioner*

The overall tracking accuracy is within sub-degree. The COTS tracking antenna controller unit from Sea Tel is selected to track the EOS series of NASA, MetOp and NOAA. The Sea Tel tracking antenna controller unit can cope with both wide band TVRO receiver (950 - 2050 MHz, detection bandwidth 16 MHz) and narrow band SCPC receiver (950 - 1750 MHz, detection bandwidth 30 kHz).

From the link budget as shown in Table 4, for the X band reception, the special type of scalar waveguide feeder is selected to support conical scanning and auto switching between RHCP and LHCP. The maximum axial ratio is 0.8 at 8.2 GHz, with 1.4 of VSWR (Voltage Standing wave Ratio). The estimated total loss of X band feeder is 0.25 dB. The selected LNA module X band is based on GaAS FET. The LNA gain is 22 dB with 800 MHz bandwidth. The noise temperature of LNS is 50 K. The selected X band downconverter provides the IF output at 720 MHz. The conversion gain is typically 10 dB, with 500 kHz of synthesiser step size. The converter makes use of 7 pole cavity filter which response to 3 dB at 700MHz, -20 dB at 900 MHz and -60 dB at 1500 MHz, respectively. The overall noise figure of X-band downconverter is 16 dB. The phase noise at 10 kHz, 100 kHz, and 1 MHz are -70 dBc/Hz, -100 dBc/Hz and 120 dBc/Hz, respectively.

For L band reception, the integrated module of Feed/LNA/Down converter is chosen. The L band feeder type is dual crossed dipoles with RHCP polarisation. The axial ratio at 1.7 GHz is 2.0, and VSWR ratio is 1.5. The LNA has 38 dB gain, and 43 K noise figure. The PLL-LO (phase locked loop local oscillator) of downconverter at 1565 MHz provides the IF signal at 17 MHz, with 50 MHz bandwidth, and 17 dB gain. The total noise temperature with preselect filter is 120 K.

In the acquisition subsystem, the COTS X band receiver, DSP (Digital Signal Processing) based digital receivers from Quorum is selected for Terra and Aqua direct receiving. The input frequency is 720 MHz, with 75 MHz BW. The demodulator modes are BPSK, QPSK, SQPSK and OQPSK. The receiver supports the symbol rate up to 50 MSPS (symbol per second). The typical implementation loss is 0.2 dB. The typical system G/T performance is 22.8 dB/K at 8.2 GHz.

The COTS L band receiver, DSP based digital receivers from Quorum is chosen for receiving the L band signal from the EOS series of MetOp and NOAA. The input frequency range is 126 to 154 MHz. The demodulator modes are BPSK, QPSK and PSK. The receiver supports the symbol rate up to 2.7 MSPS. The typical implementation loss is less than 1 dB. The typical system G/T performance is 12.2 dB/K at 1.7 GHz.

Following the acquisition stage, the baseband signal driven from the RF COTS receiver is acquired to generate the bit stream (against the overall noise) by using the bit synchroniser. The received data will be converted in to non-return-to-zero-level (NRZ-L) format. The continuous data stream is divided into a block of data (or frame) by using the frame synchroniser. The raw framed data can be stored in the mass storage which is handled by NAS (Network Attached Storage).

From this stage, the stored raw data will be processed by IMAPP, NASA DAAC and NASA SeaDAS algorithms for producing the various GIS products. The detail of data processing and solution subsystem will be published in next consecutive article.

4. INSTALLATION, TESTING AND RESULTS

The MARS installation commenced in April 2018. The antenna with radom was installed on the roof of 11th floor (63 metre height from mean sea level), D building of MUT, as shown in Fig. 8.

Fig. 8 *MARS's Antenna and Radom Installation*

Fig. 9 *MARS Control Centre*

The antenna setup and fine-tune with positioner took several weeks in order to synchronise with the function of positioner controller unit and true North direction. The satellite tracking function made use of SGP4 (Simplified General Perturbations) orbit propagator to provide the tracking information for each satellite pass. The propagator used the two-line mean element (TLE) sets which is generally provided by the Celestrak. The tracking information given by SGP4 was analysed to find the optimised tracking solution in which to minimise acceleration and velocity for all 3 axes. The standard azimuth/elevation model was performed when the elevation tracking angle below 45 degrees. The system switched to 3-axis tracking at higher elevation. This technique ensured that the acceleration and velocity should not exceed the limitation for LEO satellites.

The functional testing of antenna and acquisition subsystems was testing and fine-tuning in September – October 2018. The first preliminary signal tracking from NOAA-19 satellite was successfully on 29 October 2018, as shown in Fig. 10. And the first satellite image produced by MARS was directly broadcasted from NOAA-19 on 1 November 2018, as shown in Fig. 11.

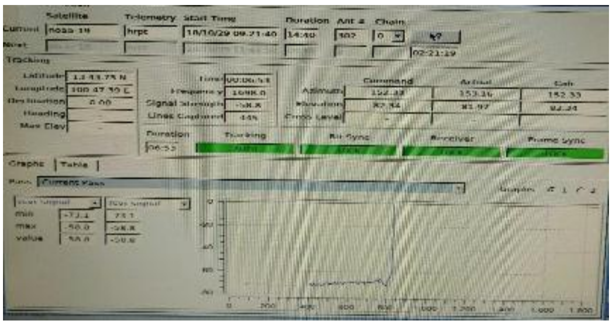


Fig. 10 *First Preliminary Tracking from NOAA-19*

Fig. 11 *Frist Satellite Image produced by MARS*

During the first week of January 2019, many countries in the Southeast Asia faced with the tropical Typhoon Pabuk. The MARS played the academic role and made the contribution to Thai Society by producing the daily monitoring of the Pabuk through the Mahanakorn Facebook. The Pabuk formed over the southern of the South China Sea on 28 December 2018. It intensified and accelerated west-northwestward and entered the Gulf of Thailand on 3 January 2019, and made landfall the southern of Thailand on 4 January 2019. The Pabuk monitoring by NOAA-19 was shown in Fig. 12.

3 Jan 2019 4 Jan 2019

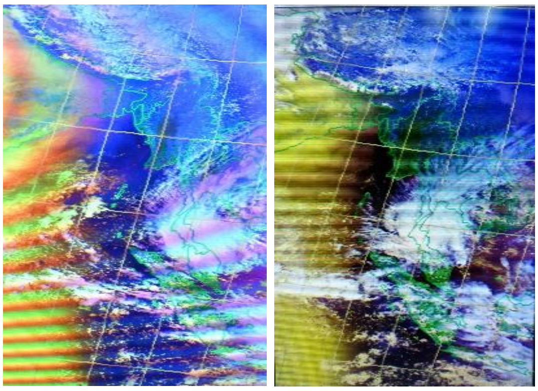
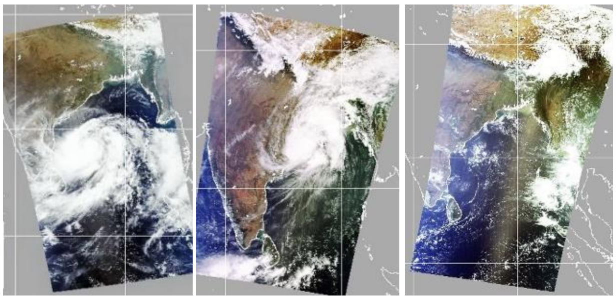


Fig. 12 *Typhoon Pabuk Monitoring by NOAA-19*

Another disaster monitoring was the cyclone Fani. The Fani originated from a tropical depression that formed west of Sumatra on 26 April 2019. It rapidly developed and intensified into a cyclone on 30 April 2019. It moved along the East coast of INDIA on 1 May 2019. It made a landfall in the state of Odisha in eastern India on 3 May 2019. Fani continued to weaken after landfall, and eventually became a deep depression and moved into Bangladesh on 4 May 2019. The cyclone Fani monitoring by Aqua and Terra satellites was shown in Figure 13. And the daily reporting on Mahanakorn Facbebook was shown in Figure 14.



30 April 2019	3 May 2019	7 May 2019
07.36 UTC by Aqua	05.04 UTC by Terra	04.38 UTC by Terra

Fig. 13 *Cyclone Fani Monitoring*

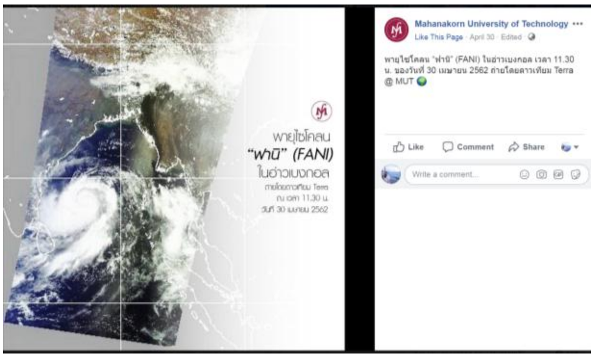


Fig. 14 *MUT reports the Cyclone Fani on Facebook*

5. CONCLUSIONS

This paper presented the participation of Mahanakorn University of Technology (MUT) in space program since 1996. The collaboration between MUT and GISTDA for mutual research in space program commenced in 2014, and led to setup the Mahanakorn sAtellite Receiving Station (MARS). The requirement information for setting up MARS which commenced from the wide area downstream applications and backward to sensors onboard satellites, available direct broadcast missions, and communication link for earth station were introduced. The architecture of MARS, particularly the detail of antenna and acquisition subsystems was described. The subsystem integration based on the COTS module and devices were briefly overviewed. The installation and testing was performed and led to the preliminary results in satellite signal tracking and satellite image production from NOAA-19, Aqua and Terra. The MARS made contribution in reporting Typhoon Pabuk and Cyclone Fani through the Mahanakorn Facebook.

6. ON GOING WORK

MUT plans to continue the research and development on satellite receiving station and image processing. The system of C band communication for receiving the geostationary meteorological-satellite will be installed by end of 2019. For the research area on image processing, the substantial data of PM2.5 and hot spot over Thailand and nearby countries will be produced and provided to the public.

7. ACKNOWLEDGEMENT

The authors would like to thank MUT research staff, Mr. Aniwat Plodpai and Mr. Shariff Manuthasna from their hard work contributions in setting up and testing the satellite receiving station. In addition, MUT would like to thank GISTDA and GISTDA staff for their fully support and advices.

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