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Measuring Contention and Congestion on Ad-Hoc Multicast Network Towards Satellite on Ka-Band and LiFi Communication Under Tropical Environment Region

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ABSTRACT Diversified interest in the low-cost broadband satellite has overgrown to support a wide range of services in the satellite network. There is a need to explore alternative parts of optical communication towards Light Fidelity (LiFi) to offload the overcrowded radio frequency segments and improve the overall throughput. Ad hoc networks are the most suitable solution to provide a non-trivial challenge towards system design due to efficiency and quality of service (QoS). Both contention and congestion issues can severely affect the performance of a multicast network where video streaming becomes part of the day-to-day life. In this paper, we present network congestion characterization related to LiFi and High Throughput Satellite (HTS) under the Ka-band modulation schemes during adverse weather conditions in the tropical region. The heterogeneous network performance presented in this paper comprehensively provides systematic information for Satellite communication (SatCom) & LiFi and optimization of throughput by reducing network contention ratio. The measurement results have shown that when Deep Packet Inspection (DPI) policy is applied, an improvement of 80.26% in the packet delivery ratio is achieved as compared when without a DPI policy. However, using an on-premise Software-defined-wide access network (SD-WAN) alone provides 58.20% improvement in the overall network system. As a result, DPI provides a well managed QoS approach to manage the entire hybrid network, mainly in the tropical environment region.

INDEX TERMS Contention ratio, QoS, DPI, SD-WAN, LiFi, HTS, Ka-band satellite communication.

I. INTRODUCTION

The consistent improvement of broadband internet network alongside the continuous advances in voice and video has brought eagerness up in interactive multimedia services. Analysis survey has revealed that the demand for data communication will be higher than standard telephone services where cloud IoT will undoubtedly accelerate [1]. Demand on multimedia services for mobile users has shifted from fixed or on the pause legacy users to the On-The-Move (OTM) access. Continuity of global coverage service with adequate QoS raises severe problems in some instances to find cost-effective through an appropriate satellite constellation [2].

Satellite signal strength is reduced under severe rain conditions. Moreover, signal strength tends to decay at a faster pace when being operated under Ka-band frequency [3].

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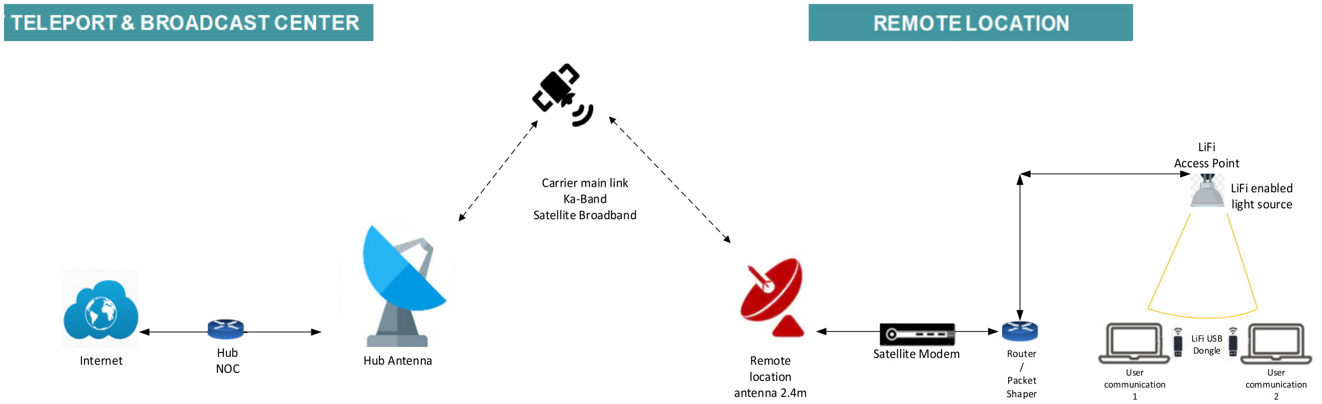


FIGURE 1. Heterogeneous network connectivity.

Maintaining the bandwidths and small jitter within the defined spectrum range faces a variety of technical challenges.

The unprecedented growth of social media or apps requires data to be at a breakneck speed. With multicast communication under video streaming technology, through all its advantages, gives a difference between traditional broadcast and unicast network. Newly coined LiFi optical communication technology offers high data rates of 3-4Gbps under the 2-dimensional optical beam-steering [4].

Compatibility on the integration towards the bent-pipe satellite and LiFi communication opposed challenges due to the mixture of heterogeneous access points. The conventional way of network management is rather manual than flexible automatic control [5]. Last-mile client device access requires a solution to switched out dynamically between different resolution, bitrate, and framerates depending on satellite bandwidth availability [3], [4].

Focusing on these two hybrid network communication architectures, the study is made under the rainy and clear sky conditions to determine the network utilization and contention ratio. This study also aims to provide pre-empts enhancement on overall throughput performance in a tropical region by analyzing the rainfall effect. The real-time data trending for two subsequent months was captured during the clear sky and rainy day to further analyse the performance of both RF and LiFi network. In order to simplify the calculation and the concept in this paper, the data on February 14th, 2020, has been selected and analysed further for the paper. This was due to the recorded high duration of rainfall within the analysed area [6].

The main contribution of this paper can be summarized as follow:

- The combination of hybrid broadband over satellite via Ka-band & LiFi system is to provide benchmark connectivity under the tropical region with various weather conditions and different scenarios (e.g. rainy) where such information is currently limited.
- The meteorological impairments is a serious problem in satellite communication, mainly in a tropical region, which is generally described by heavy rainfall, especially at a high frequency. For this reason, the paper investigates the entire heterogeneous network connectivity and throughput performance improvement, which has driven the adoption of network management tools.
- At present, the available network solution is mainly focused on the leased line, fiber or direct broadband internet access. An evaluation system demonstrates the feasibility of the proposed methods with real free-space broadband network access.

II. SYSTEM DESCRIPTION

The need for using satellite links is mainly due to geographical landmarks where the mountainous core dominates it. The same scenario could be observed in most of the tropical regions where the satellite link is still relevant. This provides advantages over fiber or microwave communication apart of overcrowded on existing frequency usage where the HTS Ka-Band approach is used. In the design, the illustration from a hybrid SatCom and LiFi networking testbed is presented in Figure 1 and Figure 2.

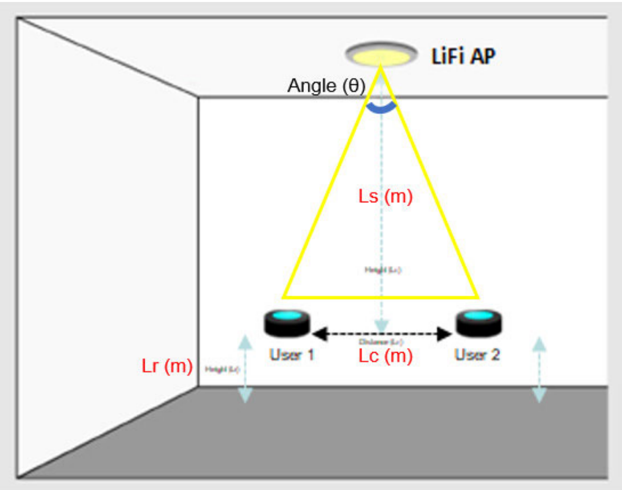


FIGURE 2. The architecture of LiFi system for the measurement scenario.

TABLE 1. Characteristics of heterogeneous systems setup.

Component/ Subsystem	Characteristics
HUB NOC	A gateway which provides internet connection to the subscriber terminal.
HUB Antenna and remote location antenna	Physical components installed to access the broadband which receives/sends data from/to satellite.
Satellite modem	A modulator and demodulator contained in the same unit to convert digital data into analogue signals typically at IF or L-band
Router/Packet Shaper	Optimize network performance under policy-based control to prioritize every on-prime IP flow via DPI or SD-WAN technology.
LiFi access point	Converting the IP network information to bits and vice versa.
User terminal	Small piece of hardware that allows user secure connection to the internet. The dongle is also used to send information back to LiFi AP.

The characteristic of the heterogeneous component and the detailed functions are summarised in Table 1. LiFi product uses a lighting network as an indoor wireless communication network by replacing of other legacy methods.

The LED light act as an optical access point (AP), which serves user access to a multicast network within the illumination area/cell. The return channel is also light-based but uses a smaller bandwidth compared to the inbound traffic to the remote location.

The Commercial Off The Shelf (COTS) white LED USB dongle has been selected for the research works where the data throughput is up to 100Mbps with an optical power of 3W. RGB (Red Green Blue) LED could potentially show more excellent performance up to 12.5Gbps [7] although high fabrication cost and poor color rendering index (CRI) could potentially not suitable for the research demonstration works [8], [9]. Indeed, medium-size room and usage of warm white (2000K) LED light on other parts of the room area to ensure no co-channel interference [4], [10]. Moreover, throughput was measured with two user equipment (UE) to ensure concurrent multicast data are to be captured during the clear sky and rainy day.

Enhanced network management is necessary to support internet access under the hybrid network. This is due to the geographical condition of the remote location, which is solely relying on such a hybrid system to stay connected. In other words, differentiated and customized service provisioning for clients is highly required in order to maintain the connection with hybrid network.

Efficient load balancing in such a hybrid network is one of the main issues in addressing network congestion problems [11], [12]. SD-WAN is a software-defined approach to manage the WAN network, whereas the DPI to streamline the flow of network traffic at user client [13]. The use of packet shaper with Deep Packet Inspection (DPI) technology could offer an advantage in limiting the congestion in a network line more rapidly by competing with SD-WAN at the centralized location [14]. By this, the analysis can be made in comparing the effectiveness of network management with high throughput satellite data during limited bandwidth

III. MEASUREMENT AND INVESTIGATION

The performance is assessed by measuring at different weather conditions, mainly during the clear sky and rainfall for each UE during inbound and outbound of multicast requests.

Two different locations are selected for the study, which is Bukit Jalil and Cyberjaya, due to the availability of the piezoelectric detector to precisely measure the raindrop and the attenuation. The locations are approximately 20km apart, which provides better HTS frequency planning under the beam spot capacity. Two months of attenuation trending data were captured and analysed at two different locations, mainly Bukit Jalil (Figure 3) and Cyberjaya (Figure 4) [6]. Based on the rain data obtained, on February, 14^{th}2020, Bukit Jalil provides the highest and longest duration of the rain rate as compared with other rainy days and locations at Cyberjaya. This provides better analysis data for both hybrid RF and LiFi network.

The main carrier parameters described above on the heterogeneous network connectivity are shown in Table 2 for the Satellite system parameter and Table 4 for the LiFi system parameter. The measured inbound & outbound traffic is also summarized in Table 5 and Table 6.

The measured data tabulated in Table 4 are referring to the setup and scenario from Figure 2. Changes in the distance between AP and UE reference to the height and angle are recorded and summarized accordingly in Table 4. In order to limit the scope of the paper, the LiFi communication measurement is limited to three different steps and scenarios, as outlined in Table 3. Measurement Scenarios mainly focuses on the geometry angle of the LiFi AP, and the Steps are the movement of UE from the centre point. In LiFi networks, the channel variation is mainly due to the UE axis movement and/or rotation [13], [14]. Each variance in the scenario and steps are measured with the throughput using the user client terminal with the iPerf command.

The signal quality of different scenarios and steps of LiFi network is analysed in terms of a parameter, as described in Table 3. One of the essential issues in the LiFi signal is how much optical output power is required by both AP and the UE to transmit a signal with absolute strength without distortion [15], [16]. The different combinations of LiFi characteristics provide the strongest signal lead to three main setup parameters for analysis.

P_2P (Peer-to-Peer), IM (Instant Messaging), web streaming application, including Youtube and RTMP, has been selected to emulate into the UE terminal. Continuous trending of the throughput measurement was captured where the

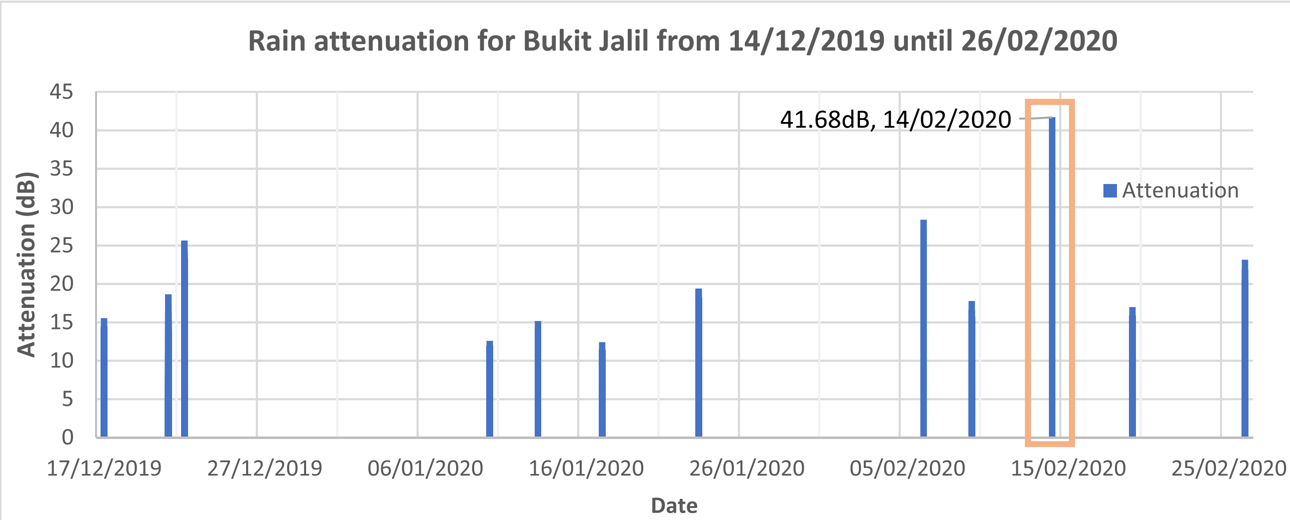


FIGURE 3. Recorded attenuation data from an onsite tracking receiver at Bukit Jalil [6].

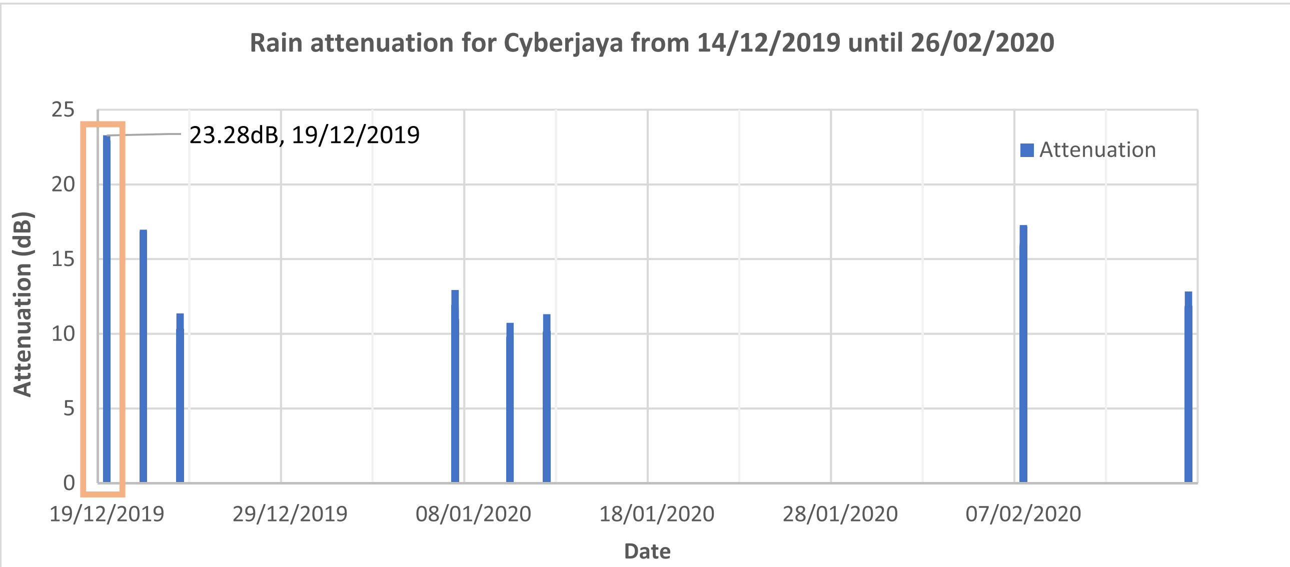


FIGURE 4. Recorded attenuation data from an onsite tracking receiver at Cyberjaya [6].

bandwidth capacity is critical for system performance metric analysis [17], [18].

A DPI and SD-WAN application periodically monitors or estimates the bandwidth usage by each UE terminal. A measure is taken to reduce the access bandwidth usage rate to value or lower than carrier link bandwidth.

DPI and SD-WAN technology detects the load content of the IP packet during network interaction or data transmission and determines the type of application. P_2P file-sharing, or other standard protocol for transferring large files, provides temporary disallowed protocol during lowest modulation and coding, thus improving the overall rate of network traffic during high attenuation [19].

As compared to Table 5 and 6, the DPI-based method has significantly improved the network connection and users experience during lower MODCOD (Table 7) with a target of 1Mbps per user. A simple SD-WAN will not be able to provide well advance network orchestration as compared with DPI based on the analysed data [17]. With DPI, it provides better, well-managed network and bandwidth performance, which continuously performs more advanced inspections to the packet as resulted in Table 5 and 6.

Besides that, based on the received signal, the maximum BER measured is 5×10^{-7} before pixelization to be observed on the Youtube and RTMP video streaming.

TABLE 2. Connection status and terminal parameter.

Remote Location	Forward (Download)		Satellite Receive Signal SNR: 13.5 dB
	Return (Upload)		Satellite Receive Signal Strength: 74%
Carrier: 3dB OBO (Output Back-Off)			
Remote receive SNR during clear sky	13.5 dB		
MODCOD utilized (MAX)	16-APSK Rate 8/9		
Expected total throughput on a 21MHz carrier	46Mbps		
Measurement Sites	**Bukit Jalil (Remote Site)**	**Cyberjaya (Remote Site)**	**Cyberjaya (Hub Antenna)**
Earth Station Location	3.0587° N 101.6917° E	2.9348° N 101.6590° E	2.9348° N 101.6590° E
TX Frequency RX Frequency	27.46GHz (H-pol) 20.02 GHz (V-pol)	29.46GHz (H-pol) 20.02 GHz (V-pol)	20.02GHz (V-pol) 27.46 & 29.46 GHz (H-pol)
Satellite	iPStar-1 (119.5° E)		
Antenna Elevation	68.8°		
Antenna Diameter	2.4m		7.2m
BUC for RTN | Transmitted HPA size and UPC for FWD	BUC = 2.98 W		HPA= 42.33 W, UPC= 5 dB
Availability of the month	99.0%	99.1%	99.80%

TABLE 3. Characteristics of LiFi setup.

Parameter	Description
Angle (θ)	The maximum strength of the incident angle to a receiving element, UE.
Ls (m)	The distance between the receiving UE and LiFi AP.
Lr (m)	The height of the UE with the room floor.
Lc (m)	The distance between two receiving UE.

TABLE 4. Line of sight analysis and the propagation channel simulation.

Scenario	Parameter	Angle (θ)	Ls (m)	Lr (m)	Lc (m)	User throughput (Mbps)	
						Clear Sky	Rainy
1	Setup 1	40°	1.0	0.65	1.0	36.82	5.31
	Setup 2		2.0	0.65	1.0	22.41	4.22
	Setup 3		3.0	0.65	1.0	14.01	2.01
2	Setup 1	60°	1.0	0.85	1.0	33.36	4.99
	Setup 2		2.0	0.85	1.0	29.56	4.03
	Setup 3		3.0	0.85	1.0	11.78	1.07
3	Setup 1	90°	1.0	0.95	1.0	25.36	3.69
	Setup 2		2.0	0.95	1.0	11.56	1.23
	Setup 3		3.0	0.95	1.0	1.78	0.36

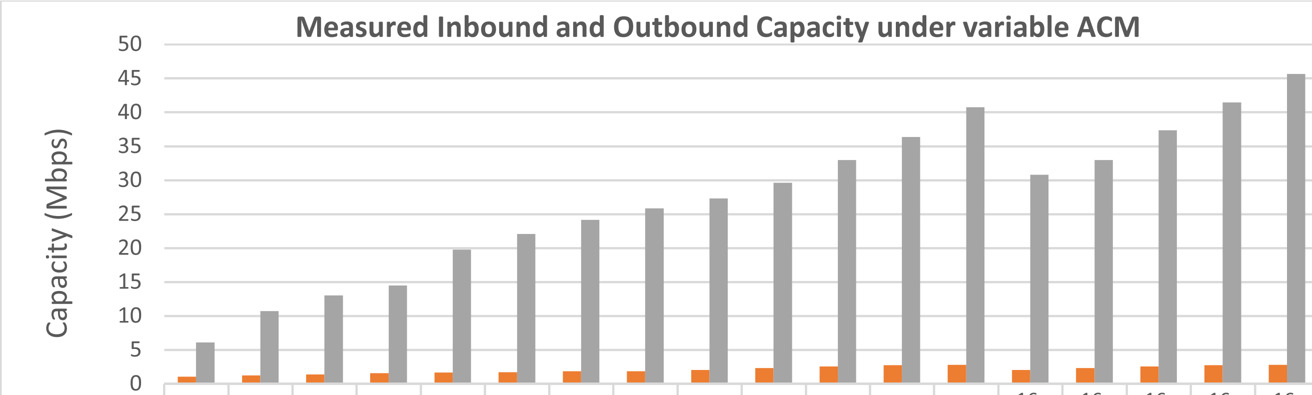
The connection from the remote location to the HUB are continuously traced using the tracert and pathping command to ensure there are no changes on the WAN routing during measurement [20]. The packet drop and the delay are further measured and recorded using the client-server iPerf command to further analyse the behaviour of the network mainly during the higher rain attenuation [21].

TABLE 5. Traffic identification result on with and without DPI algorithm.

16-APSK Rate 8/9, LiFi Scenario 1 (Setup 3)		
Protocol	**Traffic Bandwidth utilization rate**	
	With DPI (Mbps)	**Without DPI (Mbps)**
BitTorrent (P2P)	14.41	32.41
WWW	1.02	0.23
IM (Whatsapp)	0.03	0.01
Youtube	5.25	3.25
RTMP	19.27	4.33
QPSK Rate 1/4, LiFi Scenario 1 (Setup 3)		
Protocol	**Traffic Bandwidth utilization rate**	
	With DPI (Mbps)	**Without DPI (Mbps)**
BitTorrent (P2P)	-	4.03
WWW	0.71	0.01
IM (Whatsapp)	0.02	0.02
Youtube	1.72	0.37
RTMP	2.41	0.26

IV. RESULT AND DISCUSSION

The network traffic has been analysed and captured using the packet shaper monitoring tools, as presented in Figure 6. Besides that, the Carrier Monitoring System (CMS) has been enabled to cross-compare the C/N of the received signal (Figure 7). With this, the performance of the ACM can be substantiated during environment condition changes (from clear sky to rainy day). Each fluctuates in the attenuation (Figure 8 and 9), optimise the link modulation and impact the total bandwidth, including the capacity of a received signal. The recorded rain data are further analysed and plotted using complementary cumulative distribution function (CCDF) to



	QPSK Rate 1/4	QPSK Rate 1/3	QPSK Rate 2/5	QPSK Rate 1/2	QPSK Rate 3/5	QPSK Rate 2/3	QPSK Rate 3/4	QPSK Rate 4/5	QPSK Rate 5/6	8PSK Rate 3/5	8PSK Rate 2/3	8PSK Rate 3/4	8PSK Rate 5/6	16-APSK Rate 2/3	16-APSK Rate 3/4	16-APSK Rate 4/5	16-APSK Rate 5/6	16-APSK Rate 8/9
Outbound	1.0240	1.2288	1.3653	1.5360	1.6384	1.7067	1.8204	1.8432	2.0480	2.3040	2.5600	2.7307	2.7648	2.048	2.304	2.56	2.7307	2.7648
Inbound	6.0900	10.710	13.020	14.490	19.740	22.050	24.150	25.830	27.300	29.610	32.970	36.330	40.740	30.791	32.97	37.339	41.439	45.612

FIGURE 5. Measured capacity under variable ACM on Feb, 14th 2020 at Bukit Jalil.

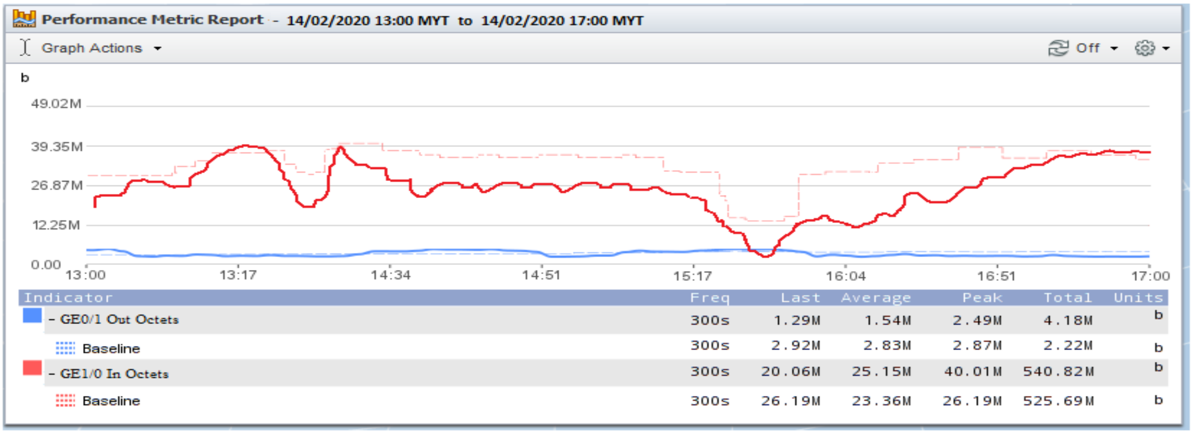


FIGURE 6. Utilization recorded on February, 14th 2020 at Bukit Jalil for both Inbound (Red) and Outbound (Blue).

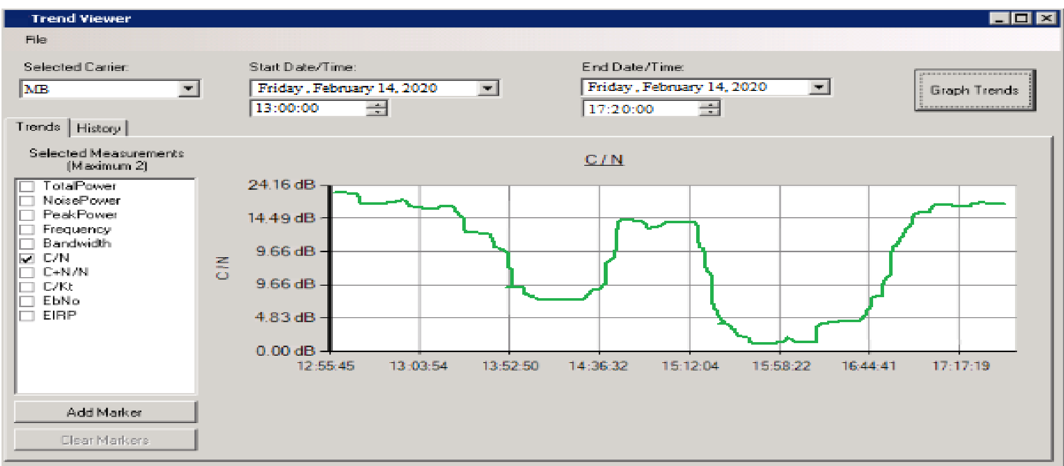


FIGURE 7. Carrier to Noise (C/N) recorded on Feb, 14th 2020 at Bukit Jalil.

identify the rain rate at $R_{0.01}$% of the time, which provides the duration of unavailability of RF link for the necessity in implementing a gap-fillers network [6]. During the higher modulation and code rate, the bandwidth is able to boost up to 45Mbps and $\leq$ 6Mbps during lower code rate and modulation.

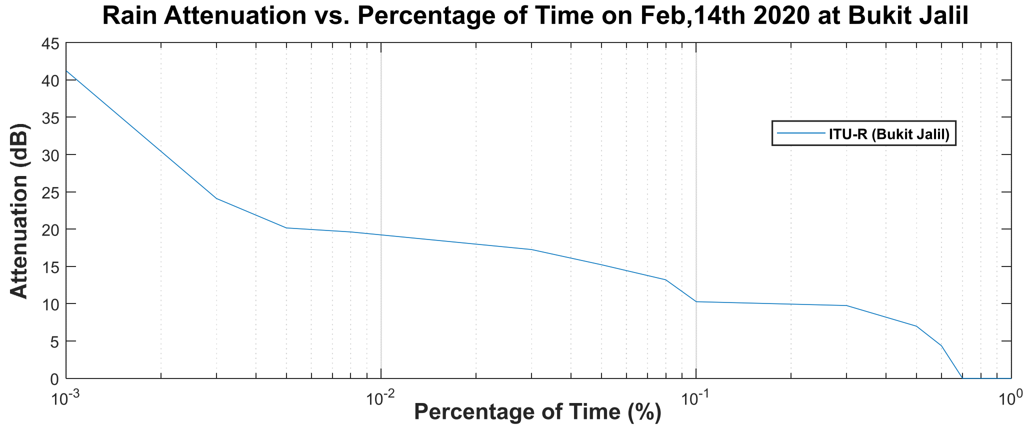


FIGURE 8. Cumulative distribution of rain intensity measured at Bukit Jalil.

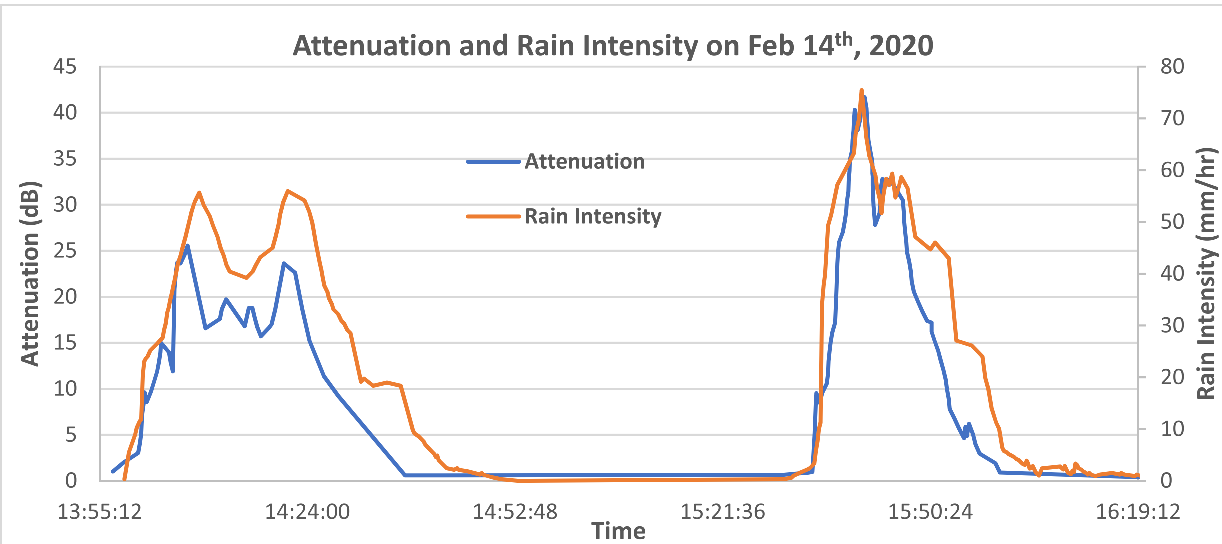


FIGURE 9. Display of attenuation and rain intensity data recorded. Rain intensity is collected using an onsite weather station using a piezoelectric detector.

TABLE 6. Traffic identification result on with and without SD-WAN algorithm.

16-APSK Rate 8/9, LiFi Scenario 1 (Setup 3)		
Protocol	Traffic Bandwidth utilization rate	
	With SD-WAN (Mbps)	Without SD-WAN (Mbps)
BitTorrent (P_2P)	27.22	32.41
WWW	1.72	0.23
IM (Whatsapp)	0.11	0.01
Youtube	7.19	3.25
RTMP	7.31	4.33
QPSK Rate 1/4, LiFi Scenario 1 (Setup 3)		
Protocol	Traffic Bandwidth utilization rate	
	With SD-WAN (Mbps)	Without SD-WAN (Mbps)
BitTorrent (P_2P)	2.03	4.03
WWW	0.71	0.01
IM (Whatsapp)	0.02	0.02
Youtube	1.72	0.37
RTMP	1.41	0.26

To provide a well-managed bandwidth optimisation for a hybrid network, a data processing application has been implemented to segregate the service and user application. During the rainy day, the DPI or SD-WAN act to deny P_2P application to ensure the Real-Time Messaging Protocol multicast has sufficient bandwidth. Implementation of the DPI or SD-WAN data processing application could potentially reduce multiple retransmission channels, which reduces receiver processing costs.

The key implementation issue is how to efficiently manage the multiple channels or users under the satellite and LiFi hybrid network. With DPI implemented, more effective network management packet filtering applies, in which such actions are not available on the SD-WAN application. (i.e protected zip file is still able to be shared under the SD-WAN policy. However, DPI denies the file-sharing during limited bandwidth without additional advance policy).

Network contention measured to be 30:1 and 55:1 during the clear sky and rainy day, respectively [22]. We considered two different implementation options, one using existing ACM modulation mechanisms and the other using additional DPI or SD-WAN router support for selective packet forwarding [23]. The proposed congestion control and data obtained

TABLE 7. Measured Inbound and Outbound of network traffic under ACM at a remote location on Feb, 14th 2020 at Bukit Jalil.

Modulation and Coding			Received Signal Level at Remote Location		Outbound network traffic from the remote location		Inbound network traffic to the remote location	
Modulation and Coding	Modulation	Coding	Eb/No Measured (dB)	C/N Measured (dB)	Carrier BW (MHz)	Capacity (Mbps)	Carrier BW (MHz)	Capacity (Mbps)
QPSK Rate 1/4	QPSK	1/4	2.80	0.70	1.28	1.0240	18	6.0900
QPSK Rate 1/3	QPSK	1/3	2.40	0.70	1.28	1.2288	18	10.7100
QPSK Rate 2/5	QPSK	2/5	2.40	0.10	1.28	1.3653	18	13.0200
QPSK Rate 1/2	QPSK	1/2	2.80	1.00	1.28	1.5360	18	14.4900
QPSK Rate 3/5	QPSK	3/5	2.80	2.50	1.28	1.6384	18	19.7400
QPSK Rate 2/3	QPSK	2/3	2.90	3.30	1.28	1.7067	18	22.0500
QPSK Rate 3/4	QPSK	3/4	2.90	4.30	1.28	1.8204	18	24.1500
QPSK Rate 4/5	QPSK	4/5	3.20	4.90	1.28	1.8432	18	25.8300
QPSK Rate 5/6	QPSK	5/6	3.60	5.50	1.28	2.0480	18	27.3000
8PSK Rate 3/5	8-PSK	3/5	4.00	6.30	1.28	2.3040	18	29.6100
8PSK Rate 2/3	8-PSK	2/3	4.70	7.40	1.28	2.5600	18	32.9700
8PSK Rate 3/4	8-PSK	3/4	5.30	8.50	1.28	2.7307	18	36.3300
8PSK Rate 5/6	8-PSK	5/6	5.90	9.60	1.28	2.7648	18	40.7400
16-APSK Rate 2/3	16-PSK	2/3	7.30	10.00	1.28	2.0480	18	30.7911
16-APSK Rate 3/4	16-PSK	3/4	7.70	10.92	1.28	2.3040	18	32.9700
16-APSK Rate 4/5	16-PSK	4/5	8.20	11.72	1.28	2.5600	18	37.3388
16-APSK Rate 5/6	16-PSK	5/6	8.60	12.40	1.28	2.7307	18	41.4390
16-APSK Rate 8/9	16-PSK	8/9	8.93	13.22	1.28	2.7648	18	45.6122

provides a basic conception behind adaptive transmission in the tropical region for High Throughput Satellite (HTS) with Ka-band frequency.

V. CONCLUSION AND FUTURE WORKS

This study will provide useful information for researchers by understanding and considering the rain attenuation predictions in the hybrid communication network, mainly in the tropical region, where such information is limited. The measurement was thus performed by varying the RF modulation and LiFi performance to ensure maximum data rate of 6Mbps at a BER value of 5×10^{-7}. This paper would potentially provide comprehensive information to support future technology development for both Ka-band and LiFi network, including with Fade Mitigation Technique (FMT). Besides that, the enhancement in the ACM and DPI will potentially provide us with the idea of how to manage the network performance during peak hours based upon which the prioritization should be done.

The comprehensive and well-planned network may introduce more network management components at two different layers, namely; (i) at the edge where the internet gateway endpoints reside and, (ii) the orchestrator/controller to set the policy. This management component provides an ideal end-to-end network connection control over free-space communication. However, such implementation will be very costly to meet the desired need for the system network. As the proposed method, the overall architecture can also be best suits under the OTM (On-The-Move) application such as long-distance rail where more performance degradation in channel fading is expected, and advanced level of management is required [26].

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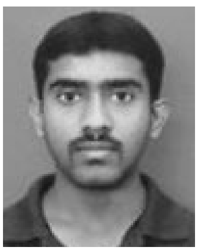

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