IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received April 21, 2021, accepted April 26, 2021, date of publication April 29, 2021, date of current version May 19, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3076484

On-The-Move Measurement Analysis for Ka-Band High Throughput Satellite and LiFi Communication Networks in Tropical Region

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This work was supported by the EMOSEN—Energy Efficient MIMO-Based Wireless Transmission (SWIPT—Enabled Network) for technical and resource support with signed mutual non-disclosure agreement (NDA) with ERL under Grant UPM/800-3/3/1/GPB/2019/9671600.

ABSTRACT With the point in evaluating the performance of the On-the-Move (OTM) Satellite Communication and Light Fidelity (SatCom-LiFi), an extensive study of measurement has been conducted to give a wide vision of the SatCom-LiFi potential under a tropical region. As the interest for OTM network connectivity to offload the C-band capacity arises due to frequency spectrum scarcity, satellite networks offer to balance topographical requirements under tropical environment as the Next Generation Networks (NGN) trend for OTM communication system solutions. To date, mobile satellite terminal propagation model was carried out at temperate regions where further experimental measurement is needed under the OTM scenario in tropical region. This paper discusses on the areas where there are limited real-time data under the OTM scenario (e.g. rain attenuation, power arch) at Ka-band frequency. Integration infers, to be specific, the use of new elements capable in providing performance analysis of all systems involved and to take possible decision, in determining the need for a technically feasible solution. Measurement results reveal that, throughput data rate of 15 Mbps were able to be delivered for more than 80% of the time under the speed of 150 km/h with shielded mesh antenna. In addition to that, this paper reveals the favorable circumstances and inadequacies of OTM network quality, in which the measurement presented plays an important role for future researchers in distinguishing highly accurate predictions.

INDEX TERMS OTM, HTS, SatCom-LiFi, Ka-band satellite communication.

I. INTRODUCTION

It is imperative to comment that these days where SatCom-LiFi does not fulfill the full set of solution/technology criteria under tropical region. With the demand of anticipated broadband access capacity, big data and stringent requirement for OTM application shall be established [1], [2]. Focusing on these two heterogeneous network communication architectures, more challenging criteria fall under the high-speed rail (HSR) communication solution. High Throughput Satellite (HTS) solutions become technically feasible for last mile client device to handshake with the throughput between SatCom and LiFi network. Latest invented optical LiFi communication technology offers high data rate (3 $\sim$ 4Gbps) for commercial communication application [3].

Concentrating on these hybrid network communication design, technical feasibility investigation is made under the

The associate editor coordinating the review of this manuscript and approving it for publication was Shah Nawaz Burokur.

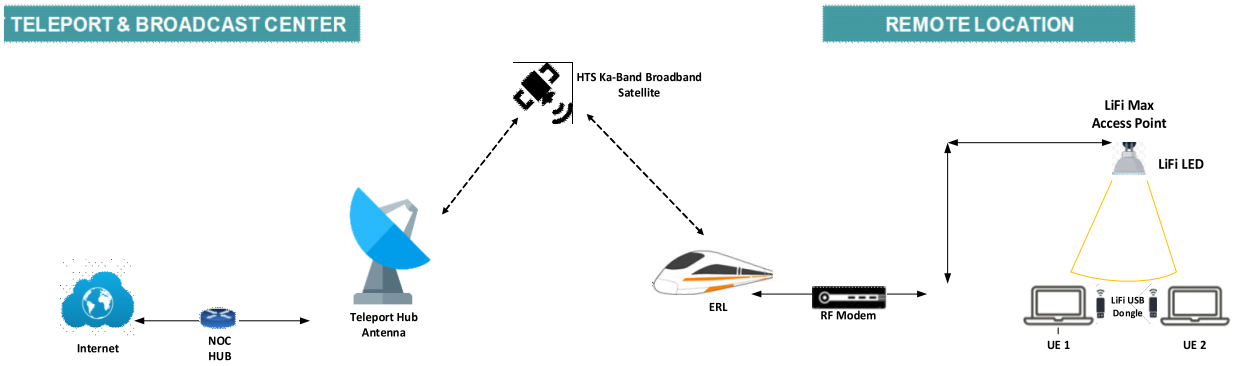


FIGURE 1. Heterogeneous apparatus network connectivity.

clear sky and rainy conditions including measurement of physical constraints (e.g power arch) to determine the network performance, parameter utilization data rate, packet loss and latency [2]–[4].

The primary contribution of the paper can be outlined as follows:

- Measurement analysis of network performance are being carried out in order to improve the network utilization. For the purpose of facilitating the network throughput analysis in tropical region. Under the OTM performance, a heterogeneous hybrid network broadband over HTS via Ka-band and LiFi system are being analysed and validated. To the best of our knowledge, OTM analysis measurement under tropical region are currently limited and to fill this gap, this paper focuses real time measurement and analysis.
- Reference towards SatCom-LiFi network broadband service under the tropical area with various weather conditions and varying scenarios (e.g. clear sky, rainy, power arch and etc.). Several historical attempts (Tropical-Land Mobile Satellite Channel) [5] were presented under Ku-band application to provide complete solution architecture in improving the overall link availability under tropical region [6]–[8].
- Measurement of the actual network response time (network latency and packet loss) for a broadband activity that require minimal delay such as fast paced online-gaming under the OTM system [9].
- Faster implementation of HTS application compared with complex terrestrial network under tropical geographical infrastructure is worth to be analysed (under limited terrestrial coverage area) [10].

Most of the available research paper focuses on a specific channel model (i.e Markov-chain based model) due to absence of direct measurements [5]. For these reasons, the research paper presented real-time measurement analysis campaign to estimate the link performance under the tropical rail condition. The highlight of this paper is to technically evaluate real-time SatCom-LiFi network and its requirement. The future OTM communication architecture is understood to be tailor made with respect to the driver's critical communication system.

TABLE 1. System setup characteristic.

Subsystem/ Subsystem/ Element	Denotation
NOC HUB	A ISP gateway that handle internet access to the subscriber remote terminal.
Teleport HUB Antenna	RF Interface to access the broadband via radio waves which sends/receives data to/from satellite.
Phase array antenna	Electronically steered to point to the satellite.
GPS antenna	Receive signal for location, velocity and time synchronizer.
SPG	Provides 10MHz reference to RF modem as alternate to outbound satellite carrier
RF modem	A MODEM (MODulator and DEModulator) embeded within the same devices. Hardware that converting digital data into analogue signals typically at IF/L-band
DPI-WAN	Streamline network capacity under Deep packet inspection (DPI) with policy-based technology.
LiFi Max access point & LED	Translating IP network to bits information and vice versa.
User terminal (UE) /USB Dongle	The dongle permits user with secure connection to the internet and moreover used to deliver information backwards to LiFi AP.
Server	To measure the effectiveness of LiFi AP and dongle position before activating the RF transponder

II. SYSTEM DESCRIPTION

The end-to-end high-level architecture (Figure 1) and the system setup hardware component with complete function are summarized in Table 1. The typical block diagram of the RF component and On-the-Shelf (OTS) LiFi access point (AP) and dongle (LiFiMax®) are shown as per Figure 2 and Figure 3 respectively.

In downlink chain, the RF Ka-band signal modulates at different code rate and received via the array antenna on-top of the rail. The signal is then converted to the intermediate frequency L-band before feeding into the RF modem which then connected to the router with built in deep packet inspection-wide access network (DPI-WAN) software [11], [12]. The network is connected to the LiFi AP with the power over ethernet (PoE) enabled to support power to the LiFi LED [13]. The information bit is then securely established and delivered to the user terminal dongle for active network access.

The duplex communication via HTS, takes reverse part to reach the satellite at different Ka-band frequency,

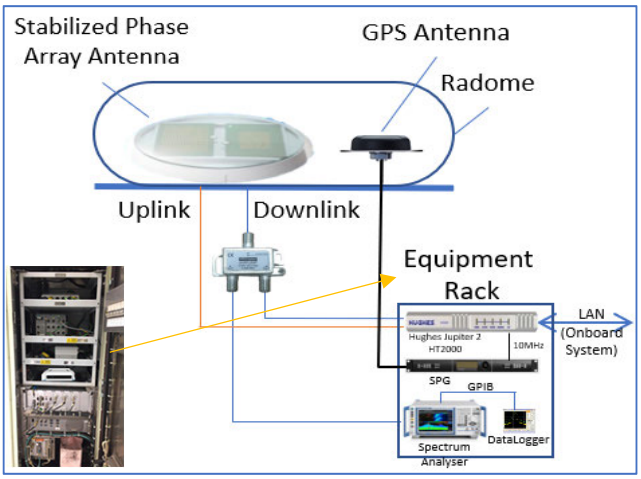


FIGURE 2. SatCom RF connectivity on HSR network.

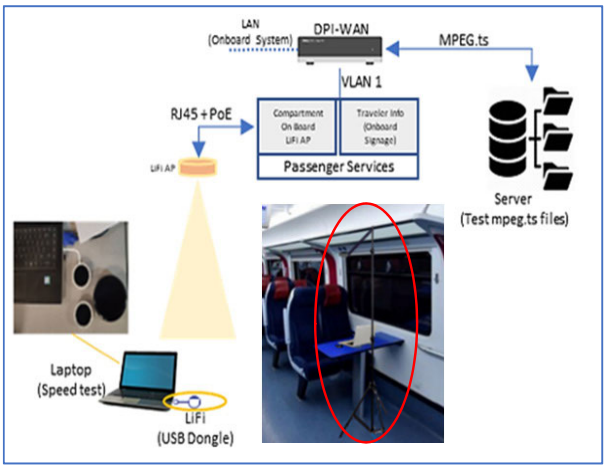


FIGURE 3. Network structure of on-board LiFi network.

polarization and code rate with comparison under the downlink receiving signal. Network signal are then handed over to the teleport to establish secure connection to the internet. Both RF level is implemented in line with link budget calculation to match with real-time results before establishing end to end connection.

III. MEASUREMENT AND INVESTIGATION

The rain data was collected continuously for past two months (Jan and Feb 2020) at Bukit Jalil and Cyberjaya where analysis is nearest to the track sties. The data was obtained from the locally installed piezoelectric detector sensor from the product of Vaisala RAINCAP® sensor technology. For the measurement analysis, array antenna was used and mounted on top of the train. Table 2, represent the antenna and sites specification for the OTM scenario. The downlink chain undergoes several principle functions mainly receiver, filtering, amplification and down conversion which contributed to 2 dB of measured loss.

The minimum mandatory tests with crosspol isolation (CPI) measurement is adequate to guarantee the efficiency deployment of OTM system [6], [14]. CPI minimize

TABLE 2. Antenna, satellite and sites specification.

Measurement Sites		Bukit Jalil	Cyberjaya
Earth Station Location		3.059°N 101.692°E	2.935°N 101.659°E
Beacon Frequency		20.20 GHz (H-pol)	
Satellite		iPStar1 - (119.5°E)	
Antenna Elevation		68.8°	
Antenna Diameter		13.1m	
Antenna, OTM		1.2m	
Ka-band Test Freq.		Tx: 27.46 GHz (V-pol) Rx: 20.02 GHz (H-pol)	
Rain Rate 0.001%	Jan, 2020	137.4 mm/hr	101.2 mm/hr
	Feb, 2020	97.8 mm/hr	86.8 mm/hr

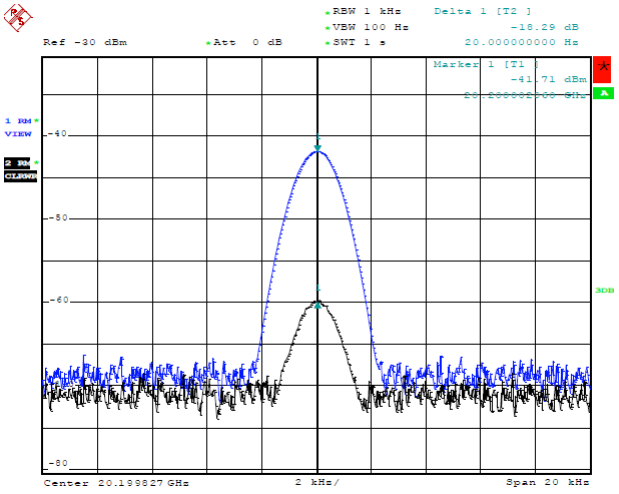


FIGURE 4. Crosspol Isolation measurement of OTM.

interference during uplink by maintaining all potential operational conditions, and to confirm consistence compliance with radio regulations (ITU-R S.580-5) [15]. An extensive set of gain and co-pol measurement have been executed to assess the performance of the array antenna before deploying online. Satellite operator can only approve terminal with lower Cross-Pol Isolation (CPI) values upon conditions of tests results. Based on the CPI measured, $>$ 15 dB isolation achieved, which provide good clearance for transmitting signal (Figure 4) [16], [17].

To benchmark the performance of the array antenna, installation compliance and the beam pointing agility, one-way test (Figure 5) are presented before getting a clearance from both satellite operator and Apparatus Assignment (AA) approval for two-way transmission. The Odin F-50 Forsway modem is connected with receiving downlink from splitter and the 3G/LTE USB dongle as presented in Figure 5.

The sample result for Line of Sight (LoS) situation and clear sky weather condition are captured along the Malaysia Express Rail Link (ERL) route and result of the 3G/LTE are presented in Figure 6 with an average of 0.8Mbps packet sent under the 3G/LTE. Since the track sites are approximately 7 km radius from the analysis area and limited 3G/LTE

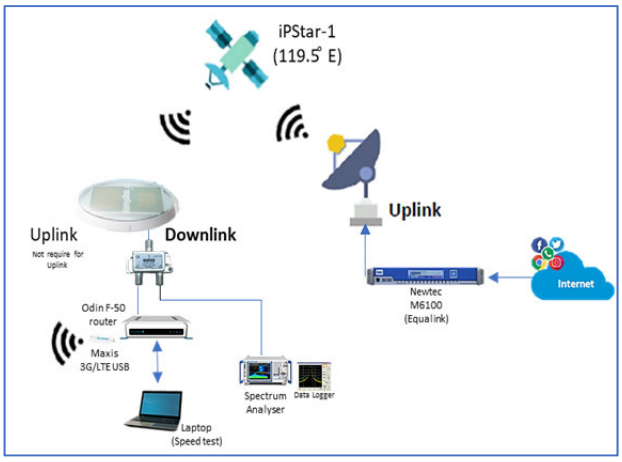


FIGURE 5. One-way connectivity setup.

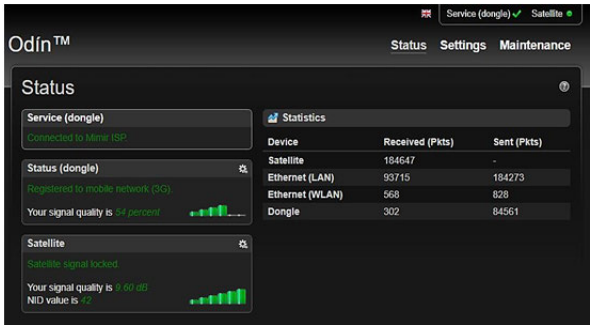


FIGURE 6. Screenshot from modem odin F-50 router webpage.

coverage, the signal strength is recorded as 54%. However, the signal strength is sufficient to verify the antenna pointing agility for one-way test with the result recorded in Table 3.

TABLE 3. One-way connection status.

Measurement	Bukit Jalil	Cyberjaya
Forward (Download)	Ka-band (H-pol) 20.02 GHz	9.6 dB, QPSK 5/6
Return (Upload)	3G/LTE	54%

TABLE 4. Throughput test connection status.

Measurement	C/N	Throughput	PING
With Equalink	9.6 dB	DL:29.97Mbps UL:1.31Mbps	329 ms
Without Equalink	7.1 dB	DL:18.57Mbps UL:1.88Mbps	329 ms

To increase the forward link data throughput, Newtec M6100 modulator with Equalink® linear and non-liner pre-distortion technology were added by the operator [18]. Extra 2 dB link margin has been achieved which improve the overall coverage and increase the symbol rate with lower roll-off factor as result presented in Table 4 and Table 7. By implementing the special features of Equalink®, the margin and transmission error are well corrected [19] including to compensate the downlink path losses mentioned earlier.

The second stage of setup are focuses on the in-cabin optical communication by using LiFi transceivers (on the shelf LiFiMAX selected for analysis). The analysis focuses on the most important parameter which is *Distance* vs. *Throughput* at which LiFi communication took place as presented in Figure 3 setup [22]. To achieves a high throughput of LiFi AP and correct position of the setup, 9 different scenarios has been tested with no external lights interference to limit the scope of measurement. In summary, the test characteristic and analysis results are shared in the Table 5 and Table 6 respectively. Table 6 represent the maximum achievable throughput by both of the user 1 and user 2 by comparing with other measurement test scenario. User 1 and 2 represent the passenger siting position in the cabin with the separation denote as *Xc* (m) [3].

TABLE 5. LiFi setup characteristics.

Specification	Description
ϑ - *Angle*	Incident angle from the LiFiMAX AP to the user equipment (UE) receiving element
X_s *(m)*	Separation length between receiving UE to the LiFi AP
X_r *(m)*	Level between UE with the ERL floor.
X_c *(m)*	Separation length between two receiving UE

A local LAN network test connection has been performed by using locally stored server/PC in the ERL during the alignment. The laptop and the server are fortified with network ethernet cards: Inter Corporation 82579LM Gigabit Ethernet Controllers. The network interface controller (NICs) support 10/100/1000M speed to ensure a high throughput is supported for LiFi communication [23]–[25].

Line of sight analysis and an optimum position were identified based on the characteristic of LiFi setup as Table 6. This is to ensure a correct position of both the AP and USB dongle is in place for high data rate before connecting to RF network.

TABLE 6. Throughput simulation analysis.

ϑ - *Angle*	X_s *(m)*	X_r *(m)*	X_c *(m)*	Throughput measurement	
				UE 1	UE 2
40°	1.0	0.65	1.0	36.82	35.31
60°	1.0	0.65	1.0	22.41	24.22
90°	1.0	0.65	1.0	11.56	11.23

Table 6, summaries the achieved throughput measurement which is 36.82Mbps and 35.31Mbps at a vertical distance of 1.0m and angle of 40° respectively, since the average vertical distance of sitting position in the ERL are within this range. The small angle (40°) contribute to higher throughput as both UE are concentrated focuses to the LiFiMAX AP. Once both the antenna (1st Test) and LiFi optimum (2nd Test) position has been identified (based on both of the earlier test), the experimental measurement is extended based on heterogenous SatCom-LiFi integration with inbound and outbound capability along ERL route.

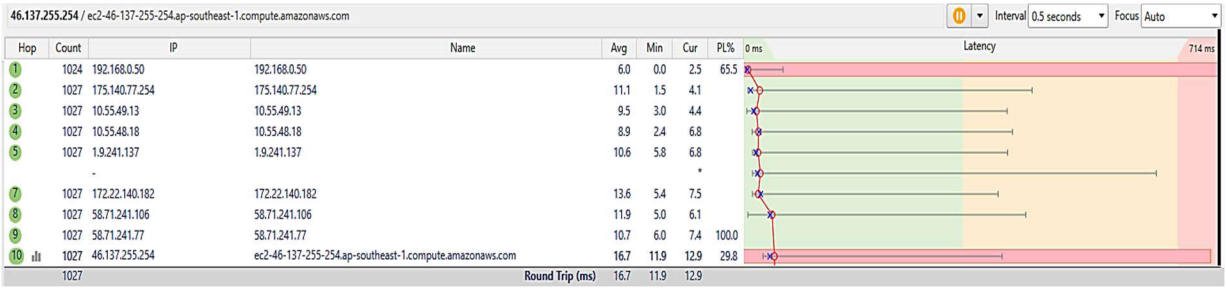
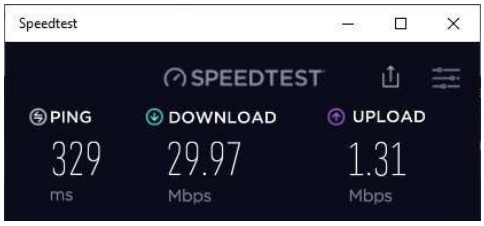
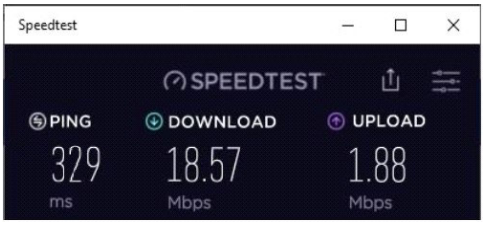


FIGURE 7. Packet loss result for the ERL with constant speed of 150km/h.

TABLE 7. Throughput test connection status.

	File Transfer (measured using NetPerSec)	Speedtest.net
With Equalink	 Average: 30 Mbps	
Without Equalink	 Average: 20 Mbps	

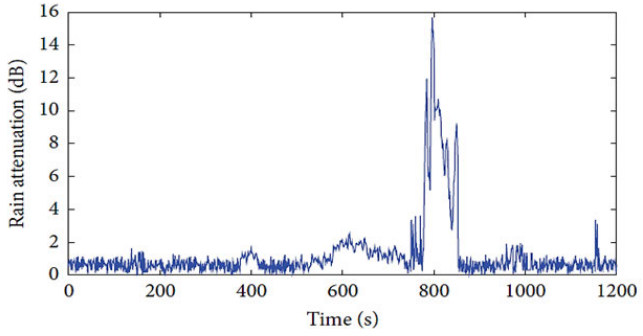


FIGURE 8. Measured rain attenuation during ERL OTP on Feb 14th, 2020.

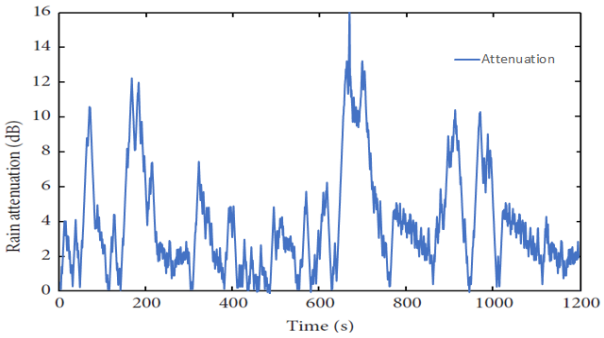


FIGURE 9. Measured rain attenuation during ERL in OTM under the speed of 150km/h on Feb 14th, 2020.

The PsTools and PingPloter is used to measure the handover latency with a recorded of an average of 767ms. Packet loss for both of rainy and clear sky condition [26] were captured and presented in Figure 7.

The measurement set-up basically consists of both transmitter and receiver in the ERL up to the LiFi network and Teleport NOC with both act as forward and return link (Figure 1, Figure 2 and Figure 3). Both outbound and inbound of Adaptive Coding Modulation (ACM) information are measured during the clear sky to rainy day and ERL is moving with a constant speed of 150km/h [10].

A followed-up on the investigation, the ACM performance can be substantiated [28] in the event of atmospheric fading effects (under rain fading effect commencing the clear sky towards rainy day on Feb 14th, 2020).

Each shift in the attenuation (Figure 8, 9 & 10), streamline the link connection modulation and coding

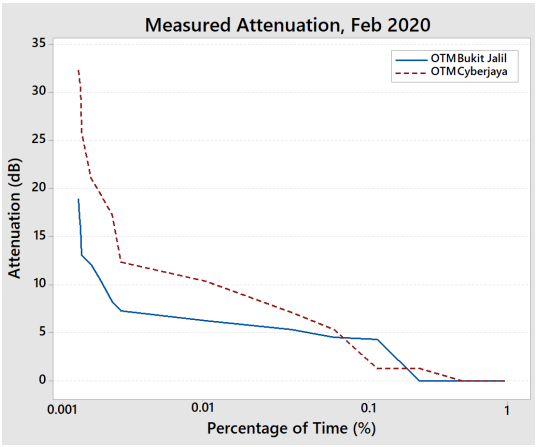


FIGURE 10. Measured rain attenuation along the ERL track sites.

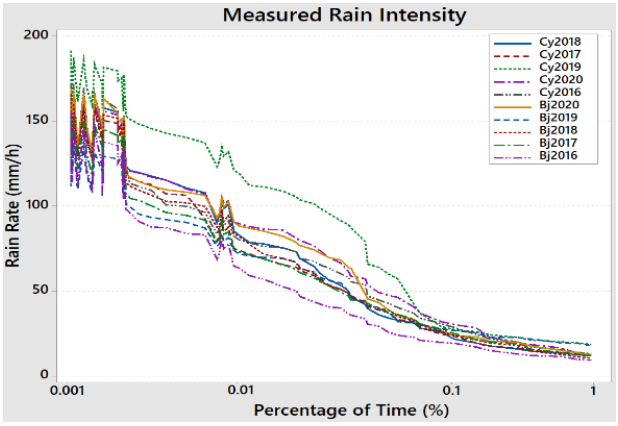


FIGURE 11. Measured rain intensity from 2016 until 2020 for both Cy and Bj.

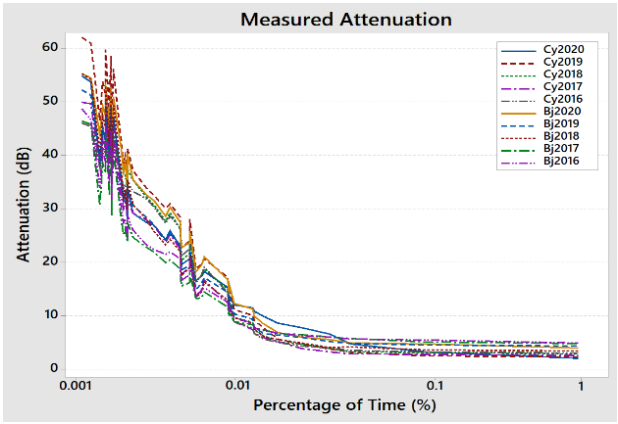


FIGURE 12. Measured attenuation from 2016 until 2020 for both Cy and Bj. until 2020 for both Cy and Bj.

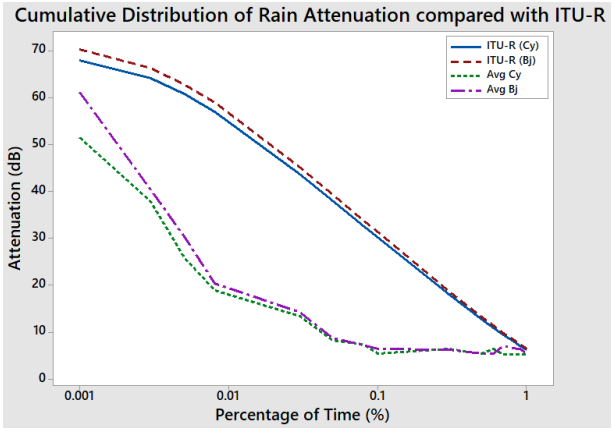


FIGURE 13. Comparison of measurement with attenuation ITU-R model.

schemes (MODCODs) and affect the total bandwidth, that include the rate limit of a received signal.

To ensure a reliable comparison between OTP and OTM rain attenuation, a 20 minutes analysis duration with a 1 second of sweeping time was performed on Feb, 14th 2020 which recorded highest and longest rain rate in the month. Figure 8 represent measured rain attenuation loss in the downlink signal power when the ERL was On-The-Pause (OTP). Whereas, Figure 9 show the measured rain attenuation in the downlink signal when the ERL is OTM. Figure 8, shows the effective rain start from the 10th minutes (580 second) and reached to the higher attenuation of 16 dB at minute of 13 (800 second).

However, for the OTM measurement as presented on Figure 9, the attenuation recorded starting from the 1st minutes (80 second) until the ERL stops after 20 minutes (1200 second). The downlink beacon level including rain rate were logged every second simultaneously to ensure no missing data for analysis. A cumulative distribution function (CCDF) is plotted (Figure 10) to identify the duration unavailability of RF link for OTM system analysis [28]. The ACM automatically tunes to higher coding and modulation without impacting of the overall network packet and throughput once the link condition improves.

The average precipitation was measured and recorded at two points along the ERL track which is Bukit Jalil (Bj) and Cyberjaya (Cy) which is close to 15 km apart with an elevation angle of 68.8^0. An average of rain intensity for 5years from 2016 till 2020 is captured and presented in Figure 11 with the attenuation in Figure 12. It shows that the average rain intensity at 0.01% for Cyberjaya is at 80 mm/h and for Bukit Jalil is at 70 mm/h respectively. The analysis estimation rain intensity in ITU-R P.837 [29] is 90 mm/h and almost to the recorded measurement but not close to the actual on-site measure value. The attenuation at both location experience higher attenuation value with a range of 45 dB to 60 dB as plot presented in Figure 12.

The maximum rain rate of each year from 2016 till 2020 is taken and averaged for the analysis based on the recommendation from REC-P.618-13 [30] which presented in Figure 13. The root means square error (RMSE) is calculated and based on the comparison of the measured data and ITU recommendation.

To well capture the effect of the electrical bridge, the ERL are drive with a low speed of 12km/h. This is to ensure the result are more accurate (Figure 14) and observation found

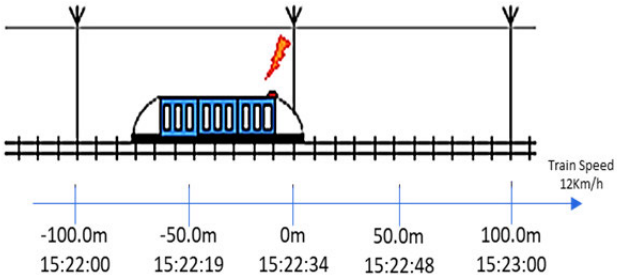


FIGURE 14. Electrical bridges and posts with time taken for analysis.

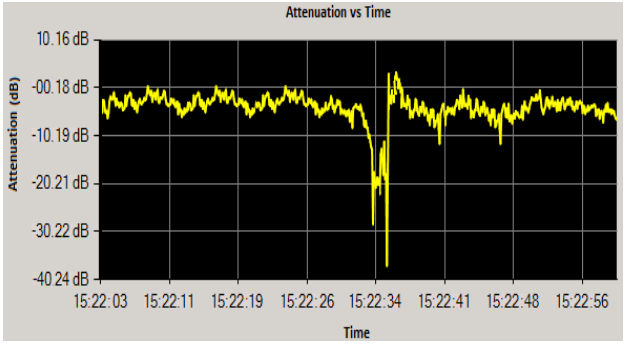


FIGURE 15. Attenuation due to an electrical bridge.

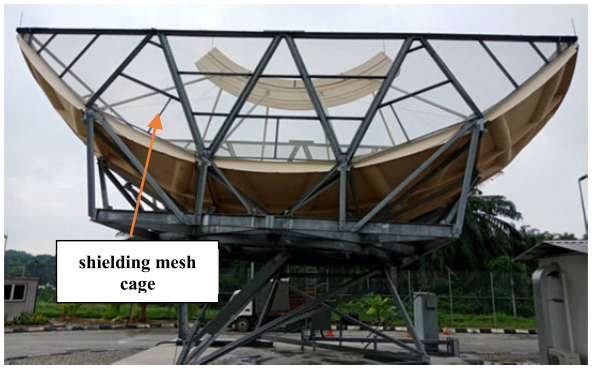


FIGURE 16. A shielding mesh cage installed at the simulsat 7 (SS7) multibeam to avoid EMI interference.

that the packet loss is getting higher compare to the both of the previously analyzed scenario (Figure 9).

The EMI effect is clearly noticeable via spectrum analyser (SA) (Figure 15) which induce interference to the primary carrier of the transponder. This impact badly on the video and its QoS link availability on the user experience [29].

A faraday shielding mesh cage [30] (Figure 16 and 17) with specific dimension (using the equation of $c = f$ x λ), where the $c = 3 \times 10^8$ m / s, f = require operating frequency and λ represent the spacing of the mesh dimension based on specific frequency to be allowed which shields mainly target frequency.

It has suitable shielding effectiveness which weaken wireless communication in other unwanted frequency band with improved packet loss (Figure 18 and Figure 19 respectively). The comparison of carrier performance under the unshielded and shielded mesh were clearly noticeable via SA as shown

FIGURE 17. A shielding mesh cage installed on top of the array antenna which act as EMI radome.

in Figure 20. The efficient grounding is required to ensure no electric spark when the ERL are passing by catenaries [31]. This is to ensure proper safety mechanism conformity with EN-50155 compliance [32].

IV. RESULT AND DISCUSSION

The primary objective of the study is to provide a benchmark communication measurement between end-user equipment and power line emission including the atmospheric impairments under tropical region. Thus, a clear separation between power arch (PA) and other type of attenuation (i.e. rain, temperature) is require for a precise design of rail infotainment communication system. An earth terminal receiving signal elevation angle effect heavily to the communication performance. Which means, high elevation angle reduces the signal propagation path and rain attenuation [15].

Based on the Figure 10, the recorded attenuation is around 40 dB and as discussed [26] the rain attenuation plays a vital role under tropical region additional to the mobility impairment. Cyberjaya experience early outage on 2019 and 2020 at 0.01% of time reference towards the Figure 11 and Figure 12. The recorded average precipitation is at 172.39 mm/h and 157.44 mm/h respectively during Northeast Monsoon. This provide good analysis for designing communication system for OTM application in Malaysia region with the reference towards the rain pattern and attenuation level. Northeast Monsoon season (November to March) normally experience heavy rainfall and Feb 14th, 2020 been selected for the analysis due to maximum record rainfall. However, the ITU-R does not able to match the measured value (Figure 13) which it could possible due to the attenuation fading effect on the OTM antenna and further in-depth analysis is required.

Additionally, a reliable channel model validation can be formed based on the reference measured channel parameter as presented in Figure 10 with the changes of tropical rain pattern. Even a good signal strength could possibly provide a bad QoS due to the degradation of signal quality [35]. This can be seen on the packet loss result with a different of 18% recorded before and after the mesh installed. Ambient noise temperature might potentially affect the gain of receiving signal thus reduces the effective gain of the amplifier [36].

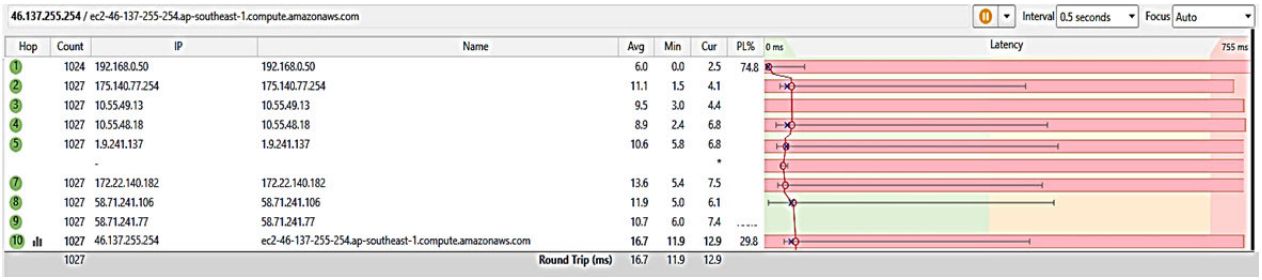


FIGURE 18. Packet loss result for the ERL during passing by the electric bridge before the shielding mesh cage installed.

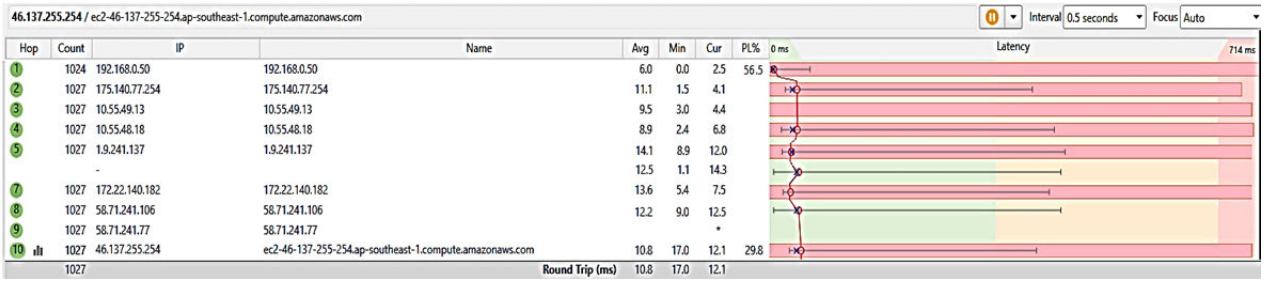


FIGURE 19. Packet loss result for the ERL during passing by the electric bridge after the shielding mesh cage installed.

TABLE 8. Percentage error analysis for both Cy and Bj with ITU-R model.

	Average Prediction		Average Measured		Cy	Bj
	ITU-R (Cy)	ITU-R (Bj)	Avg Cy	Avg Bj	ε(P)	ε(P)
0.001	67.92	70.11	51.42	61.03	0.32	0.15
0.003	64.09	66.23	37.82	40.27	0.69	0.64
0.005	60.71	62.77	25.77	30.27	1.36	1.07
0.008	56.87	58.82	18.75	20.36	2.03	1.89
0.03	43.57	45.12	13.26	14.21	2.29	2.18
0.05	37.91	39.28	8.11	8.65	3.67	3.54
0.08	32.64	33.83	7.41	7.25	3.40	3.67
0.1	30.13	31.25	5.37	6.35	4.62	3.92
0.3	18.03	18.72	6.36	6.24	1.84	2.00
0.5	12.66	13.16	5.32	5.37	1.38	1.45
0.6	10.83	11.26	6.36	5.37	0.70	1.10
0.7	9.34	9.71	5.24	6.97	0.78	0.39
0.8	8.10	8.43	5.27	6.44	0.54	0.31
0.9	7.05	7.34	5.16	6.36	0.37	0.16
1	6.16	6.42	5.24	5.33	0.18	0.20
				μ	1.61	1.51
				δ	1.36	1.33
				RMS	2.11	2.01

So far, Railway Technical Research Institute (RTRI) and the National Institute of Information & Communication Technology (NICT) in Japan had carried out the measurement campaign at the satellite frequency above K-band [37].

TABLE 9. ERL communication performance.

Condition	ACM	Outbound throughput from remote location (Mbps)	Inbound throughput to remote location (Mbps)	Max Packet Loss (%)	Max Latency (ms)
Clear	16-APSK, 8/9	2.7648	45.6122	32.3	723
Rain	QPSK, 1/4	1.0240	6.0900	65.5	755

However, all the measurement campaigns focuses under the temperate region which the direct reference towards tropical region is inaccurate [38]. The available model such as Ali *et. al.* [6], Sujan *et. al.* [39] and Mandeep *et. al.* [40] are used to compare the actual measured channel performance with an average of 2.11 and 2.01 root mean square error (RMSE) for both Cyberjaya and Bukit Jalil respectively from ITU-R P.311-10 [26]. The detail RMSE result are presented in Table 8. As the near zero RMSE measurement are needed, more in-depth investigation of existing models and long term measured data is required.

Under the inbound link, this solution relies on the ACM DVB-S2/X standard, which characterizes mechanisms to guarantee a significant level of continuity with a Deep Packet Inspection (DPI) technology to limit the bandwidth usage based on the available throughput.

A network throughput (Table 9) is identified with maximum at a clear sky (16-APSK Rate 8/9 – 14.41 Mbps average per user) and minimum at rainy condition (QPSK Rate 1/4 – 2.41 Mbps average per user) before the signal completely attenuated [27]. An advance data processing application such as deep packet inspection is needed during the rainy condition. This will potentially reduce congestion during lower code rate (QPSK, 4) in managing overall network traffic.

(a) (b)

FIGURE 20. Carrier snapshot of spectrum analyser when ERL during passing by the electric bridge (a) without shielded mesh and (b) after shielded mesh installed.

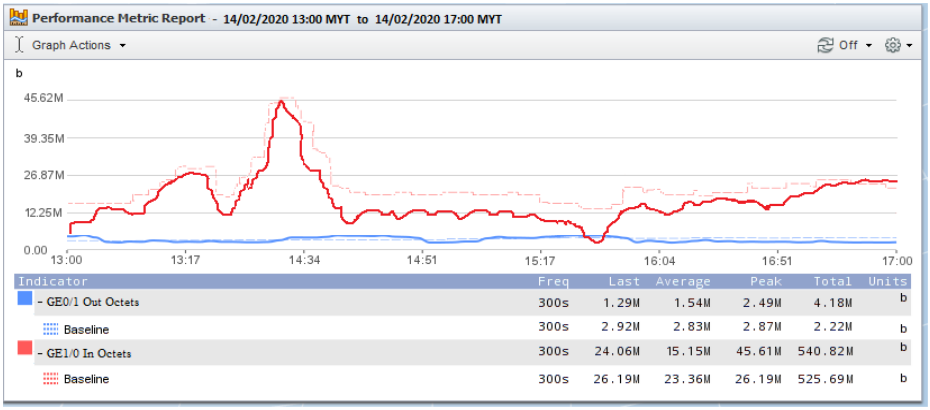


FIGURE 21. Average throughput per day during ERL in OTM on Feb 14th, 2020 with shielded mesh.

TABLE 10. Wireless network communication performance [33]–[35].

Technology	Data rate (Mbps)	Operating frequency (GHz)	Speed (km/h)
38G mmW (Maglev)	~ 8	37.1 ~ 38.5	< 500
Ku-Band (TGV)	~ 42	11	< 300
HTS Ka-Band (ERL)	~ 15	20.02	< 150
LTE (For common rail application)	~ 50	0.450 / 0.800 / 1.4	< 500
5G NR - FAST (Frequency Division Duplexing Assists Super Time Division Duplexing)	~ 1200 (up to 2Gbps)	2.1 & 3.5	< 500

As the indoor communication throughput is higher than the SatCom network, higher packet loss is observed (Figure 15). A reliable QoE and QoS as shared in Figure 21 with an average of 15Mbps can be achieved with a successive interference cancellation mechanism with a shielded mesh added to the receiver.

It is always a goal under the tropical region to achieve a throughput close to 5G NR wireless technology and an overall performance comparison available under the temperate region as summarised in Table 10. The most importunity criteria for heterogonous SatCom LiFi solutions are: Availability for critical analytic applications, the packet loss and transfer delay between SatCom & LiFi remote terminals and customised throughput for multi-user handhelds devices.

V. CONCLUSION AND FUTURE WORKS

Heterogeneous Satcom-LiFi had entered next revolution long term potential solution under HTS for wireless communication. This investigation will provide useful information to system designer and analysts by understanding and considering the real environment of hybrid communication system network, predominantly in the tropical region, where such data is inadequate.

The comprehensive and well-planned measurement may introduce more precise hybrid network design mainly; (i) at OTM application, (ii) and at the policy-based orchestrator/controller layer. However, such executions will be expensive for researcher to reach the ideal requirement of the OTM communication network.

The main conclusions obtained are as follow:

- Reliability – Performance of the hybrid application
- Low latency – Immediate setup for cost avoidance is highly demanded in current era.
- Realtime analysis - Measurement under tropical geographical constraints and power arch performance examination.

Assuming that, the outbound teleport traffic are perfect, future works may include other available spectral efficiency scheme (proprietary of NovelSat®) for bandwidth efficient estimation techniques to further tweaking OTM service interruption.

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