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Development of A Solar Powered Fixed Wireless Network Extender

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***Abstract*—**User devices connect to Access Points (AP) to obtain internet access through Wi-Fi networks. But with the increment of the distance from the AP, signal reception quality reduces, and the power will be lost due to signal interferences through free space. The design was focused on providing internet accessibility by an existing Wi-Fi network to a remote site using low cost and high-performance antenna. The research was conducted to design an antenna for obtaining internet accessibility during off-peak times at staff and student residential areas from the existing fixed Wi-Fi network deployed in the academic buildings. The designed system consists of a parabolic antenna that uses the Line-of-Sight technique for unidirectional transmission having a center-feed of programmed microcontrollers to capture Wi-Fi signals through wireless media. According to the literature we have conducted, system deployed with solar powering system which is a fully sustainable energy source, with a low-power consuming microcontroller is the novelty of the design. This entire antenna system was tested for receiving signal strength, downloading and uploading speeds at the targeted distance from the transmitter under 2 tests. The results confirm that the residential area where Wi-Fi connectivity was not available for internet access, was provided with the connectivity with better signal quality having a user-friendly, low power consuming, and easily deployable system.

***Keywords*—**Wi-Fi Extension, Antenna Design, Parabolic Dish Antenna, Line of Sight antennas, ESP8266, Solar PV cells

I. INTRODUCTION

In recent days, wireless communication which is allowing users to communicate even in remote areas has become an integral part of several types of communication devices. The term “Wireless” refers to the communication or transmission of information over a distance without requiring wires, cables, or any other electrical conductors (Bayari, 2008). Wireless networks are an extension of Local Area Network (LAN) systems (Flickenger, Okay, Pietrosemoli, Zennaro, Fonda, 2008). Wi-Fi is a cost-effective technology of choice for network extension in rural areas (Ab-Hamid, Tan, & Lau, 2011). Wireless networks commonly use IEEE standard protocol “802.11” with a range of about one hundred meters (Wade, 1998). Mobile Stations (Eg. Mobile phones, laptops) are connected to Access Point (AP) to utilize Wireless LAN (WLAN) communication. One of the main wireless communication techniques used is “Line of Sight (LOS)”, which is widely used to transmit and receive data for a long distance in the telecommunication industry throughout the world. Line of Sight (LOS) is the path between two antennas and it is categorized into three main categories as, full LOS where there are no obstructions in between two antennas, Near Line of Sight (nLOS) which is included with partial obstructions between two antennas and lastly, Non-Line of Sight (NLOS) which is fully obstructed the path between the antennas. (McNeil, n.d.). The internet connection obtained from LOS can receive a better Quality of Service (QoS). But with the increment of the distance of the user from the AP, then the signal strength decreases and the power will be lost due to interferences to the wireless signal when transmitting through free space.

In this research, a pair of parabolic dish reflectors are used as the reflector type, and as the feeder antenna, a pair of microcontroller units are programmed to feed the reflector surface with Wi-Fi signals which are placed at the focal point of the parabolic reflector antenna to extend the coverage area of a fixed Wi-Fi (Figure 1). Following Figure 2 shows the flow chart of the proposed design.

The rest of the paper is organized as follows. Section 2 explains related work, section 3 is included with the proposed system and section 4 describes experimental results and discussion. Finally, conclusions and the future work are stated in the last section.

II. RELATED WORK

Ismail et al., 2020 presented the development of a low-cost extended wireless technology and its performance experiments and results at a low coverage area. The Wi-Fi AP network was created by configuring and programming Raspberry Pi 3B+. In the testing level, various aspects such as the energy efficiency of the Raspberry Pi and also the signal strength of

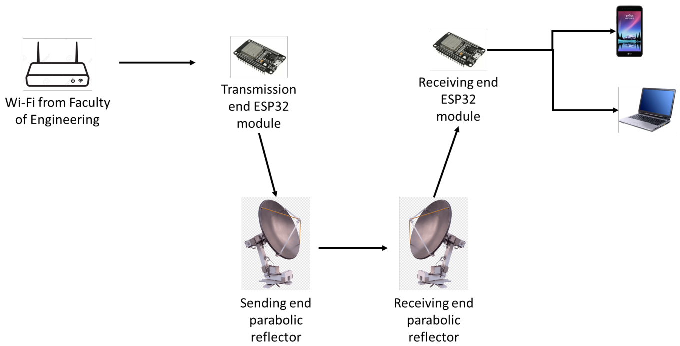


Fig. 1. Main components of the proposed system

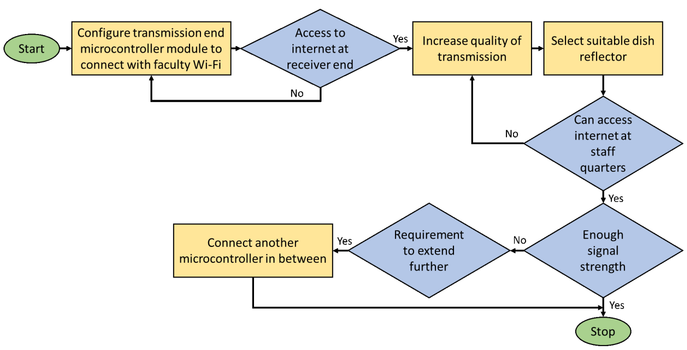


Fig. 2. Flow chart of the proposed system

the network were considered and analysed. The measurements results showed that the network signal was extended by 80 m, especially in the free space environment (Ismail et al., 2020).

A portable wireless range extender (PWRE) was developed by Harum et al., 2017 by using a low power consuming microcontroller board called, Raspberry Pi to obtain the internet access by assist Mobile Station (MS) that is located out of the coverage area, to get the internet access. Connecting to the existing WLAN network and broadcasting a new WLAN network are the two major processes involve in developing a PWRE and the performance was evaluated with or without placing the PWRE by comparing signal strength received by an MS located in the cell edge from an AP. Results showed that the MS signal strength improved significantly with the deployment of PWRE (Harum et al., 2017).

Bozdag, 2019. had discussed a wideband printed bow-tie antenna which is designed for the entire band of GPS L5 (which is the third civilian GPS signal), Personal Communication Service (PCS), IMT-2000, Bluetooth, Wi-Fi, WiMAX bands, and the most of the frequency range of Ultra-Wideband (UWB). Compared to the traditional designs, the design by Bozdag, 2019. included a tapered printed line with a feeding point patch and triangular bows with rectangular edge extensions, which makes the antenna more compact and operates in the 1.49-9.5 GHz frequency band. According to measurement results, the gain had varied with a 4.44 dBi average. A dipole-like radiation pattern with higher cross-pole discrimination levels was obtained at the lower frequencies of the operating band, while they degrade at the higher frequencies due to an increase in the gain (Bozdag, 2019).

Khan & Ansari, 2016 discussed that the usage of cables over a long-distances to connect different networks is infeasible and not wise. Therefore, to create the long-distance network, one of the best cost-effective counterparts is the usage of wired links. It shows that, links will make the network with a high-speed, centralized and easily manageable through LOS. Khan & Ansari, 2016. had presented a Long-Range Wireless Point to Point Link Network on 5 GHz frequency band with Voice over Internet Protocol (VoIP). The design consisted with a soft Private Branch Exchange (PBX) for a university campus or an organization. They had analysed the QoS of the setup by the measures of data rate and connectivity using the bandwidth test and ping test for both Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) scenarios (Khan & Ansari, 2016).

Ibrahim & Harum, 2018 had presented that the increment of the number of modern devices and sensors and Internet of Things had entered the many other things in our world. The best way to provide better internet everywhere with fewer base stations is the combination of Wi-Fi internet access with a mobile network and blanket coverage. The objective of "Hybrid Wireless Range Extender" was to solve the low coverage issue by using a broadband data and transmit that data as a Wi-Fi router through 802.11ac protocol. The result was a Wi-Fi hotspot which allows the internet accessibility (Ibrahim & Harum, 2018).

In "Optimal position to place Wi-Fi Extender to improve its performance", Nishimura et al., 2020 discussed that Wi-Fi extender receives the radio signals from an AP and rebroadcast it to a new group of Service Set Identifier. According to their experiments and observations, the design offered a slower connection compared to original AP. Deployed position of the extender effected on the speed of their obtained internet network. Therefore, they investigated the correlation between the speed of the connection with the distance and the Received Signal Strength Indicator (RSSI). Through their control experiment for the extender usage, they found that just placing an extender might degrade the performance compared to the direct association to an AP in the service area in the AP (Nishimura et al., 2020).

III. Proposed System

The proposed system consists of three main parts as explained in the following sub-sections: parabolic dish reflector; antenna feeder and feeder holder; and the solar power supply system.

A. *Parabolic Dish Reflector*

Gain is the ratio of the power produced by the antenna from a far-field source on the antenna's beam axis to the power produced by a hypothetical lossless isotropic antenna, which is equally sensitive to signals from all directions. The Gain (G) of the parabolic dish reflector is,

$$G = 10log_{10}k(\pi D/\lambda)^2$$

where, k is the efficiency factor, D is the diameter of the parabolic dish reflector in meters, and is the wavelength of the signal in meters (Wade, 1998). The wavelength () of the signal transmitted through free space is,

$$\lambda = C/f$$

where, C is the velocity of the signal through free space/air (= 3×10^8 ms^{-1}) and f is the frequency (Wade, 1998). As per the graph of gain vs diameter for different k values based on the equation (1), the gain of the parabolic dish reflector behaves approximately linear for the values D $\geq$ 0.6 m (Figure 3 (a)). Hence, the diameter D = 0.6 m and the depth d = 0.055 m was selected for the proposed parabolic dish reflector (Figure 3 (b)). The wavelength of the transmitted Wi-Fi signal λ = 0.125 m as per equation 1 considering Wi-Fi signal (= 2.4 GHz). As per equation 2, the gain of the proposed parabolic dish antenna G = 20.56 dB for the efficiency factor k = 0.5 (= 50%).

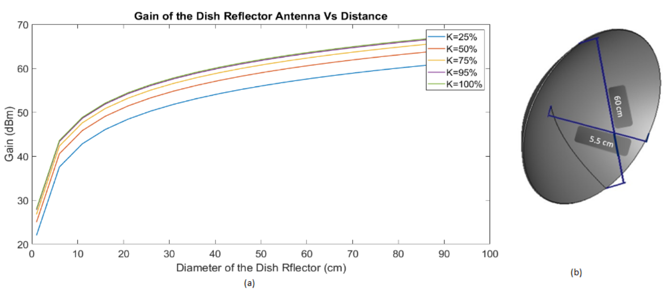


Fig. 3. Parameters of the parabolic dish, (a) gain G vs radius D for different k values, (b) parameters

B. Antenna Feeder and Holder

The ESP8266 microcontroller is used due to its easiness of configuration, low cost, considerably low power requirement (5V and 70mA max.), and ability to monitor, route and shape traffic (Espressif Systems, 2015). ESP8266 microcontroller can be used to perform various Wi-Fi related activities with applications in home automation and beyond. There are two ways to connect ESP8266: (a) input Wi-Fi credentials into the ESP8266's firmware to establish the required connection and start sending data; and (b) after building own AP into the board, creating a universal firmware that will establish a connection to any available network (Espressif Systems, 2015). Two ESP8266 microcontrollers are used each at the transmitting end and the receiving end of the proposed system. The transmission end microcontroller is programmed as a station router and the receiving end microcontroller is programmed as an access point using Arduino IDE software.

When feeding a parabolic dish reflector, it is necessary to place the feeding element at the focal point of the reflector. Designing and placing the feeding antenna of the dish reflector surface is categorized mainly under four mechanisms: (a) Focal feed (axial or front feed system) where the feeding element is placed directly on the focal point of the dish reflector; (b) Cassegrain feed system where the transmission and reception of Wi-Fi signal are done with the support of a second convex reflecting surface; (c) Gregorian feed system where the similar mechanism to the Cassegrain design is used but instead of convex reflector surface, a concave reflector surface is used; and (d) Off Axial (Offset feed system) where an asymmetrical segment of the parabolic shape normally used and in this design, the focus and the feed antenna are located to one side of the reflector surface (Wu Lin, 2015). In the proposed system, the feeding element is placed using the Focal feed mechanism. The focal length of the parabolic dish reflector surface is,

$$F = D^2/16d$$

where, d is the depth of the reflector surface (Wade, 1998). As per the values calculated in section 3.1, from equation 3, the focal length F = 0.409 m. Accordingly, the feeder holder is designed as in Figure 4.

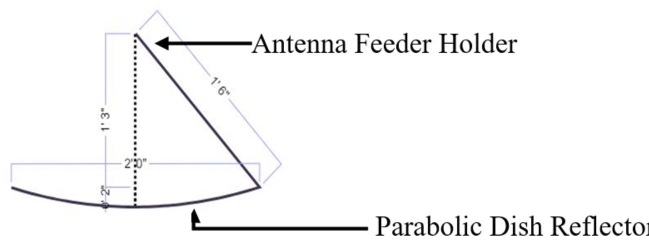


Fig. 4. Feeding element design for the parabolic dish reflector(CAD Drawing — Free Online CAD Drawing, n.d.)

C. Solar Power Supply System

Today, with the advancement of the technology in consumer electronics to renewables and the smart grids, the world has reached to a place where consumers are using energy-driven batteries as one of the major energy sources. Since the batteries are energy limited recharging with solar energy can offer a convenient option for smart consumer electronics. Meanwhile, batteries can be used to address the intermittency concern of photovoltaic (PV). With the consideration of cost, three major matrices are addressed by the PV battery, namely stability, efficiency and energy density. Since our design is a low-power consuming system, a flexible integrated PV battery system was required where it could be provided by Polymer Solar Cell (PSCs). The overall efficiency of the PV battery system can be obtained by the product of photoelectric conversion efficiency of PV and energy storage efficiency of the battery. The estimated maximum charge current output of the solar charge controller (Iout) can be taken by;

$$I_{\text{out}} = \frac{P(solar)}{V(battery)}$$

where, P(solar) is the wattage of the solar panel and V(battery) is the voltage of the battery (Claus Jager, 2015). Since the used solar panel was a 1.5 W with a 3.7 V battery, the output current according to the equation (04) is 0.405 A. According to the rule of thumb, system losses are 20%, and the PWM controller's efficiency is approximately 75%. So, the actual output current (I(out-Actual)) can be calculated by multiplying obtained I_{out} by the efficiency factor and the loss factor. This gives a value of 0.243 A. DC battery capacity is taken into consideration along with the rule-of-thumb efficiency of the battery type. Here, the actual battery capacity (C_{bat}) can be calculated by;

$$C_{\text{bat}} = \frac{C^{'}}{\eta(battery)}$$

where, $C^{'}$ is the actual battery capacity and η(battery) is the efficiency of the battery type according to the rule-of-thumb (For Li-Ion battery it can be taken as 95%) (Claus Jager, 2015). So, as we used a battery with total capacity of 7.2 Ah, the actual capacity of the battery used in our proposed design can be calculated using the equation (05) as 7.579 Ah. The time to charge the entire battery (T(charge)) is given by,

$$T_{\text{charge}} = \frac{C_{\text{bat}}}{I(out - actual)},$$

where, C_{bat} is the actual battery capacity and I(out-Actual) is the actual output current of the charging controller (Claus Jager, 2015). So, according to the equation (06), the charging time T(charge) can be determined as 31.189 hrs (here, the depth of discharge (DoD) is considered as 100%). In our proposed design, the used charging controller (PWM controller) originally has an energy absorption at the charging stage. Therefore, this charging time is summed up with 2 hours to obtain the actual charging time, which is 33.189 hrs.

According to statistics, the solar radiation limit in Sri Lanka is between 1,247 – 2,106 W/m2 for around 10 hours a day (Board, 2020). So, under the powering mechanism of the antenna feeding system, we mainly focused on three major sections as solar PV (1.5 W and 5 V), Battery bank (as 3.7 V), and powering of the ESP module (as 3.3 V) to obtain the simulation outputs. According to the above calculation, the charging time can be reduced with the increment of the number of solar panels. Because our design was tested with a 1.5W solar panel, we could conclude that the number of solar panels required to charge the battery within one day was '04' as shown in Figure 5 (taking into account the number of hours that could receive proper sunlight).

Since this design is proposed with a programmed microcontroller, the power requirement is a maximum of 5V DC for the feeding component. To have a continuous power supply, a battery bank is included (Figure 6 (a)). As in Figure 6 (b), electrical equivalent circuit modelling for a solar PV cell can be considered with multiple series diodes (D) and Shunt Resistors (Rsh which is negligible). But when the number of Shunt resistors is increased, then it can be considered. as an open circuit.

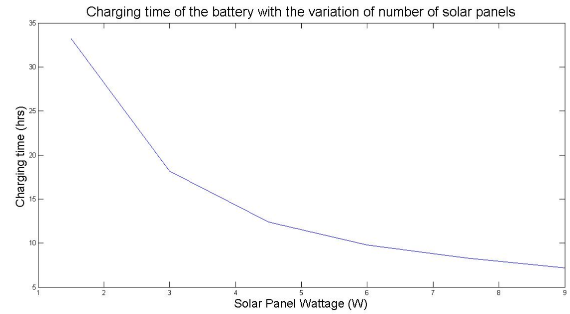
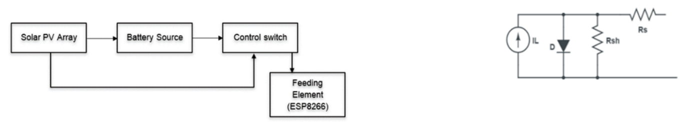


Fig. 5. Charging time variation with the number of solar panels



(a) (b)

Fig. 6. Solar power supply system, (a) Connection diagram, (b) Equivalent electrical circuit modeling for a solar PV cell

IV. Experimental Results and Discussion

The proposed system was tested with simulations and field experiments as explained below.

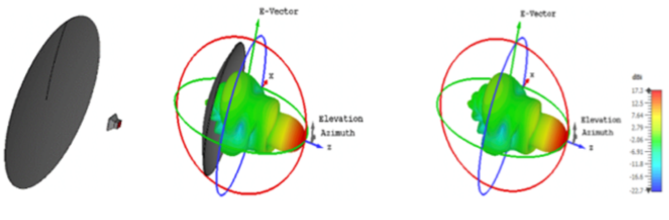
A. Simulation

Two simulations were done, the parabolic dish reflector simulation and the solar power supply system simulation.

1) Parabolic Dish Reflector Simulation: For the simulation of the proposed parabolic dish reflector, CST Studio Suite 2020 software was used. A high-performance software package namely, CST Studio Suite was used for designing, analysing, and optimizing electromagnetic (EM) components and systems. Since the method used in designing the system is similar to the method of direct feeding the antenna by a horn antenna, the 3D model in Figure 7 (a) was used for the horn feed system (Figure 7 (b)). The modelled design was simulated and the lobes created were given in Figure 8. The obtained simulated results are summarized in Table I.

(a) (b)

Fig. 7. Horn feeder of the proposed system, (a) 3D Model of square-faced Horn Feeder for simulation using CST Studio Suite, (b) Horn Feeder prepared to place in the antenna system.



(a) (b) (c)

Fig. 8. (a) Dish 3D modeling for simulation with Horn feed, (b) Lobes in the antenna, (c) Simulation by using CST Studio Suite 2020 to obtain design simulated values

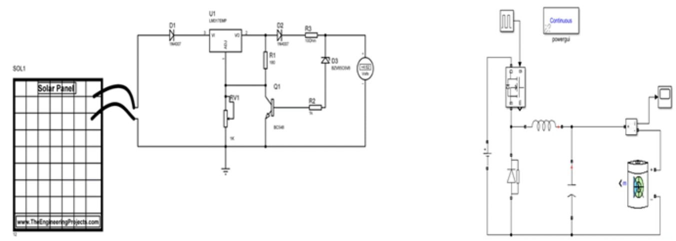
TABLE I
OBTAINED SIMULATED OUTPUT

Type	Far-field
Approximation	Enabled (KR¿¿1)
Component	Abs
Output	Directivity
Frequency	2.4 GHz
Radiation Efficiency	-0.01372 dB
Total Efficiency	-10.01 dB
Directivity	17.33 dBi

2) Solar Power Supply System Simulation: Figure 9 (a) shows the circuit diagram that was designed for solar cell simulation. In Figure 9 (b), it shows the output obtained for the simulation for the solar PV using MATLAB-Simulink. So, the current and voltage values from the simulated solar panel are 197 to 204 mA and 8.874 to 9.185 V. The output from the solar PV was input to a buck converter to power up the battery (for charging) as shown in Figure 10 (a). The mean output current obtained is 0.8 A (where the inductance and the capacitance of the simulated system are used as 140 nH and 50 nF respectively). The voltage that flows to the battery was 8.417 V where it was similar to the level of voltage produced by the solar cells. Feeding element of the antenna (ESP8266) minimum requirement is 3.3 V. Hence, Figure 10 (b) illustrates that in the simulated model, the power requirement of the microcontroller can be fulfilled by taking the battery bank as the source (the input voltage to the ESP8266 module was 3.347 V). Figure 11 shows the completed circuit diagram of the solar powering system designed for the feeding element of the Wi-Fi extending antenna where the DC voltage source indicates the solar PV. So, according to the simulation, the solar powering module circuit diagram is as follows (as in Figure 12 (a)). The system was printed on a circuit board as in Figure 12 (b) and implemented. According to the simulation output voltage was 4.67 V in the morning and 4.95 V at noon which is enough to charge a battery and Power up the ESP module.

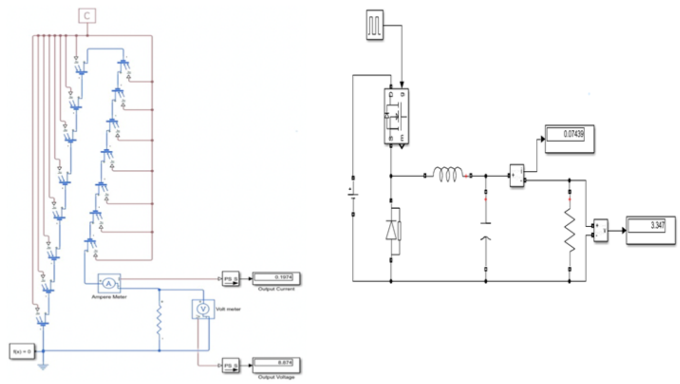
B. Field Experiments

For this design, two on-site experiments were performed at the Faculty of Engineering, South Eastern University of Sri Lanka to test the internet connectivity with the use of single-user equipment (tested with a mobile phone) and download speed and the upload speed and the corresponding results were recorded accordingly.



(a) Proteus (b) MATLAB

Fig. 9. Solar charging system, (a) Circuit Diagram for solar cell simulation, (b) Circuit Simulation for the solar charging system for the battery



(a) (b)

Fig. 10. Power supply unit MATLAB, (a) Simulation Output for Solar PV Array, (b) Simulated circuit model to supply power to the feeding element by the battery bank

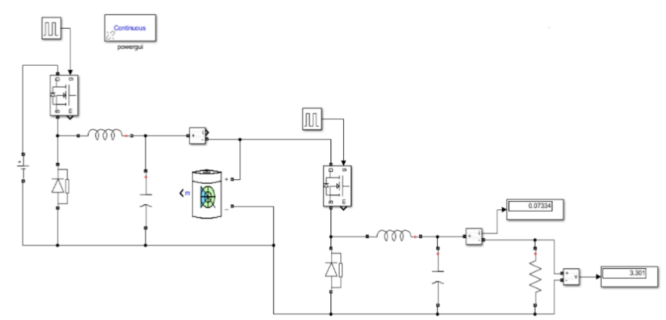
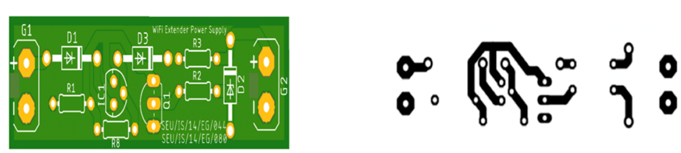


Fig. 11. Complete Circuit Diagram of the Solar Powering system to the Feeding Element of the antenna



(a) (b)

Fig. 12. Solar powering circuit, (a) Circuit board diagram for solar powering module, (b) PCB Design of the powering system

1) Experiment 1: In Experiment 1, the transmitter module was connected to the existing Wi-Fi network, and the receiving end microcontroller was connected to the transmitter end module. The user device was connected to the receiving end access point (Figure 13), and the download/ upload speeds of the network were obtained at different distances between the receiver end module and the user device (Figure 14).

Fig. 13. Experiment 1 Connection Diagram

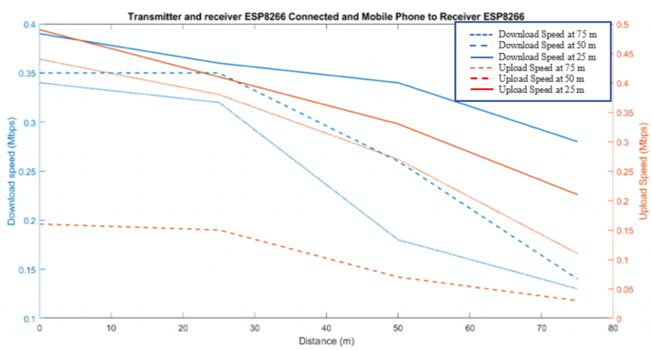


Fig. 14. Experiment 1 Download/Upload Speeds vs. Distance

2) Experiment 2: Experiment 2 was conducted by placing the transmitter and receiver end microcontrollers to feed the transmitting and receiving end parabolic dish reflectors and the user device was connected to access the Internet (Figure 15), while measuring the download/upload speeds at different distances (Figure 16).

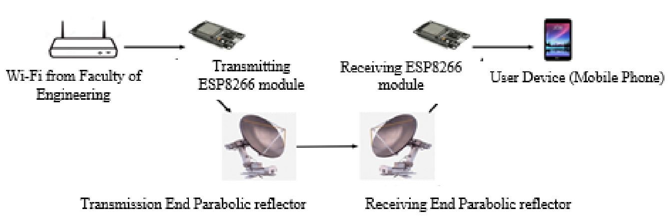


Fig. 15. Experiment 2 Connection diagram

C. Discussion

According to the below Figure 18 comparison of the previous work, our design is better in Wi-Fi network extended distance compared to the design done in Ismail et al., 2020. The cost of the Raspberry Pi microcontroller board is comparatively higher compared to ESP8266 (Smets et al., 2015). Here, in our design, likely similar objective is fulfilled with a low-cost module when compared with the designs described in Ismail et al., 2020 and Harum et al., 2017. Since the consumption of power is considerably low, our proposed design is deployed with a solar powering system, which is the novelty of our antenna according to the literature we conducted.

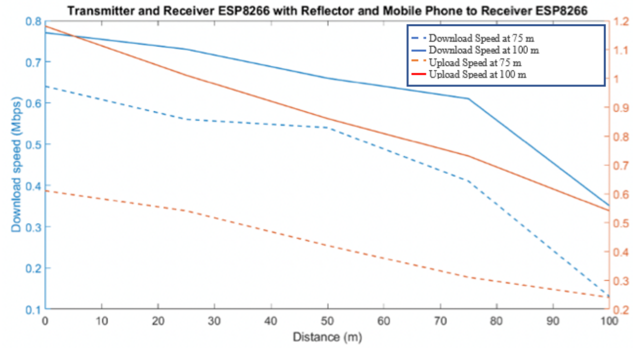


Fig. 16. Experiment 2 Download/Upload speeds vs. Distance

A prototype of the proposed parabolic dish antenna for outdoor WLAN point-to-point application was constructed and tested. Here, the parabolic dish is the key feature of directing the Wi-Fi signals captured from the existing Access Point or the router. With the increment of the distance between the user equipment and the transmitter antenna, the signal strengths, upload/ download speeds automatically get reduced due to the signal interferences in the free space while transmitting from the transmitter antenna to the receiver antenna. Figure 17 and Figure 19, clearly illustrates that the download/ upload speeds are high when the feeder antenna uses the parabolic dish reflector (Download/ upload speeds in the experiment 2 ¿ Download/ upload speed in the experiment 1).

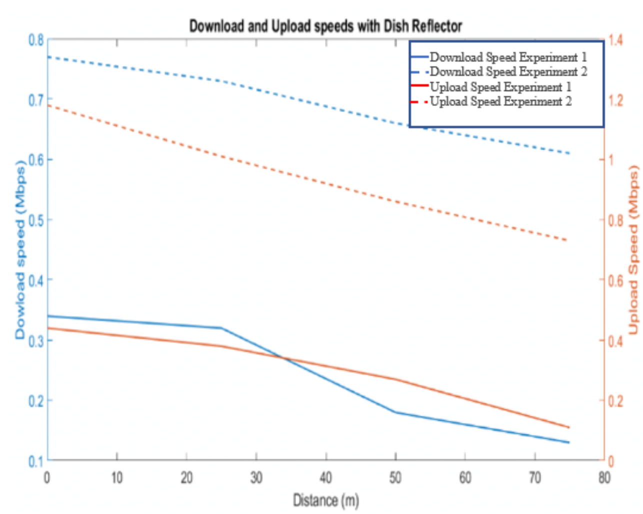


Fig. 17. Impact of the dish reflector in point-to-point signal extender, Download/ upload speed of the antenna with the dish reflector

The increasing rate of internet users is causing the web service delay, slow response time as a result of the rise in

Design	Features								
	Low-Cost	Antenna used	Technique used	Board	Distance(m)	Voltage(V)	Power-Consumption	Gain	QoS Measurement
Reference 1 (Ismail et al., 2020).	Low	_	Hotspot creation	Raspberry Pi 3B+	80	5	Low	_	Signal strength
Reference 2 (Harum et al., 2017).	_	PWRE	Broadcasting new WLAN	Raspberry Pi	_	5	Low	_	Signal strength
Reference 3 (Wiley Online Library, n.d.).	_	Bow-Tie Antenna including tappered printed line with a feeding point patch and a triangular bow with rectangular extention	set of stringent antenna performances	_	_	_	_	varies between 1 to 6.5 dBi (Average 4.44 dBi)	Radiation pattern
Reference 4 (Khan & Ansari, 2016).	Low	soft private branch exchange (PBX) system	Line-of-Sight	_	_	_	Low	_	Data rate and connectivity using bandwidth test and ping test respectively, for both transmission control protocol (TCP) and user datagram protocol (UDP) scenarios
Reference 5 (Ibrahim & Harum, 2018).	_	Transmit data as a Wi-Fi router(hotspot)	Using a broadband data source to transmit data locally	_	_	_	_	_	_
Reference 6 (Nishimura et al., 2020).	_	_	_	_	_	_	_	_	Slow connection compared to original AP, but stable connection to hard-to-reach places. Distance, Received Signal Strength Indicator (RSSI), Speed
Our Proposed design	very much lower	Parabolic Dish antenna	Line-of-Sight	ESP8266	100	3.3	Low	Approximately 20.56 dB (simulated)	Using download and upload speeds (Data rates) at receiver end

Fig. 18. Comparison of the proposed design and the related previous work

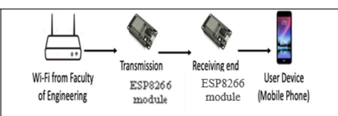
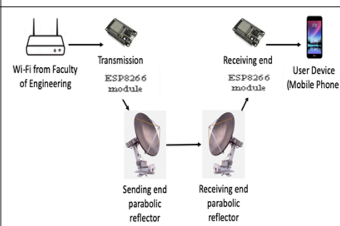
Experiment \ Distance (m) (btn mobile and esp)			0	25	50	75	100
1		Download	0.34	0.32	0.18	0.13	_
		Upload	0.44	0.38	0.27	0.11	_
2		Download	0.77	0.73	0.66	0.61	_
		Upload	1.18	1.01	0.86	0.73	_

Fig. 19. Comparison of download/ upload speeds (Mbps) vs. distance (m)

network congestion caused by the web traffic. So, the usability of a wireless network can be analyzed based on the QoS. Our design is tested for the gain and internet access which are basic matrices of performance for QoS and analyzed the performance of the network. Further experiments are proposed to analyze the performance matrices parameters of latency, bandwidth, MTBF (Mean Time Between Failures), MTRS (Mean Time Restore Service), throughput, jitter, loss rate.

V. Conclusion and Future work

In this work we proposed increasing the range of coverage of the existing Wi-Fi network, and in the meantime, designing a low cost and high-performance parabolic dish antenna which gets a long range of distance link up to at least 100 m using the technique of LOS. Here, parabolic reflector feeding is proposed to be designed with a low power-consuming horn feeder antenna, and it is proposed to be powered with a fully sustainable solar energy uninterruptible power supply (Solar UPS) design. This design is tested for two major scenarios at the receiving edge of the system as mentioned in the field experiments in the paper for internet accessibility and with the concluded facts regarding the data rates for download and upload speeds, the objectives were successful. This design is further proposed to test for the QoS parameters such as latency, bandwidth, throughput, jitter and the loss rate.

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References

Bayari, M. R. (2008). *Extending the Range of Wireless LANs by Developing a New Antenna* (Master's thesis, Near East University). Retrieved from http://docs.neu.edu.tr/library/4022153807.pdf .

Board, M. o.-C. (2020). *Sri Lanka Sustainable Energy Authority.* Retrieved from Lanka Electricity Company Pvt Ltd.: http://www.energy.gov.lk/index.php/en/.

McNeil, P. (n.d.). *Wi-Fi Antenna Installation Best Practices* [White paper]. L-com Global Connectivity. https://www.l-com.com/images/downloadables/white-papers/Wi-Fi-antenna-installation-best-practices.pdf

Kawade, S., Van Bloem, J. W., Abhayawardhana, V. S., Wisely, D. (2006). Sharing your urban residential Wi-Fi (UR-Wi-Fi). In *IEEE 63rd Vehicular Technology Conference: Vol. 1* (pp. 162-166). IEEE. doi: 10.1109/VETECS.2006.1682796

Ab-Hamid, K., Tan, C. E., Lau, S. P. (2011). Self-sustainable energy efficient long range Wi-Fi network for rural communities. In *2011 IEEE GLOBECOM Workshops (GC Wkshps)* (pp. 1050-1055). IEEE. doi: 10.1109/GLOCOMW.2011.6162337.

Wu, F. J., Lin, W. C. (2015). Understanding wireless network coverage, connectivity, and locations using opportunistic sensing for a Wi-Fi advisory system. In *2015 IEEE Tenth International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP)* (pp. 1-6). IEEE. doi: 10.1109/ISSNIP.2015.7106938.

Pravin G., Rastogi, A. K. (2018). Low cost microstrip patch antenna for wireless communications. *Journal of Emerging Technologies and Innovative Research, 5(3), 540-543*.

Flickenger, R., Okay, S., Pietrosemoli, E., Zennaro, M., Fonda, C. (2008). Very long distance Wi-Fi networks. In *Proceedings of the second ACM SIGCOMM workshop on Networked systems for developing regions* (pp. 1-6). https://doi.org/10.1145/1397705.1397707.

Espressif Systems. (2015). *ESP8266EX: Datasheet-Version 4.3*. Retrieved from https://cdn-shop.adafruit.com/product-files/2471/0A-ESP8266__Datasheet__EN$_v4.3.pdf$.

Wade, P. (1998). Parabolic Dish Antennas. In *The W1GHZ Online Microwave Antenna Book.* Retrieved from http://www.w1ghz.org/antbook/chap4.pdf

CAD Drawing — Free Online CAD Drawing. (n.d.). Retrieved March 16, 2021, from https://www.smartdraw.com/cad/cad-drawing.htm

Bozdag, G., Secmen, M. (2019). Compact wideband tapered-fed printed bow-tie antenna with rectangular edge extension. *Microwave and Optical Technology Letters*, 61(5), 1394-1399.

Harum, N., Yusof, N. A. M., Zakaria, N. A. (2017). *The Development of Personal Portable Wireless Range Extender for IEEE 802.1.* 10.

Ibrahim, K., Harum, N. (2018). *Hybrid Wireless Range Extender: LTE (3G/4G) Over Wi-Fi.*

Ismail, N. S., Abd Rashid, N. E., Zakaria, N. A., Khan, Z. I., Mahmud, A. R. (2020). Low-Cost Extended Wireless Network Using Raspberry Pi 3B+. *2020 IEEE Symposium on Industrial Electronics Applications (ISIEA),* 1–4.

Khan, R., Ansari, R. (2016). Long Range Wireless Point to Point Link Network on 5 GHz Frequency Band with VoIP. *International Journal of Applied Mathematics Electronics and Computers, Special Issue-1*, 190–195. https://doi.org/10.18100/ijamec.270089

Nishimura, T., Wibowo, M. J. A., Gunawan, T. T., Sajid, M. J. (2020). *OPTIMAL POSITION TO PLACE WI-FI RANGE EXTENDER TO IMPROVE ITS PERFORMANCE*. 6.

Smets, A. H., Jäger, K., Isabella, O., Swaaij, R. A., Zeman, M. (2015). Solar Energy: The physics and engineering of photovoltaic conversion, technologies and systems. UIT Cambridge.

