ISSN 2502-1613/E-ISSN 2541-3740

Efficient Fault Detection Algorithm in Fiber Optic Communication Systems

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Abstract—Primary concern of optical communication system is the signal loss, which need to be traced precisely to enhance the efficiency of the system. Among numerous available techniques, optical time domain reflectometer (OTDR) is the most suitable one for characterizing and tracing the losses. It measures the fraction of a probe pulse that scatters back from the fiber optic cable. Due to the presence of small levels of backscattering in single-mode fiber at long wavelengths, very sensitive optical detector is necessary to achieve sufficient range performance. In the present research, a novel yet simple approach has been demonstrated to understand the range of optical fiber cable feasibility on fault detection and rectification technique. The actual place of fault is marked with the variation in the measured values of OTDR. Thus, it becomes a difficult task to trace and locate the actual place of fault detection, which leads to an inefficient rectification method. The observed values of OTDR shows a gradual decrease of accuracy in locating the actual place of fault. To resolve these issues, here we try to develop an algorithm which is able to easily and efficiently trace the exact location of fault on earth.

Kata Kunci— **OTDR, single-mode fiber, Fault detection, Backscattering signal.**

Intisari—Perhatian utama dari sistem komunikasi optik adalah hilangnya sinyal, yang perlu ditelusuri secara tepat untuk meningkatkan efisiensi sistem. Di antara banyak teknik yang tersedia, *optical time domain reflectometer* (OTDR) adalah yang paling cocok untuk mengkarakterisasi dan melacak kerugian. Ini mengukur fraksi pulsa *probe* yang tersebar kembali dari serat silika optik. Karena adanya tingkat hamburan balik yang kecil dalam serat mode tunggal pada panjang gelombang yang panjang, deteksi optik yang sangat sensitif diperlukan untuk mencapai kinerja jangkauan yang memadai. Dalam penelitian ini, pendekatan baru namun sederhana telah ditunjukkan untuk memahami sejauh mana kelayakan teknik deteksi dan perbaikan kesalahan kabel serat optik. Tempat sesar yang sebenarnya ditandai dengan variasi nilai OTDR yang terukur. Dengan demikian, menjadi tugas yang sulit untuk melacak dan menemukan lokasi kesalahan serat patah yang sebenarnya, yang mengarah pada metode perbaikan yang tidak efisien. Nilai OTDR yang diamati menunjukkan penurunan akurasi secara bertahap dalam menemukan lokasi kesalahan yang sebenarnya. Untuk mengatasi masalah ini, kami mencoba mengembangkan algoritma yang dapat dengan mudah dan efisien melacak lokasi patahan yang tepat di bumi.

Kata Kunci— **OTDR, Serat mode-tunggal, Deteksi patahan, Sinyal hamburan.**

I. Introduction

Optical fiber communication has evolved as the most rapidly growing field in the past two decades. Optical fiber has become an integral part of modern-day communication infrastructure and can be found along a wide range of areas such as roads, in buildings, hospitals and machinery. Optical fiber is a strand of silica-based glass, with dimensions similar to those of a human hair, surrounded by a cladding. The foremost beauty of optical fiber is that light can be transmitted through the fiber over great distances at very high data rates, thus proving it as an ideal medium for the transport of information.

Optical fiber technologies play a significant role in opening up real broadband access to the end user. Monitoring and identification of fault(s) in the fiber optic communication system is essential for continuous delivery of service to customers. Therefore, any service outage or failure due to a fiber fault translates into a tremendous financial loss in business for the service providers and also a great degree of inconvenience to the customers. Thus, correction of fault(s) in a fiber optic communication system in minimal time is of prime importance for the service providers [1-7].

Conventional but still one of powerful methods that is widely known in telecom industry for fault detection of optical fiber is the use of Optical Time Domain Reflectometer (OTDR) as shown in Fig. 2 & 3 [8, 9]. OTDR uses the effects of Rayleigh backscattering as a main cause loss beside other attenuation losses to measure the various characteristics of an optical fiber [10-15]. OTDR can provide the following information about an optical fiber: total fiber loss, loss per unit length, connector insertion loss, connector return loss (reflection), splicing and inter-splicing loss, absolute fiber length, evidence of macro- or micro-bending, and the exact location of cable defects or breaks. However, this method has its own challenges and problems. One of the major challenges is being fading of precision and accuracy due to the increased variations of distances measured which causes more uncertainty in precise fault localization. This work proposes an algorithm that is trying to locate the precise location of fiber break or fault on earth. The results obtained from OTDR and algorithm simulations are analyzed and compared.

The rest of this paper outlines as followed. Section II gives explanation regarding fault detection and rectification phase. Section III talks about loopholes and algorithm in measuring fault detection. Section IV presents the algorithm simulation results and analysis. Lastly, Section V is Conclusion.

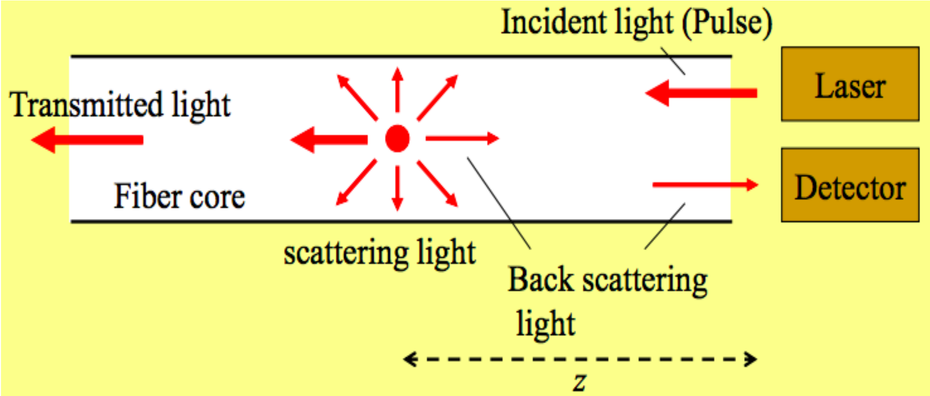

Figure 1. Basic principle of OTDR [8].

II. Methods

A. *Fault Detection Phase*

Here, we have explained the fault detection phase by considering a practical example. Assuming, there are two telephone exchanges, ‘A’ and ‘B’ located at distance ‘D’ apart from each other. The telephone exchanges are connected to each other with an optical fiber link. Now, suppose due to any reason the OFC which connects telephone exchange A to B has been cut. As soon as the OFC breaks between A & B, the optical fiber transmission equipment that is installed at both exchanges A & B begin to show different visual alarms. After observing visual alarms, we can assume that there may be OFC break or fault between exchanges A & B. Confirmation this assumption is done by connection of OTDR to fiber at exchange A or B or both. OTDR also helps us to know the actual place of OFC break as it measures the length of fiber. Let ‘D’ be the total length of fiber installed between A & B and ‘Y’ be the distance measured by the OTDR. Only two possibilities can arise, which are:

A) The length of fiber (Y) = D which means there is no OFC break.
B) The length of fiber (Y) < D which means OFC has been broken.

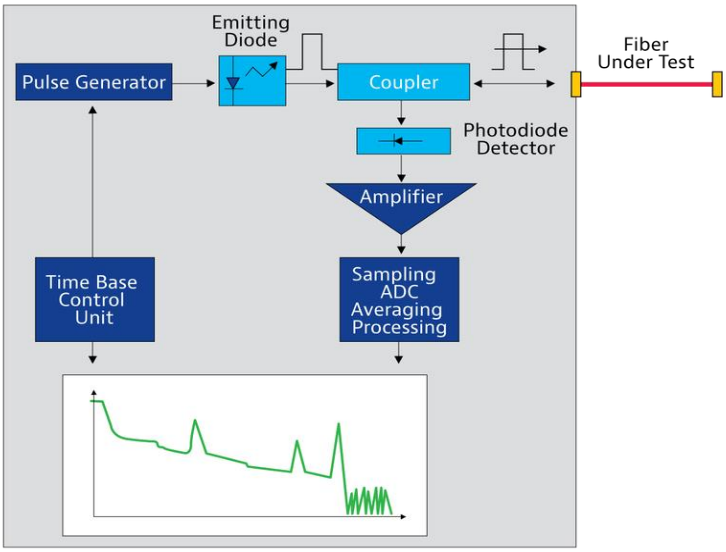

Figure 2. Working mechanism of OTDR [9].

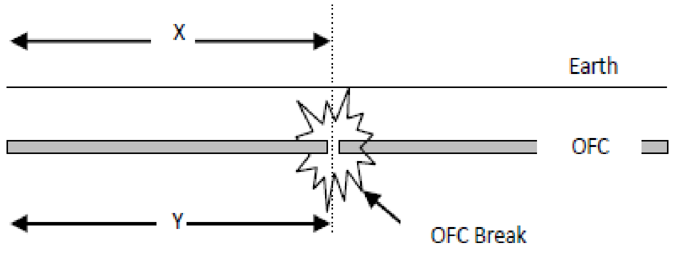

Figure 3. OFC break [2]

Once the length of fiber Y measured by OTDR is known to use which is less than D because the OFC has broken or has some fault, we can work to rectify or repair the fault. To rectify the OFC break fault, the distance X which is equal to Y (X = Y) from exchange A is measured along the OFC route above the ground through distance meter or any vehicle. The process can be understood with the help of Figure 3. Thus, so far, we have made an estimate about the location of fault in the fiber cable. So, the fault detection phase is over, and we can move on to the fault rectification phase.

B. Fault Rectification Phase

After reaching at the distance of X, two digs are made in earth on both the sides of the cut as shown in Figure 4. The digs are made at an approximate distance of 10-20 meters from the cut. We need to make sure that the distance between digs and the cut are not too much. If the distance is large it becomes difficult to pull the broken cable from the earth.

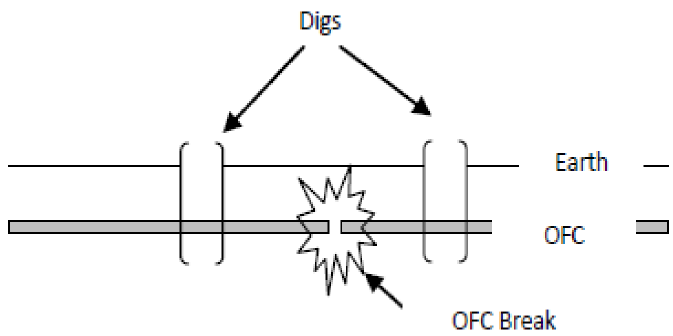

Figure 4. Depiction of digs on both ends of fiber [1]

After making two digs on either side of the cut, the broken cable is pulled out from the earth on both the digs. After pulling out the broken cable a new cable is laid out between both the digs. Figure 5 can help us to understand this process.

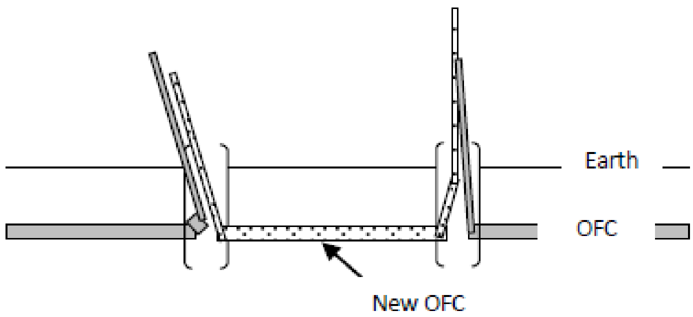

Figure 5. Adding a new cable [1]

Now both the ends of the new cable put in the ground is joined with the broken ends of old cable. The instrument which we use to make this OFC joint is known as fusion splicer or splicing machine. Both the OFC joints are cover by joint closure box which helps to protect it from environmental factors. The joint closure boxes are then placed under the digs made earlier and digs are filled with earth. to cover the fiber cable as shown in Figure 6.

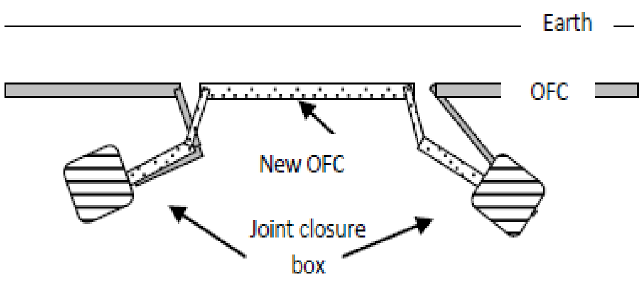

Figure 6. New OFC and Joint closure [1].

Thus, in this way in the communication between exchanges A and B is restored as the OFC fault is rectified. Now the distance between A and B increases by the length of new fiber. The new distance between the exchanges A and B can be given as (D + the length of new fiber).

C. Loopholes in Measuring Fault Detection

The fiber fault location distance measured by OTDR is not the actual location of fault on the earth. The distance which is measured by OTDR is basically the entire length of the fiber from starting point to the fiber fault location. Whenever there is a fault in the fiber the faulty part is cut and replaced with a new fiber cable. This increases the length of the fiber.

So, if there are multiple cuts in the fiber, the effective length of the fiber increases proportionally. So, the distance which the fiber calculates is basically the distance between the point of observation and the fiber fault location plus the extra length of the fiber (Fig. 7).

So, if Y is distance measured by the OTDR then the actual location of fault on earth X would be:

1. X = Y if there is no fault.
2. X < Y if fault is detected.

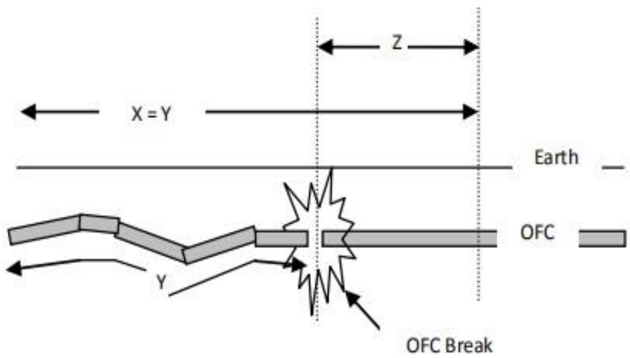

Figure 7. The figure depicts the actual fault location and the distance measured by OTDR [1]

Thus, whenever there is a cut in the fiber two OFC joints are made so as to replace the faulty part which ultimately increases the length of the fiber. Thus, for every cut we introduce two joints. So, in order to get the exact location of fiber fault we have to subtract this extra length from the length of the fiber fault detected by OTDR.

This technique of tracing fault in a fiber cable faces the following challenges:

1. With increase in distance the variation in the measured distance (theoretically by OTDR) starts varying at a higher rate. Thus, fault tracing becomes more uncertain.
2. We need to determine the first fault so that the next fault can be traced & eliminated. Thus, it is difficult to trace successive faults
3. OTDR is not well suited for aeronautical applications, due to usage of short optical fiber marches. This is due to the limitations of launch and the dead zone of the event inherent in the OTDR.
4. This method is quite expensive.

Algorithm and Calculation

We are proposing an algorithm which determines the actual location of fault on earth from data collected from some equipment. In this algorithm we use the total loss measured from OTDR to come up with the actual location of fault. There are

ISSN 2502-1613/E-ISSN 2541-3740

some general assumptions which we need to make in order to proceed forward which are as follows: A) There is an increase of two OFC joints per cut. B) Link Loss = [splice loss x of OFC joint] + [connector loss] + [fiber length (km) x fiber attenuation per km]. x stands for multiplication. The algorithm of this method can be written as follows:

Let,

fiber_loss=fiber length (km) x fiber attenuation per km
conn_loss = connector loss
C= greatest integer smaller than fiber length (if fiber length is 1.65 km, then C's value would be 1 km)

Then we can calculate ideal link loss (without any fault) as
Link Loss = fiber_loss + [splice loss x number of OFC joint] + conn_loss

Now, the expected number of OFC joints on the basis of Link loss measured by OTDR can be given as
No. of OFC joints (expected) = {Link Loss(measured from OTDR) - (fiber_loss + conn_loss)}/ splice loss

There are basically two types of joints:
A) OFC joints at the time of installing fiber cable.
B) OFC joints being made due to faults. (These are the joints which increase the total fiber length).

We have:

- Initial OFC joints = C. (if C is equal to 10 km, it means initial OFC joints would be 10)
- Predicted OFC joints (these increases fiber length) = OFC joints (expected) - Initial OFC joints
- Predicted OFC cuts = Predicted OFC joints /2
- Increase in fiber length (in km) = Number of predicted OFC cuts x increase in fiber length per predicted OFC cut
- Deviation of actual fault location on earth = Increase in fiber length
- Location of fault on earth (km) = Distance measured by OTDR - Deviation of actual fault location on earth

In this way, the above algorithm can be used to predict the actual location of fault on earth.

Let us implement the above algorithm with an example:

Fiber length = 9.362 km.
So, initial OFC joints would be 9.
Link loss (measured by OTDR) = 5 dB
Number of connectors = 1 (used in OTDR)

Now we calculate the actual fault location on earth taking values of fiber parameters as shown in Table 1:

- fiber_loss(dB) = fiber length (km) x fiber attenuation per km = 9.362 x = 0.3 = 2.8086 dB
- conn_loss (dB) = connector loss x number of connectors = 0.75 x 1 = 0.75 dB
- C = 9; Therefore, Initial OFC joints = 9
- No. of OFC joints (expected) = {Link Loss – (fiber_loss+ conn_loss)}/ splice loss = {5 – (2.8086 + 0.75)}/0.1= 14.414 ≈ 15
- Predicted OFC joints = OFC joints (expected) – Initial OFC joints = 15 – 9 = 6
- Predicted OFC cuts = Predicted OFC joints /2 = 6/2 = 3
- Increase in fiber length = Number of predicted OFC cuts x increase in fiber length as per predicted OFC cut = 3 x 10 = 30 meter
- Deviation of actual fault location on earth = Increase in fiber length = 30 meter
- Location of fault on earth (km) = Distance measured by OTDR – Deviation of actual fault location on earth = 9362 – 30 = 9332 meter = 9.332 km.

Hence, we are able to find out the exact location of fault on earth and we can dig it accordingly.

Programming language used to implement the algorithm

The programming language which we have used for implementing this algorithm is PHP. PHP code can be executed with a command line interface, embedded into HTML code, or it can be used with various web systems, web frameworks and web content management systems. We have chosen PHP over other languages because of the following reasons:

A) It is very easy to learn and use. It is also a very powerful language and has more resources.
B) It is a widely used platform, so if any errors are detected it can be quickly rectified.
C) When compared with other languages PHP is relatively fast.
D) It can interact with different databases quickly, so if we want to store the fault information in any database for later processing of data, we can do that efficiently using PHP.
E) It is platform independent. It can run on Windows, Mac and Linux. It is a very powerful language and has more resources.

III. RESULT AND ANALYSIS

After implementing the above algorithm with the use of PHP, we get the output results as shown in Figure 8.

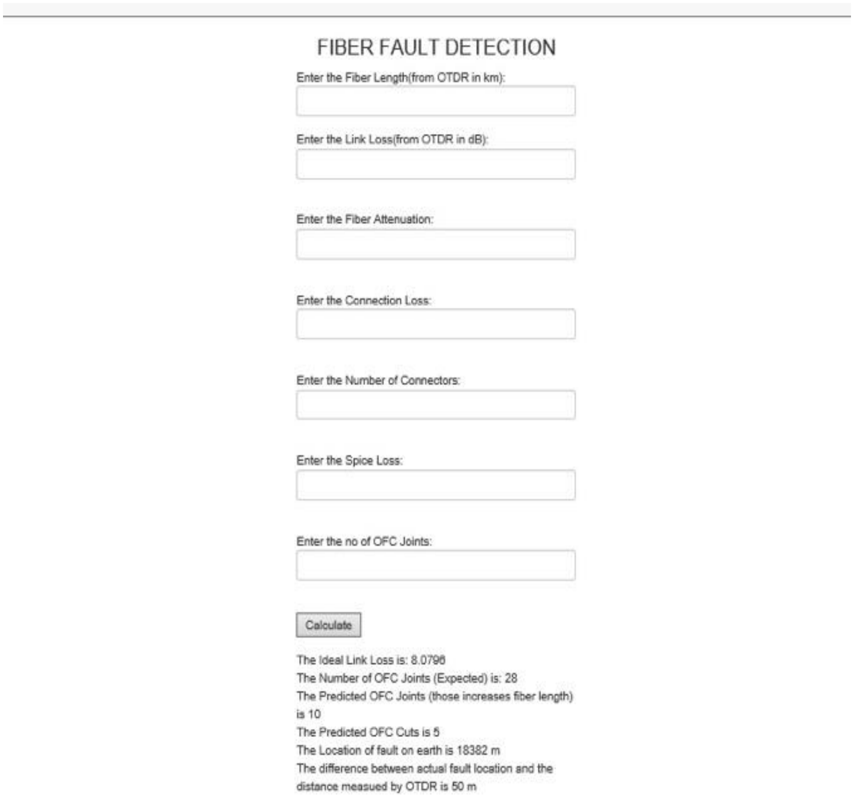

Figure 8. Screenshot of the PHP output

Fiber parameters used for calculation are shown in Table I.

TABLE I. FIBER PARAMETERS [1]

Parameter	***Specification***
Transmission Wavelength	1550 nm
Fiber Attenuation per km	0.3 dB/km
Connector Loss	0.75 dB
Splicing Loss	0.2 dB
Fiber Length per drum	2 km

TABLE II. RESULTS BY THE PROPOSED ALGORITHM

	DM	LLOTDR	OFCJ	EXPOFC	IDLL	OFCJA	OFCC	AD	DIFF
1	10.221	5	10	12	4.8	2	1	10.211	10
2	12.62	6	12	15	5.736	3	2	12.6	20
3	14.222	7	14	20	6.4166	6	3	14.192	30
4	15	7	14	18	6.65	4	2	14.98	20
5	17.124	8	17	22	7.5872	5	3	17.094	30
6	18.432	9	18	28	8.0796	10	5	18.382	50
7	20.242	9	20	22	8.8226	2	1	20.232	10
8	22.122	10	22	27	9.5866	5	3	22.092	30
9	24.466	11	24	30	10.4898	6	3	24.436	30
10	25.656	11	25	26	10.9468	1	1	25.646	10
11	27.7	12	27	30	11.76	3	2	27.68	20
12	29.42	13	29	35	12.476	6	3	29.39	30
13	30.422	13	30	32	12.8766	2	1	30.412	10
14	32.262	14	32	36	13.6286	4	2	32.242	20
15	34.671	15	34	39	14.5513	5	3	34.641	30
16	37.411	16	37	41	15.6733	4	2	37.391	20
17	40.211	17	40	42	16.8133	2	1	40.201	10
18	43.333	19	43	53	18.0499	10	5	43.283	50
19	45.621	19	45	46	18.9363	1	1	45.611	10
20	50.242	21	50	52	20.8266	2	1	50.232	10
21	52.212	22	52	56	21.6136	4	2	52.192	20
22	53.444	23	53	63	22.0832	10	5	53.394	50
23	56.667	24	56	63	23.3501	7	4	56.627	40
24	58.212	25	58	68	24.0136	10	5	58.162	50
25	60.112	25	60	63	24.7866	3	2	60.102	10

From Table II above, we can make a list of parameters:

DM – Distance measured by OTDR (in km)
LLOTDR – Link Loss measured by OTDR (in dB)
OFCJ – Initial number of OFC joints (without considering any cuts or breaks)
EXPOFC – Expected number OFC joints based on link loss calculated by OTDR
IDLL – Ideal Link loss (Without any cuts or breaks)
OFCJA – Extra joint which increases the length of fiber
OFCC – Number of cuts present in fiber (no unit)
AD – Actual distance of fault (in km)
DIFF – Difference in distance calculated by OTDR and algorithm (in meters)

Then, we analysed the above data using a statistics and data analysing software known as STATA. The results of the analysis are as follows which are shown in these three figures below: Figure 9, 10, and 11, respectively.

From the implementation of the proposed algorithm, the actual locations of faults or breaks on the earth were traced which helped us to save time as well as cost, which fulfill the main objective of this research. From Table II, for example we consider the distance 17.124 km measured by OTDR, the actual location of the break as calculated by the algorithm is 17.094 km which is roughly 30 meters before the distance calculated by the OTDR. The statistical analysis of the dataset using STATA gave a perfect correlation (r =1) of the measured distance by OTDR and the actual location of fault (Figure 9, 10, and 11). So, there exists a linear relationship between both the values. A "P value" of 0.9963 obtained using STATA in the analysis of the measured distance from OTDR and the actual location of fault implies no significant difference. This result authenticated the accuracy of the algorithm in locating the actual location of faults or breaks on fibers on earth.

```
. pwcorr DM AD
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	DM	AD
DM	1.0000	
AD	1.0000	1.0000

Figure 9. Look-Up (Correlation) Table.

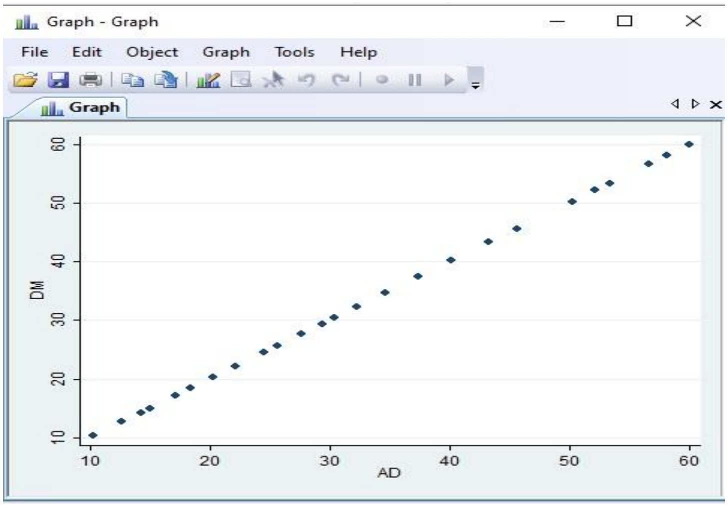

Figure 10. Linear Relation between AD and DM.

Two-sample t test with unequal variances

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
DM	25	33.2818	3.131712	15.65856	26.81826	39.74534
AD	25	33.257	3.131216	15.65608	26.79449	39.71951
combined	50	33.2694	2.191569	15.49673	28.86528	37.67352
diff		.0248001	4.428559		-8.879414	8.929014

diff = mean(DM) - mean(AD) t = 0.0056
Ho: diff = 0 Satterthwaite's degrees of freedom = 48

Ha: diff < 0 Ha: diff != 0 Ha: diff > 0
Pr(T < t) = 0.5022 Pr(|T| > |t|) = 0.9956 Pr(T > t) = 0.4978

Figure 11. Analysis of output of our algorithm using STATA.

IV. Conclusion

The objective of this present study is to obtain a more precise, economic and time-saving fault detection and rectification technique. Comparing the results given by OTDR and the algorithm, we concluded that a more efficient way to calculate the fault location has been obtained more precisely. Also, the algorithm can be implemented very easily alongside OTDR and saves our efforts in digging the ground to rectify the fault.

Reference

[1] V. Kumar and D. Rajouria, "Fault Detection Technique by using OTDR: Limitations and drawbacks on practical approach of measurement". *International Journal of Emerging Technology and Advanced Engineering (IJETAE)* ISSN, 2012, 2(6), pp.2250-2459.
[2] P.D. Murugesh, R. Damini, P. Amitha, M. Shwetha, "IoT Based Underground Optical Fiber Cable Fault Detection System." *International Journal of Advanced Research in Basic Engineering Sciences and Technology*, 2019, 5(2).
[3] J. Ilouno, M. Awoji, B.J. Kwaha, and N.M.D. Chagok, "Comparative Analysis on Fault Detection Techniques in Fiber Optics Communication Links." *International Journal of Innovative Scientific & Engineering Technologies Research* 2018, 6(2), pp.1-10
[4] A.V.N. Vamsi and A.B. Rao, "Fault Detection in Fiber Optic Communication Cable by Coherent Anti-Stokes Raman Scattering using Superconducting Nanowire Single-Photon Detector". *Indian Journal of Science and Technology,* 9(1), 2016, pp.1-6.
[5] G. Baskaran and R. Seethalakshmi, "Intelligent Fault Detecting System in an Optical Fiber*." J. Theor. Appl. Inf. Technol.*, 2012, 39(2), pp.178-187.
[6] K. Swain, J. Sahoo, M.V.S.V. Prasad, and G. Palai, "Fault Detection System in an Optical Fiber Using Arduino". *International Journal of Applied Engineering Research*, 2015, 10(44), pp.31745-31749.
[7] Technical Review by NTT, "Fault Cases and Countermeasures for Optical Fiber Cables in Optical Network Facilities" 2011.

[8] B.C. Choudhary, Optical Time Domain Reflectometry (OTDR), *Power Point Presentation*, 32 slides, NITTTR.
[9] Agilent Technologies, *OTDR Guide*, April 2001.
[10] J. W. Simatupang and S.-L. Lee, "Transfer matrix analysis of backscattering and reflection effects on WDM-PON systems," *Opt. Express* 21(23), 27565–27577 (2013).
[11] Simatupang, J.W.; Pukhrambam, P.D.; Huang, Y.R. "Performance analysis of cross-seeding WDM-PON system using transfer matrix method." *Opt. Fiber Technol.* **2016**, *32*, 50–57.
[12] Simatupang, J.W.; Lee, S.-L. "Theoretical and g simulation analysis on potential impairments in bidirectional WDM-PONs." *In Proceedings of the IEEE 3rd International Conference on Photonics*, Penang, Malaysia, 1–3 October 2012; pp. 61–65.
[13] Simatupang, J.W.; Lin, S.-C. "A study on Rayleigh backscattering noise in single fiber transmission PON." *Int. J. Innov. Res. Technol. Sci.* 2016, 4, 11–15
[14] J. Simatupang, "Theoretical Analysis of Backreflections in Bidirectional Wavelength Division MultiplexingPassive Optical Networks," *Bulletin of Electrical Engineering and Informatics (BEEI)*, Vol. 2, no. 1, pp. 45–52, Mar. 2013.
[15] T.A. Ali and J. J. H. Ameen, "Study of Fault Detection Techniques for Optical Fibers," *ZANCO Journal of Pure and Applied Sciences*, Vol.31(s3), pp.143-149, DOI: http://dx.doi.org/10.21271/ZJPAS.31.s3.20.