Sādhanā (2020)45:90
https://doi.org/10.1007/s12046-020-01333-1

Design of an improved automatic fiber cut localization with OTDR using GIS mapping

BIMLENDU SHAHI

ION Optics NSM Optical R&D, Nokia Networks, Bangalore, India
e-mail: bimlendu.shahi@nokia.com

MS received 1 June 2019; revised 15 September 2019; accepted 3 February 2020

Abstract. Optical fiber line, considered to be highly effective for signal transmission, sometimes suffer from fiber cut resulting in signal loss. It is highly desired that the exact cut location is found by use of fiber length so that entire fiber cable need not be replaced. An optoelectronic instrument OTDR (Optical Time-Domain Reflectometer) is used to find the position of the cut along the fiber length. There is the need to find the physical location on the GIS map which can provide the exact location where the replacement of fiber or maintenance activity has to be carried out. This paper proposes Vincenty's formula to be used for fiber cut localization using GIS mapping which assumes the Earth to be oblate spheroid instead of exact sphere. This method will be highly accurate than any other method for exact localization of fiber cut.

Keywords. OTDR; fiber cut; GIS; oblate spheroid.

1. Introduction

With the evolvement of optical network, a revolution has materialized in the world of telecommunication. Whatever application may it be, most of the digital traffic being generated is carried by the underlying core network, the optical network. The growth of various such applications including telephony, computer communication, Cloud data accessibility, usage of Internet, etc. has led to excessive demand being placed on optical network. However, there is a huge installation cost associated with it. Further, the cost associated with the O&M activity also impacts the complete adoption of optical fiber. The maintenance activity in the optical network includes the detecting and localising the fiber cuts which results in signal loss. There is the need of the technique which can quickly locate the exact fiber cut location in the optical network and restore the service. Such technique can even reduce the O&M cost.

Traditionally, the optoelectronic device OTDR is used to detect the fiber cut along the fiber length. The OTDR instrument sends light pulses into the fiber and collects the light that has been reflected from various points in the fiber. The instrument then measures strength of the returned pulses which are known as "traces". It is integrated as a function of time and further a plot is created as a function of fiber length. The data thus obtained is relayed to Network Management System and stored in a SOR (a Standard OTDR Record) file which can be viewed and analysed. SOR is an OTDR trace file. However, this traditional method is a manual method and time consuming. It requires a great deal of time to restore the service in case of any service outage due to fiber cut. OTDR instrument is taken to the place where there is the service outage to locate the exact fiber cut. Embedded OTDR (eOTDR) has recently been proposed which can make the process automatic [1]. However, still there is a need of finding the exact location on GIS for the maintenance work to be carried out.

The existing and known way for finding the fiber cuts using OTDR was followed with manual measurement technique. This was quite onerous to exactly localize the fiber cuts that causing the degradation and transmission failure in the connection. There is therefore needed an improved architecture, technique, and method for efficiently, accurately and quickly detecting the precise fault localization.

This paper discusses about newly designed architecture followed by integrating the Geographical Information System (GIS) data for each fiber routes carrying with the knowledge of measured fiber cut from Standard OTDR Trace Data can provide quick and efficient localization of faults in the map. However, this may leverage the OTDR by shortening the cost and time for maintenance of deployed fiber and will necessarily fulfil customers' quality of experiences of service to the product.

2. Architecture

A network management Framework provides applications enabling the users to manage and control network's independent components and performs multiple key functions.

Published online: 22 April 2020

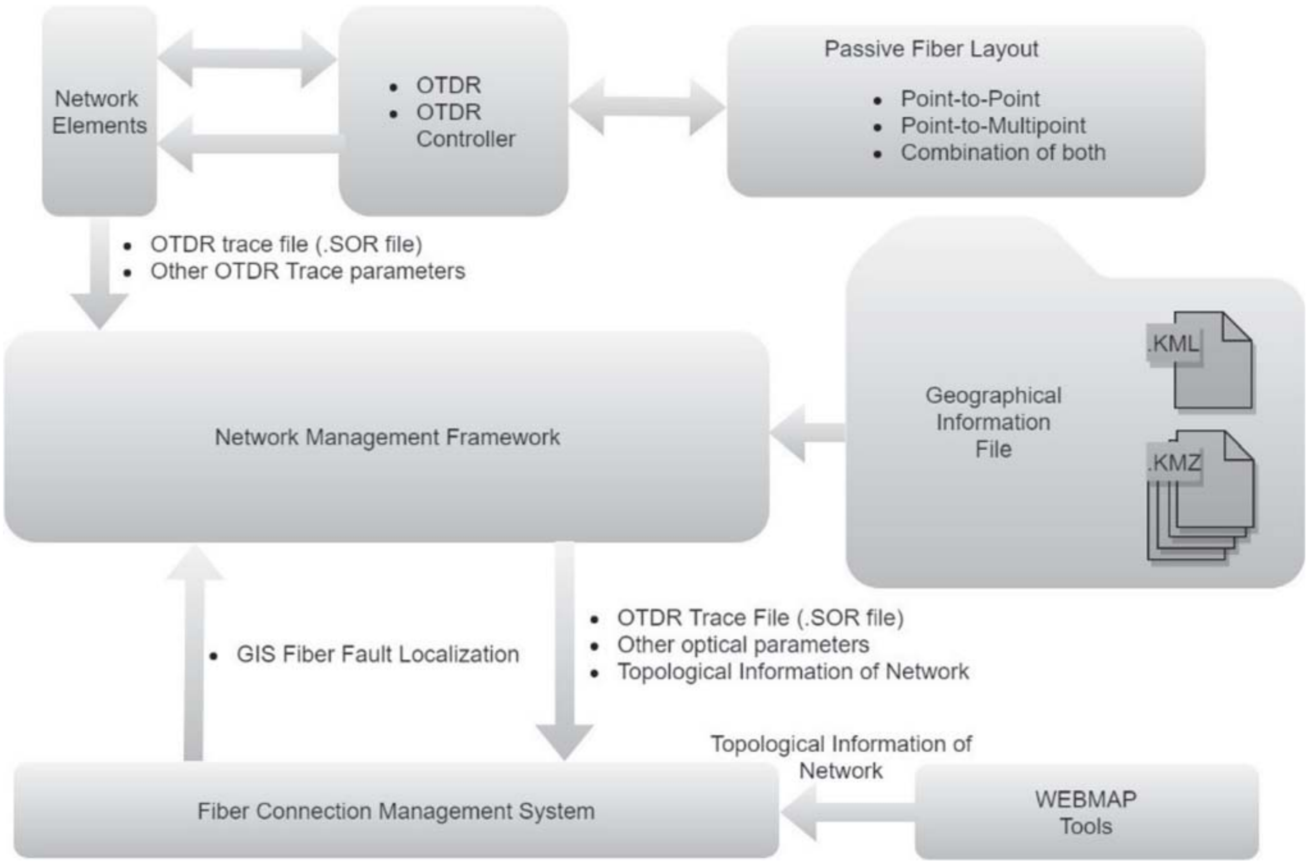

Figure 1. Fiber-cut localization architecture using GIS mapping.

It identifies, configures, updates, monitors and troubleshoots connected network elements in an enterprise network.

In each Network elements, there are small form factor pluggable (SFP) transceiver into which embedding OTDR controller is coupled for automatic detection of optical fiber cut. Generally, OTDR at periodic or certain defined interval introduces a series of optical pulses into the fiber that is under test and extracts the light scattered (Rayleigh backscatter) or reflected from different points of the fiber on the same end of the fiber. Such reflected or scattered characterizes the optical fiber. The strength of pulses returned is measured and integrated as a function of time, and a plot is generated as a function of fiber length. If the baseline fiber length differs from last scan length, there is suspicion that there is fiber cut. Fiber Connection Management System helps to maintain the KML/KMZ file having geographical information of particular deployed optical fiber physical connections. This makes easy for network Management Framework to display the information for particular physical connections.

OTDR is embedded with the one or more Network elements in an enterprise network through a Passive fiber layout. Then, OTDR reports to particular Network elements by means of an OTDR trace file (.SOR file) and further processes the information and sends the processed information to Network Management Framework. Further, Network Management Framework sends the processed information to Connection Management Framework along with the Topological information of Network. WEBMAP tools will help us to render the optical fiber in the map. Further, the GIS based fiber cut localization information is sent back to Network Management Framework for particular connections in the network to enable the network management framework to accurately indicate exact location/position of the fiber cut (figure 1).

3. Solution

The proposed solution uses Openlayers, which is open source javascript library. It provides an API for rendering dynamic map from any source like KML, KMZ, GeoRSS, etc. As KML/KMZ will have geographical information of deployed optical fiber, for example optical fiber running from Node A to node Z [2]. The KML/KMZ comprising of

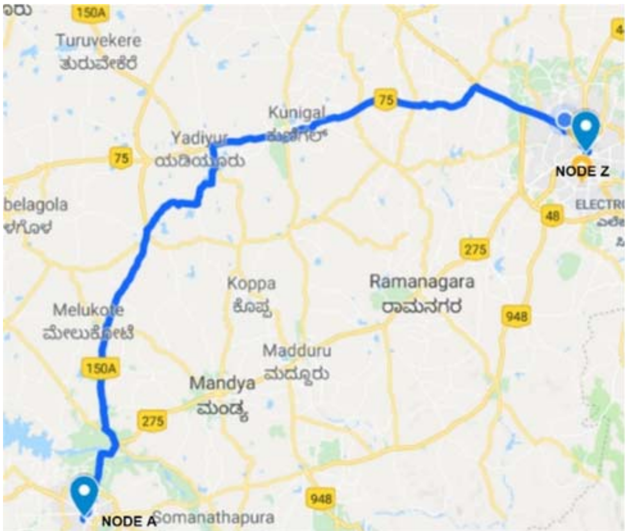

Figure 2. Rendering of Optical Fiber using OpenLayers API.

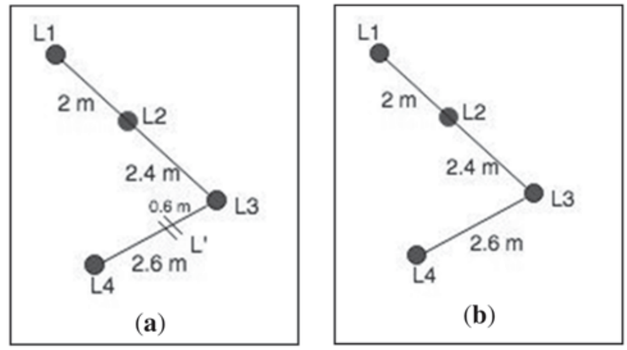

Figure 3. Illustration: (a) Direct Problem, (b) Inverse Problem.

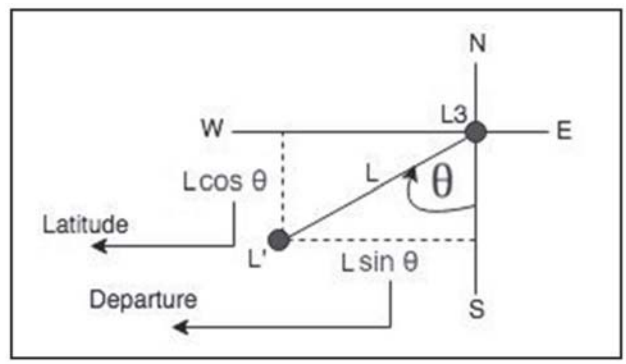

Figure 4. Illustration: Fiber-cut localization using bearing.

the Latitudes and Longitudes are in vector data. These vector data are displayed in the form of lines illustrating the optical fiber running from node A to node Z as in figure 2.

Further, Openlayers API enables the zoom option in a convenient way to display the rendered optical fibers. This enables the user to view and troubleshoot the Optical fibers deployed.

In 1975 A.D, Thaddeus Vincenty precisely formulated and solved two problems: Direct Problem and Inverse Problem. These problems are described in brief to below section, which finds solution with the iterative ways. This formula applies an accurate ellipsoidal model of the Earth, considering with Polar radius of 6356.8 (km) while the equatorial radius of 6378.1 (km) [3]. This assumption is taken to effectively consider earth as form of the egg or pear, if assumed normally. Also, in the formulations been considered the equatorial bulge, due to sort of rotation and gravity variance seen effectively if considered in the long-term effects of it. So, Vincenty formula will be a better solution to solve the problem of finding the exact fiber cut and distances between each latitude and longitude present in the KML/KMZ file. These longitude and latitude present in KML/ KMZ file fall in with the decimal degrees. Vincenty formula iterates and is able to determine the calculated or formulated accurate outcome to approx. 0.5 (mm) errors on the applied ellipsoid shape. Its iterated outcome is able to determine two geodetic problems: Direct problem and Inverse problem.

Direct Problem: On ellipsoid, given a first point (determined by its latitude θ1 and longitude λ1, the direction or the bearing α of that point, and distance from that point to a second point, find the latitude θ2 and longitude λ2 of that second point. This helps in localization of exact fiber cut.

Inverse Problem: Given two points L1 (θ1, λ1) and L2 (θ2, λ2), find the α1 and α2 (the forward and the backward azimuth respectively) and the distance s between them. This helps to find the distances between each latitude and longitude present in KML/KMZ file.

In figure 3, there is assumption that geographical information data consists of 4 points, L1, L2, L3 and L4 of optical fiber. The overall length of optical fiber is found to be 7 m using inverse problem by calculating the distance at each point between L1 and L2, L2 and L3 and L3 and L4 as illustrated in figure 3(b). In case of figure 3(b), there is assumption that L' represents the optical fiber cut between L3 and L4 points. The direct problem helps to find the exact fiber cut (θ', λ') with the help of cutD of having distance 0.6 m from point L3 and its direction as showing in figure 3(a).

As illustrated in figure 4, helps to find out the bearing (θ) between L3 and L' for localization of exact fiber cut, where negative degrees of latitude follow at west and longitude follow at south direction.

4. Algorithm

Algorithm 1: Inverse Problem

Input: Two set of latitude and longitude from KML/KMZ file.

Output: Distances between two set of latitude and longitude.

Steps:

1. Assign as Earth's semi-major axis, (a 🡐 6378137)
   Earth's semi- minor axis, (b 🡐 6356752.314245)
   Earth's polar flattening, (flat 🡐 298.257223563).
2. Assign f 🡐 inverse of Earth's polar flattening.
3. Convert the difference of two longitudes to radian. i.e. L🡐 Radian(lon2-lon1).
4. Assign iterLimit 🡐 100 times and L 🡐 lambda.
5. Assign U1 🡐 $\tan^{-1}$(1-f) with the multiple of tan(Radian(lat1)). Similarly, assign U2 🡐 $\tan^{-1}$(1-f)* tan(Radian(lat2)). Further, Assign S1 🡐 sin(L) and C1 🡐 cos(L).
6. SS🡐$\sqrt{(\mathrm{S1.\,cosU2})^2 + (cosU1.SinU2 - C1.sinU1.cosU2)^2}$
7. **IF**: (condition SS 🡐 0),
   then indicates co-incident point and return 0.

   ELSE:
   Common point is not zero, then return as equatorial Line.
8. Perform from step 7 to 8 until the following condition is satisfied: (abs(lambda - lambdaP) > 1e-12 && --iterLimit > 0).
9. **IF**: iterLimit 🡐 0, then formula fails to converge.

   ELSE: Distance is calculated at that point in km.
10. Handle the exception if any.

The steps from Algorithm 1 are repeated for each two set of latitude and longitude from the KML/KMZ file, and finally output of Algorithm 1 which gives each set of distances between them are added altogether to consider as the length of the optical fiber from KML data. Also, to find the cutD i.e Optical fiber cut happened at distance, output from each iteration of above steps from Algorithm 1 is compared each time with optical fiber cut distance found with the OTDR

Algorithm 2: Direct Problem

Input: Two set of latitude and longitude from KML/KMZ file.

Output: Calculate the bearing between the latitude and longitude and find the optical fiber cut coordinate.

Steps:

1. Assign y ← sin (Longitude2 – longitude1) *cos(lat2)
   x ← cos(lat1) *sin(lat2)-sin(lat1)*cos(lat2)*cos(lon2-lon1).
2. Assign brngA ← Counterclockwise angle in radians (not degrees) between the positive X axis and the point (x, y).
3. Assign brngD ← add 0.210 to degree(brngA). And, further, assign brng ← radian of brngD.
4. Exact optical Fiber cut latitude ←

$$\sin^{-1}\left(\sin(latitude1).\cos(distance) + \cos(latitude1).\sin(distance).\cos(brng)\right)$$

$$where, Distance = \frac{cutD}{6371.0}$$

5. Exact Optical Fiber Cut Longitude ← longitude=(lon1+a+3π)%(2π)- π).
6. Convert the latitude and longitude back to degrees.
7. Return the optical fiber Cut Coordinates.

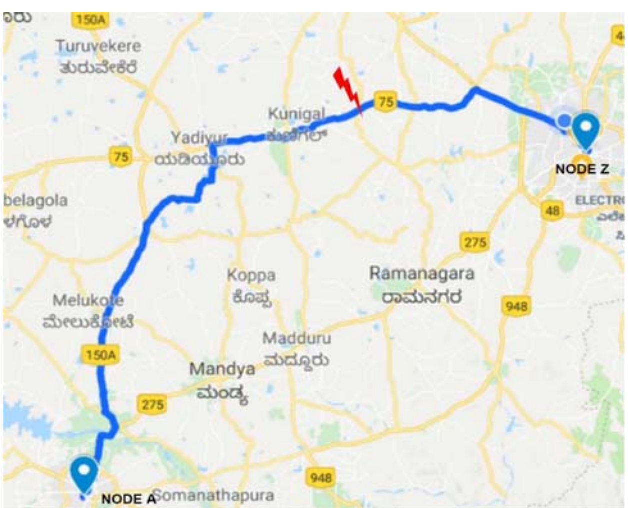

Figure 5. Fiber-cut localization in WEBMAP tools.

trace data. Further, if above comparison satisfies, at that iteration inputs having two set of latitude and longitude is given as input to Algorithm 2 to calculate the bearing between them, which helps to find optical fiber cut coordinates.

The exact optical fiber cut localization is shown in the map with bolt symbol is shown in figure 5. This helps to localize the exact optical fiber cut using Geographical Information Data (KML/KMZ file) for each fiber routes carrying with the knowledge of measured optical fiber cut from standard OTDR trace data. This will help to quickly and efficiently localize any breakage in the optical fiber within Map itself.

5. Conclusion

The ability of the optical communication system to be able to exactly localize the cut in the fiber can reduce O&M cost and also the service outage time. The adoption of Vincenty's method in the GIS enables user to view the location where maintenance or replacement activity needs to be carried out over the map itself. Since Vincenty's formula is applied to ellipsoidal shape and also the Earth is assumed to be ellipsoidal rather than spherical, the development of this system can be an added advantage to robust optical network in monitoring and maintenance activity easily and efficiently, hence one more step towards optical network being ubiquitous network.

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