Traffic Monitoring with fiber sensing for Open APN PoC Reference

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[TM for Open APN PoC Ref]

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1.1. Purpose

Smart cities, which are urban areas that leverage new, digital technologies such as Information and Communications Technology (ICT) to provide efficient services, collect data, and streamline municipal operations, are being widely studied by communities worldwide. Simply put, a smart city collects specific data through various methods, and the information obtained from that data is used to realize services for efficient city management and operation.

Automatic traffic monitoring is one example of a common service being evaluated for smart cities. Traffic monitoring can detect traffic congestion, be it people, vehicles, or materials, and the collected data can be used to effectively manage the flow of people. For example, a smart city operator can control the flow of people at a large public event by guiding them to empty streets instead of crowded ones, allowing end-users to travel more efficiently and smoothly. This, in turn, can improve the public's experience when visiting that place or event.

To achieve traffic monitoring that can be envisioned as a service of a smart city, various methods are available for collecting different types of urban data, including cameras and electrical sensors. These methods collect information by detecting the existence and movement of the object in the sensing range of the device. However, these detection technologies require active devices that require energy, such as a power supply, and are therefore relatively prone to power failures and malfunctions due to aging and are costly to manage. Further, to sense a wide urban area, it is necessary to install a large quantity of such active devices, and the construction cost increases with the monitoring area and the number of sensors. Also, if we want to use it to control the flow of people as described above, we need to detect information in real time and control a large amount of data to keep monitoring.

In response to this challenge, optical fiber sensing technology is a technique that enables the construction of a traffic monitoring system at a comparatively low cost. In optical fiber sensing, the physical movement on the optical fiber is detected by laying the optical fiber on the object to be measured and measuring the optical signal from the optical fiber. At this time, by using the communications optical fiber already deployed throughout the city, the cost of implementing the sensing medium is eliminated, and the cost of constructing the sensing system is greatly reduced. Therefore, as a method of data collection in the above-mentioned cities, optical fiber sensing using existing communications optical fibers effectively reduces construction costs. Additionally, because the electrical power is not necessary for the optical fiber and the optical fiber itself is robust, the management cost of the optical fiber as the sensing media is also small.

For traffic monitoring services targeting large urban areas covering large populations of people, these systems require the ability to monitor data in real time and with a large capacity for data control. By combining this service with the Open APN (All Photonic Network) of the IOWN (Innovative Optical and Wireless Network) Global Forum, it is possible to realize real-time performance and control over large amounts of data and thus traffic of myriad types. In other words, the data sensed with APN can be transferred at high speed and low delay, and analysis data at a remote cloud computer can be returned to the location at high speed and low delay.

Additionally, this approach offers significant cost advantages. For example, in the open APN, all the nodes of the communication network are processed in the optical domain without conversion to an electrical signal, and all the communication control, such as switching, is carried out in the optical domain. Therefore, if one optical fiber sensor interrogator is connected to the optical node, the optical fiber sensing can be carried out for many communications optical fibers connected to the optical node by one interrogator. Based on this concept, the IOWN Global Forum has evaluated the technical issues and methods for fiber sensing in APN communication optical fibers, as well as confirmed the feasibility of fiber sensing connecting to APN-G, which is for switching communication paths. These findings can be found in IOWN GF's published document [1, 2, 3].

One fiber sensing technology that can enable wide-area traffic monitoring is distributed acoustic sensing (DAS), which detects vibration in optical fibers. If vibrations caused by vehicle traffic above ground can be detected, it will be possible to measure traffic flow. By connecting a DAS interrogator that measures the vibration of an optical fiber deployed within an existing fiber network, it is possible to monitor the traffic of vehicles throughout the region of the network. The fiber sensing technology for an open Access and Processing Network (APN), which utilizes the technology discussed at the IOWN Global Forum, enables the realization of optical fiber sensing technology for optical fibers deployed for communication. Thus, by performing fiber sensing in the IOWN APN, traffic flow monitoring can be achieved, and urban services, such as those of a smart city capable of real-time traffic control, can be realized.

The purpose of this PoC is to investigate the feasibility of regional traffic flow monitoring by using fiber sensing in APNs, to verify the usefulness of fiber sensing in an APN fiber by proving that fiber sensing can monitor traffic in real time and reduce cost, and to show the possibility of traffic flow monitoring service in smart city by fiber sensing.

1.2. Objectives

The objective of this Proof of Concept (PoC) is to clarify whether ground traffic monitoring, which enables traffic flow control, can be realized using underground communication optical fiber. Specifically, it will demonstrate that wide-area traffic monitoring by fiber sensing is possible using an APN facility configuration with switches and shared connections in the APN and communication optical fibers, that inflow and outflow of vehicles to a certain range of areas can be detected, that real-time detection is possible, and that long-term monitoring is possible. It will also be shown that traffic monitoring using fiber sensing with communication optical fibers is more cost-effective than other conventional traffic monitoring methods.

1.3. Scope

In this PoC, the traffic flow on the ground is measured using a fiber optic vibration distribution measuring interrogator (DAS: Distributed Acoustic Sensing) to verify the traffic flow monitoring by sensing the underground optical fiber, utilizing a facility configuration that simulates the APN. The following list may be outside the scope of this PoC work.

- Verification of required performance and accuracy of the traffic flow monitor
- Verification of coexistence with actual commercial communication signals
- Verification of the ability to use APN-G switches to select the sensing fiber from commercial communication optical fibers

2. Reference Cases

In this PoC, fiber sensing is used to monitor road congestion. More technically, to estimate the road traffic on the ground, the vibration state of the underground communication optical fiber is measured. By measuring the movement and number of vibrations, we can detect the passage of vehicles on the ground and determine their direction. For the purposes of this document, traffic monitoring for area input/output control is assumed, and the detection of each vehicle is not critical, but the congestion of vehicles is the most important unit of measurement. We also assume a service that detects the flow in and out of an arbitrary area within a smart city, as well as the distance to that area from the city center.

The fiber sensing system should meet the following requirements:

- The Interrogator is a fiber optic vibration sensor (DAS) designed for general vibration measurement.
- The sensing fiber shall be a commercial single-mode optical fiber.
- The interrogator and the sensing fiber are connected via APN-G, as defined in Section 4 of the fiber sensing with Open APN Release 2 document.

The road congestion monitoring service should fulfill the following requirements:

- For each of the detected vehicles, the system should detect the following
  - Speed level with the following speed brackets: Low ~30 km and Middle ~50 km
  - The direction
- The measurement fiber length must be able to continuously monitor a distance on the order of at least 10 km, assuming a long inter-node distance such as APN-G.

We don’t define the required detection ratio, i.e., the radio of detected vehicles to actual vehicles, because how many vehicles can be detected separately as a whole strongly depends on the position (including depth) of the underground optical fiber cable for communication, the positional relationship of the road, and the measurement accuracy. Therefore, the detection ratio is not set as a desired feature.

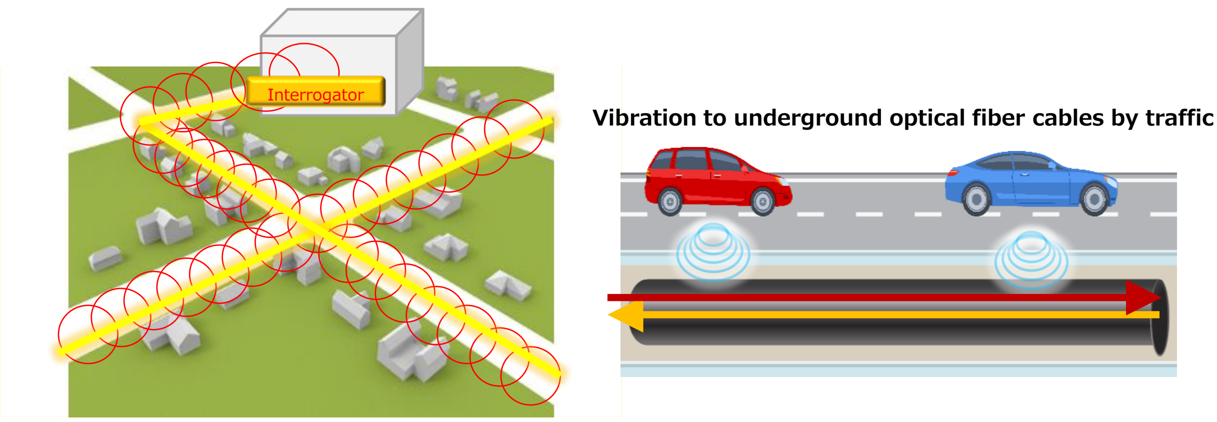

Figure 1: Image of regional traffic monitoring with ground vehicle vibration measurement

3. Desired Features

To demonstrate the cost advantage of traffic monitoring using APN optical fiber sensing, which is relatively independent of the measurement technology itself, the following function is necessary:

- As for the spatial resolution of monitoring, the system should distinguish two vehicles 2-3 m apart.

4. Key Benchmarks

Benchmark the following items

- The maximum length/size of the monitored area
    - Maximum length of the monitored range in the measured fiber
- The achievable spatial resolution of measurement,
    - The distance between two points where the information contained in the measured points does not overlap. This corresponds to the pulse width in the case of an OTDR measurement that emits pulses.
    - When measured by OTDR, $w*v/2$ is the distance resolution, where w is the pulse width and v is the speed of light in the optical fiber.
- The achievable temporal resolution of measurement
    - Real-time measurement is established by repeating the analysis and output process within x seconds for each waveform measured every x seconds.
    - If the waveform cannot be created or output within x seconds, it will take x seconds or more to output the waveform measured in x seconds, causing accumulation and puncture.

The following parameters are benchmarked in order to properly consider them as real-time measurements.

- Time interval of the measured waveform
- Results output interval

References

[1]	IOWN Global Forum, "Fiber sensing for Open APN" release-1," 2022. https://iowngf.org/wp-content/uploads/2023/04/IOWN-GF-RD-FS_for_Open_APN-1.0.pdf
[2]	IOWN Global Forum, "Fiber sensing for Open APN" release-2," 2023. https://iowngf.org/wp-content/uploads/2023/06/IOWN-GF-RD-Fiber_Sensing_for_Open_APN-2.0.pdf
[3]	IOWN Global Forum, "Open APN Architecture PoC Reference," Chapter 2.5, 2022 https://iowngf.org/wp-content/uploads/formidable/21/IOWN-GF-RD-Open_APN_Architecture_PoC_Reference-1.0.pdf

History

Revision	Release Date	Summary of Changes
1	June 2025	Initial Release