How did the data propagate?

Automated Optical Path Monitoring

With the development of 5G, our world might seem more wireless than ever. However, lurking behind this and facilitating all high-speed data transfer are kilometres and kilometres of optical fibres. The backbone network for all communication, wireless or otherwise, is this sprawling network of fibres. For reliable communications and internet access, the world's expanse of fibre optic cables must work well with faults being diagnosed quickly and easily. Takeo Sasai at NTT Laboratories has been finding novel ways to employ artificial intelligence for easy-to-use fibre monitoring and diagnosis.

Physical damage and misalignment of fibres can be easily done, and rapid diagnosis is essential.

Every second, 24,000 Gigabytes of data is uploaded to the internet. This is equivalent to nearly 50 completely full standard laptop hard drives. A significant portion of this data comes from social media sites such as Facebook and Twitter, and the technological effort to keep these volumes of data moving between data centres and end users is significant.

While many end users now make use of wireless technologies such as 4G to connect to the internet and stream information, most of the underlying infrastructure is made of a network of interconnected fibre optic cables. These cables are everywhere, with large bundles buried under the ocean floor and others running overhead in our cities.

The advantages of wired communication are that large amounts of data can be transferred faster and are inherently more secure than wireless communications. The transmission capabilities of optical fibres continue to improve, but developing, maintaining, and expanding this network of cables is a costly task. Many optical fibres are in difficult-to-access and remote locations, and when they are installed, their performance must be checked carefully.

Takeo Sasai at NTT Laboratories is an expert on modelling the inner secrets of what happens in the great lengths of fibre optic cables that cover our world. He has been working on ways to automatise the diagnosis of problems with fibre optic cables, such as information and data loss, with a bit of help from artificial intelligence.

INFORMATION AS LIGHT

Fibre optic cables carry information in the form of light. The information to be sent is encoded as little pulses of light at one end of the cable and can be decoded back to electrical signals at the other.

There are different ways of constructing fibre optic cables that are optimised for either short or distance data transfer. Still, there are two properties of the cable that are crucial in both cases – the loss and the dispersion. Loss can occur for several reasons in a cable – from attenuation of the strength of the signal due to misalignment or damage or even breakages in the fibre. Dispersion is a 'spreading' of the signal over time, which can happen due to different colours of the light signal travelling at different speeds, or different modes propagating in the fibre at different rates.

While a small amount of loss can be tolerated, if the loss rate becomes too high the fibre will no longer reliably transfer information. When fibres are installed – a complex and expensive process in itself – the loss and dispersion characteristics are usually tested to make sure signals can pass through the fibres without any problems. The challenge is that this testing process requires expert engineers and specialist equipment, such as dispersion analysers and an optical time domain reflectometer (OTDR). The test equipment injects a series of sample light pulses into the fibre to mimic a signal and measures how long it takes for them to return and their properties.

Sasai believes there is an easier way to check the quality of fibres that would also allow for constant monitoring of fibre conditions. At present, if there is a suspected problem with an optical fibre, engineers will have to travel on-site with test equipment like an OTDR to carry out measurements for diagnosis. This is time consuming and expensive but potentially a thing of the past with Sasai's automated methods.

DATA INSIGHTS

As optical fibres are constantly transmitting information, Sasai's new approach makes use of this data as a diagnostic tool in itself. Using a machine learning algorithm, Sasai can identify particular patterns in the received datasets that reflect the loss and dispersion the signal has undergone on its journey through the fibre.

The reason this analysis method works is because we have an equation that can be used to understand and describe how light propagates through an optical fibre, known as the nonlinear Schrödinger equation (NLSE). The mathematical structure of the NLSE is quite similar to a neural network – a computing system that is a series of algorithms, or neurons, connected in different ways by a 'net' to represent the relationships between them.

Neutral networks are supposed to imitate how our brains work and are widely used in machine learning as they can capture even very complex relationships between the 'neurons' or processing points. Often, these patterns and relationships would be very hard for a human to spot, and the data processing and analysis for a neural network can also be automated. In Sasai's case, he has created a network of 'learning NLSE', taking advantage of the similar structures between the equations and a neural network to use received data to calculate the signal loss and dispersion without the need for any additional measuring equipment like OTDR.

The reason to use neural networks for NLSE is that they cannot usually be solved analytically, but require numerical methods that undergo many iterations to try to converge on an approximate solution. One of the numerical methods used for the NLSE is known as digital backpropagation, which involves a complex series of operations, including concatenation of a linear (dispersion) operation block and a nonlinear (phase rotation) operation block *(see figure 1)*. The phase rotation is one of the main limitations on the performance of optical communications, but this can be compensated through careful treatment with the digital backpropagation.

AI learns propagation equation in an optical fibre, and enables automated testing of optical networks.

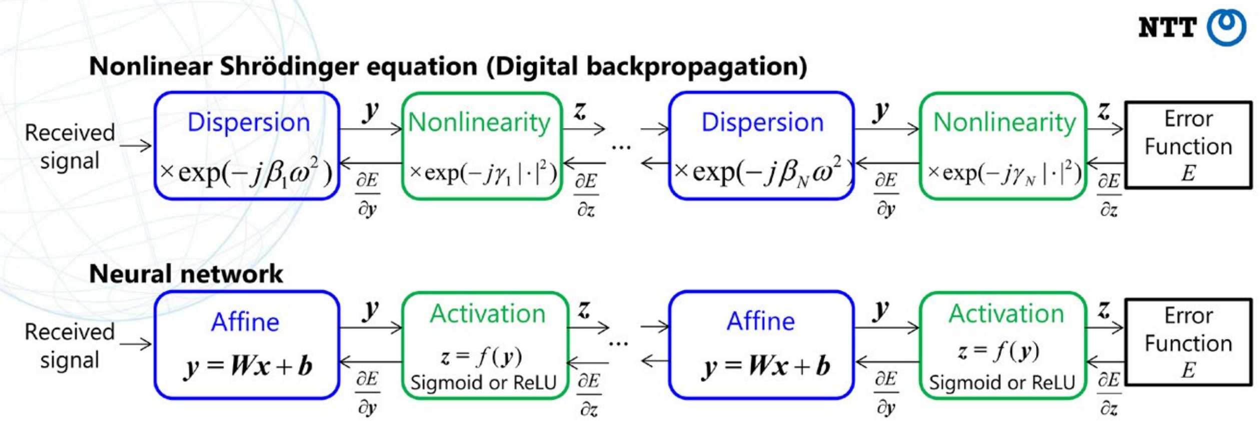


Fig 1: NLSE has essentially the same structure as neural networks, consisting of linear and nonlinear functions.

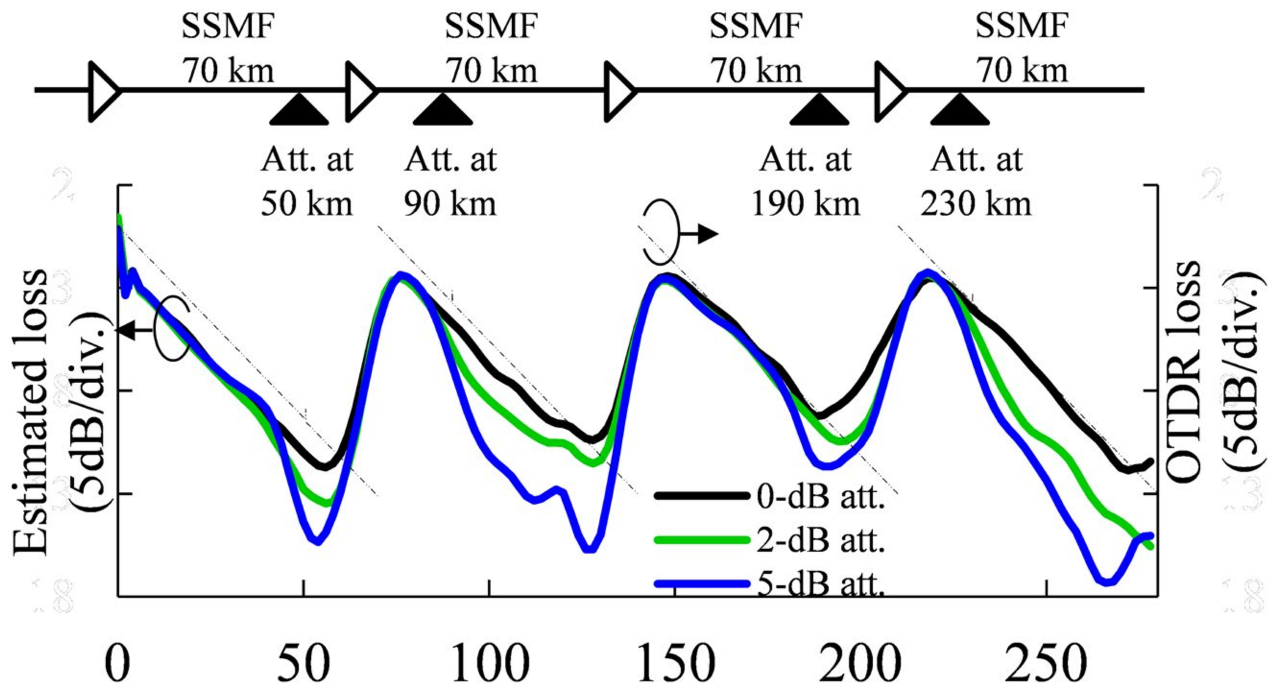


Fig 2: The estimated loss profile of 70 km x 4 spans systems, obtained using Sasai's method. The dashed line is the loss profile measured using a traditional optical time-domain reflectometer (OTDR) for reference. The estimated profile fits the reference OTDR line well, and clearly exhibits the fibre loss, intentional attenuation, and even amplification by optical amplifiers. It is noteworthy that the loss over multi-span link can be estimated, which is impossible for standard OTDRs. For dispersion profile, see the original paper shown in References.

The similarity between the neutral network and the NLSE means that all the coefficients that are required for the best digital backpropagation steps can be 'learned' from transmitted and received data. From the learned values of these coefficients, it is possible to tell the optical power and dispersion at each and every point of the fibre.

As the process is fully automated, and make sure of data that would be transmitted anyway, the automated diagnosis could be set up as a continual monitoring approach and does not need any extra measurements to be made with additional equipment. Sasai is excited by the possibility of monitoring of fibre optic cable status, as this will allow prediction of failures before they occur and advance warnings of problems to ensure even better network stability.

PREDICTION AND MODELLING

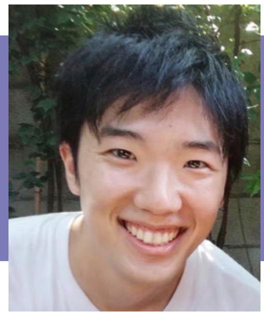
No additional equipment like OTDR is needed for Sasai's diagnostics as the received dataset will indirectly contain information on the fibre loss and dispersion. Using the NLSE, given an input value and set of fibre conditions, it is possible to predict what the output signal should look like. In the case where the output is known, it is possible to use these relationships to try and calculate what the fibre conditions must have been to generate such a signal.

This will allow easier network building and monitoring to ensure even better network stability.

Combining the knowledge of the optical propagation in the fibre from the NSLEs with the learning capabilities of the neural net, it is then possible to work out information such as which region of the fibre is experiencing high loss and pinpoint perhaps where structural works need to be carried out and where the fibres have become problematic.

Sasai's approach opens up many new possibilities for maintaining optical fibre networks, which will become increasingly important in an ever-more connected world with a push for faster and faster internet connections. Even the rollout of new wireless transmission technologies such as 5G will require an expansion of fibre optic cabling to connect masts and other equipment.

While fibre optic cable bundles are surprisingly strong, physical damage and misalignment of fibres can be easily done, particularly when there are nearby construction works. Having full online monitoring of cables would make rapid diagnosis of problems a reality, without the need to ever call out, or potentially even consult, an engineer.



Behind the Research

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Research Objectives

Takeo Sasai has developed a technique that reveals the loss and dispersion profile of optical fibres without special equipment, enabling the monitoring and maintenance of optical fibre paths.

Detail

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Bio

Takeo Sasai studies the modelling of optical fibre communication systems, from both behavioural and data-driven approaches at NTT Laboratories, particularly the modelling and compensation of optical fibre nonlinearity and transceiver nonlinearity. He has research expertise in digital signal processing and machine learning and develops interpretable and complexity-efficient Artificial Intelligence agents to enhance the performance and the accuracy of behavioural modelling such as nonlinear Schrödinger equation.

References

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Personal Response

Do you think this type of fault monitoring will become commonplace in fibre optic installations in the future?

" Yes, we are currently working on the demonstration of this monitoring technique using actually installed fibre networks. We believe that optical fibre connections will be like current LAN cables, which we can use to establish connections just by inserting them into our laptops. "