Towards Costless Temperature Monitoring through PLOAM Information in TDMA PON Networks

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Abstract: Derivation of environmental temperature from FTTH networks is investigated. Ranging grants in G.984 allows estimation of average temperatures without additional hardware. This information can be valuable in smart cities and early fire warning systems.

1. Introduction

Fiber to the home (FTTH) has become the most widespread wired access network technology around the world. Once any telecom infrastructure is mature, the goal is to maximize its profit. One approach is finding new applications for the infrastructure, such as feeding mobile base stations, or developing new services. For example, in mobile networks collecting vast quantities of data from daily business operations related to local and roaming events and mining this information for user behaviors has become a relevant source of income. These operations, administration and management (OAM) data are leveraged to reveal underlying routines, for example, for monitoring city dynamics which can be sold to B2B or governments or providing context-aware services to customers.

Here, it is explored if sensing information can be extracted from the FTTH infrastructure. In particular, the optical distribution network in FTTH, especially in aerially-deployed networks, could be used to extract estimations of the average environmental temperatures just from mining information of the physical layer OAM (PLOAM) overhead in TDMA PON standards, such as ITU-T G.984. Although it can only provide averaged values, unlike conventional fiber sensors, this approach does not require any additional hardware being therefore costless. Thus, FTTH could add another layer of data collection in smart cities to provide enhanced awareness of city conditions. Additionally, it could also pave the way towards new industrial high-temperature monitoring with low-cost off-the-self interrogators from the FTTH market.

2. Concept

During ONU activation in G.984, one of the seven ONU states is devoted to ranging [1] since the upstream transmission from the different ONUs must be synchronized with the upstream GTC frame boundaries. To emulate that each ONU is at an equal distance from the OLT, an equalization delay (EqD) for each ONU is required. During the Ranging state (O4) this equalization delay is measured in bits. From this parameter that can be obtained from the OLT management interface the round trip delay (RTD) can be derived as given by (1).

$$RTD_i = T_{eqd} - EqD_i = t_i^{1490} + R_{sp}Time + t_i^{1310} \tag{1}$$

where T_{eqd} is the zero-distance EqD, which is the offset between the downstream frame and the desired reception of the upstream frame at the OLT; $t_i^{1490}$and t_i^{1310} are the propagation delay in downstream and upstream, respectively; and $R_{sp}Time$ is the ONU processing time which is $35 \pm 1\ \mu s$. The propagation delay is affected by temperature changes through the dependence of the index of refraction with temperature [2-3]. This dependence arises mainly from the thermo-optic coefficient of silica since it is one order magnitude larger than thermal expansion [3].

$$n = n_0\left(1 + \frac{dn}{dT}T + \frac{d^2n}{dT^2}T^2 + \cdots\right) \tag{2}$$

Through this dependence, changes in temperature can be estimated from EqD readings in time:

$$\Delta RTT = \Delta EqD_i = \frac{L}{c}(n_{1490} + n_{1310})\left(\frac{dn}{dT}\Delta T + \frac{d^2n}{dT^2}\Delta T^2 + \cdots\right) \tag{3}$$

Most ITU FTTH standards calculate the EqD value accurate to a single bit time with respect to the nominal upstream line rate. Thus, for a linear thermo-optic coefficient the resolution would be

$$\Delta T = \frac{\Delta EqD_i c}{\frac{dn}{dT}(n_{1490}+n_{1310})}\frac{1}{L}\ ℃/km \tag{4}$$

for a typical linear thermooptic coefficient (dn/dT) of around $7 \cdot 10^{-6}$ ºC^{-1} [3] in ITU-T G.652, the temperature resolution of G.984 would be around $\Delta T = 11\ ℃/km$. This relation can show some variability arising mainly from the thermo-optic coefficient of G.652. Different experimental estimations of this parameter can be found in the literature with a typical value around $7 \cdot 10^{-6}$ ºC^{-1} but some reported values go from $5 \cdot 10^{-6}$ ºC^{-1} up to $30 \cdot 10^{-6}$ ºC^{-1} [3], which will result in changes of resolution from $16\ ℃/km$ to $2\ ℃/km$. Additionally, the actual refraction index of the deployed fiber is also unknown. Estimations [1] point out to a variability of $\pm 0.000017 \cdot (t_i^{1490} + t_i^{1310}) = \pm 0.000017 \cdot RTT$, where RTT is the round trip time of the fiber. Thus, it has a lower impact on temperature estimation.

The process of EqD calculation is carried out during ONU activation. However, it is also performed in-service. The OLT monitors the arrival time of upstream transmission and small corrections are made on EqD without repeating the ranging process. This in-service EqD adjustment, through PLOAM message #21, *Ranging Adjustment*, is done at the request of the OLT. The OLT maintains two drift thresholds to trigger this update. The most stringent is DoW that G.984.3 recommends to keep at ± 4 bits. In order to have a continuous monitoring of environmental temperature and enhance accuracy, the DoW threshold of some PON trees should be lowered to 1 bit through a firmware modification.

3. Experimental results

Preliminary experiments have been carried out to the assess the potential of commercial G.984 components for temperature estimation. A length of 2490 meters of ITU-T G.657.A1 (bend insensitive) fiber, with a 250 µm tight-buffer and embedded in a plastic cable jacket, was employed. An OLT, ZTE C320, and one ONT, ZTE F601, were connected through the fiber which was immersed in a water bath which was heated to various temperatures. Water temperature was continuously monitored using a thermometer. The results are shown in Figure 1 where it is shown that approximate temperature estimations can be done after calibration and that the particular fiber under test shows a quadratic thermooptic coefficient (R^2=0.961). Each value is the median of five EqD recordings after forcing ONU activation since the OLT is a commercial model with limited access to firmware.

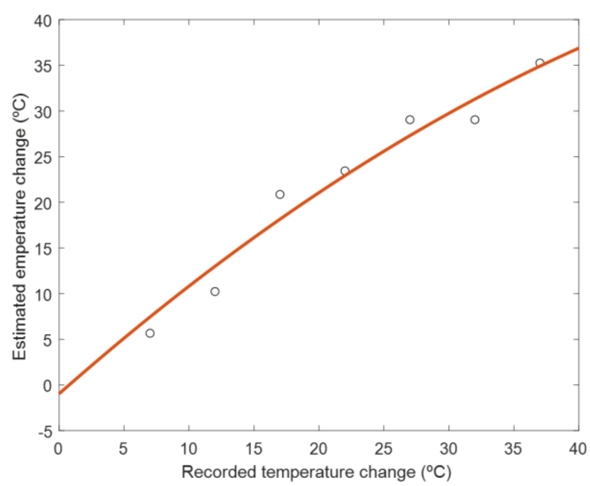

Fig. 1. Average temperature measurement using a ZTE C320 OLT and a ZTE F601 ONT with a spool of 2490 meters of G.657.A1 fiber.

Additionally, in-service tests in a commercial G.984 network with an aerially-deployed optical distribution network have also been carried out. Fig. 2 shows the temperature change estimation from EqD readings while the network was working when the average temperature in the city was 21ºC and 27ºC. Each point is the median of five measurements and a calibration has been applied to derive the temperature value since the thermooptic coefficient is unknown.

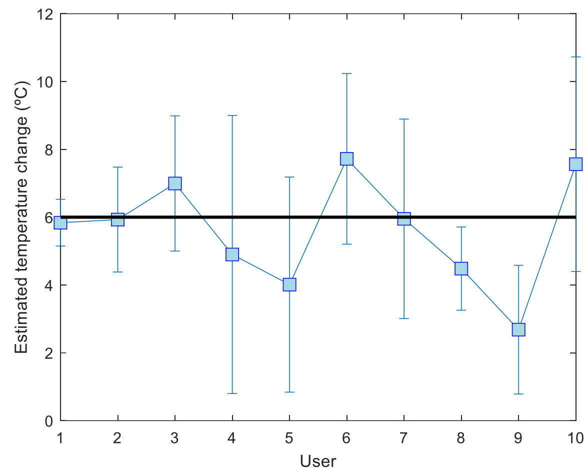

Fig. 2. Estimation of temperature change from EqD readings from a commercial FTTH network in operation.

This kind of average temperature sensor can find application in the context of smart cities for detailed calculation of temperature mappings. Its application can also be envisaged for early detection of fires given that the maximal service temperature of fused silica is about 1200 K. Figure 3 shows that this approach can be used to detect the temperature rise associated with a fire on a section of the fiber link. A linear thermooptic coefficient of $7 \cdot 10^{-6}$ ºC^{-1} has been considered for the numerical example.

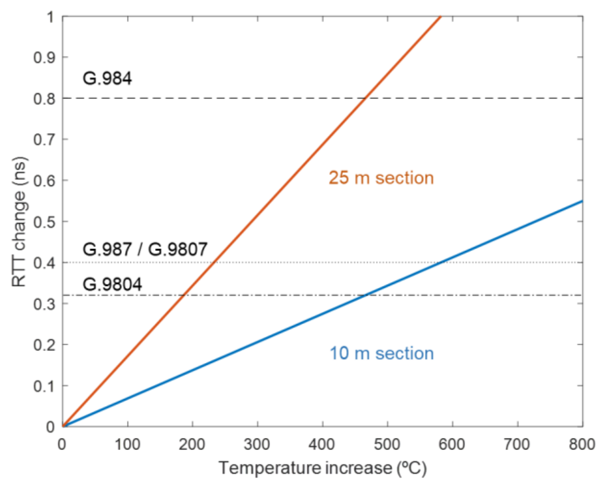

Fig. 3. Simulation of thresholds for potential application of FTTH infrastructure for fire early alert.

4. Conclusion

A new application for FTTH infrastructure has been proposed and preliminary assessed. Experimental results show the feasibility of limited environmental temperature monitoring just using standard G.984 commercial equipment. The evolution of FTTH technology with new standards, such as G.9807, G.9804 and future ones, with increased bitrates and/or slight modifications in firmware to ease probing and derive readings directly from the upstream phase drift will pave the way for enhanced temperature estimation for applications such as in smart cities and early fire warning. It can also enable a new approach for temperature fiber sensors based on low-cost FTTH off-the-self components.

4. References

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