Long-term Forecasting of Frame Alignment Losses for Circuit Emulation Implementation

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***Abstract*—The article provides a method for long-term forecast of frame alignment losses based on the bit-error rate monitoring for structure-agnostic circuit emulation service over Ethernet in a mobile backhaul network. The developed method with corresponding algorithm allows to detect instants of probable frame alignment losses in a long term perspective in order to give engineering personnel extra time to take some measures aimed at losses prevention. Moreover, long-term forecast of frame alignment losses allows to make a decision about the volume of TDM data encapsulated into a circuit emulation frame in order to increase utilization of the emulated circuit.**

The developed long-term forecast method formalized with the corresponding algorithm is recognized as cognitive and can act as a part of network predictive monitoring system.

***Keywords*: frame alignment loss, long-term forecast, predictive monitoring.**

I. INTRODUCTION

Convergent development of modern information communication networks makes actual the task of monitoring of the states and time/probabilistic characteristics of equipment. Monitoring is the main way to infer a specific state and/or performance characteristics of a maintenance entity in order to diagnose disturbances, faults and degradations [1], which allows engineering personnel to take the necessary measures to restore normal functioning of the entity.

This article proposes a method of the long-term forecasting of the frame alignment loss probability P_{AL} as the new approach to time/probabilistic characteristics monitoring. The method is based on monitoring the bit error rate ε in a mobile backhaul network that uses Circuit Emulation Service over Ethernet (CESoETH). The developed method performs forecasting of long-term change of the P_{AL} value in order to detect in advance a time instant when the P_{AL} value may exceed its threshold value denoted as P_{ALT}. Frame alignment is supposed to be lost in the time instant when the P_{AL} value exceeds the P_{ALT} threshold value.

II. ANALYSIS OF PREVIOUS RESEARCHES AND PUBLICATIONS

ITU Recommendations [1–4] define the various kinds of monitoring including telemonitoring, operational monitoring, state monitoring, quality monitoring, on-demand monitoring, performance monitoring, and proactive monitoring. All these kinds of monitoring immediately react to the faults and degradations after their occurrence. However, there is a definition of the completely new kind of monitoring called the predictive monitoring available in [5]. Predictive monitoring allows to predict emergency situations, which gives engineering personnel extra time to take the necessary actions to prevent the emergency situation or if it is unavoidable to ease the consequences.

Predictive monitoring is now commonly used in industry, healthcare, transport and logistics, environmental protection, and business [6–12]. However, possibilities of using the predictive monitoring for information communication networks are studied insufficiently.

The article [13] proposes a method for short-term forecasting of frame alignment losses in mobile backhauls using CESoETH defined in Technical Specifications MEF 3 [14] and MEF 8 [15]. CESoETH supports both structure-agnostic and structure-aware modes of operation. Unlike the structure-aware mode, an interworking function (IWF) of equipment operating in the structure-agnostic mode encapsulates incoming TDM bit stream into Ethernet frames “as is” without any structural conversions and then frames travel throughout an asynchronous part of a network.

The method for short-term forecasting of frame alignment losses, as a part of a predictive monitoring implementation, predicts the P_{AL} value over a prediction interval L = 1 using bit error rate ε monitoring in a mobile backhaul network. Using the short-term P_{AL} forecast it is possible to increase utilization of an emulated channel by increasing the volume of encapsulated data.

The article [16] describes the $P_{AL} = f(\varepsilon, n_C)$ dependence, which can be obtained for the given bit error rate ε of a TDM stream and a known number n_C of TDM frames encapsulated into an Ethernet frame.

The Recommendation [17] defines Errored Second Ratio – ESR value suitable for the synchronous part of the object under research.

The work [18] contains mathematical tools necessary to calculate bit error rate in order to simulate changes of ε within the wireless part of the research object.

The work [19] brings mathematical tools including polynomial and exponential moving average extrapolations, the Foster-Stuart method along with the method of sequential differences, which are used as a basis of the developed method for long-term forecasting of frame alignment losses using bit error rate *ε* monitoring in a mobile backhaul network with CESoETH implemented.

III. TASK STATEMENT

The method of predicative monitoring of frame alignment losses is applied for frame aligners (FA) residing in a base transceiver station (BTS) and in a mobile switching center (MSC) of the research object (Fig. 1). The research object includes synchronous and asynchronous segments. Performance degradation in each segment may affect probability of frame alignment loss.

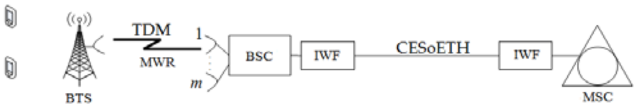

Fig. 1. Functional architecture of the research object

TDM bit stream with the bit rate of 2 Mbit/s is transferred with the help of the microwave radio (MWR) between the BTS and a base station controller (BSC). Between the BSC and MSC synchronous TDM data is carried through asynchronous segment by means of CESoETH. This article considers the case of structure-agnostic CESoETH operation mode because, compared to the structure-aware mode, the research object is exposed to higher risks of frame alignment losses [16].

The purpose of this work is to develop the method of long-term forecasting of the frame alignment losses based on monitoring the bit error rate *ε* in a mobile backhaul network using Circuit Emulation Service over Ethernet (CESoETH). Unlike the method for short-term forecasting of frame alignment losses [13] the method of long-term forecasting of the frame alignment losses uses bigger prediction interval that incorporates the t_{cr} time instant when a frame alignment loss is supposed to happen. This can be used for making a decision about the volume of TDM data encapsulated into an Ethernet frame.

IV. THE METHOD OF LONG-TERM FORECASTING OF FRAME ALIGNMENT LOSSES BASED ON BIT ERROR RATE MONITORING

The method of long-term forecasting of the frame alignment losses based on bit error rate *ε* monitoring implies calculation of the *n* values of the frame alignment loss probability P_{AL} performed according to [13] as:

$$P_{AL}(\mathrm{i}) = \left[1 - \left(1 - \varepsilon_i\right)^a \cdot \left(1 - \beta \cdot n_C\right)\right]^3, \qquad (1)$$

where

a – quantity of bits in the frame alignment signal,

$\beta = ESR \cdot 0{,}175 \cdot \Lambda / f_0$ – coefficient defining a type of TDM bit stream (f_0 – bit rate of the TDM bit stream; Λ – length of a TDM frame),

n_C – quantity of TDM frames encapsulated into an Ethernet frame,

ε – bit error rate that varies over time due to disturbances over the microwave radio path.

The threshold value $P_{ALT}(n_C)$ of the frame alignment loss probability is obtained for the known n_C value by substituting $\varepsilon_i = 10^{-3}$ for the corresponding variable of the (1). The value of $\varepsilon_i = 10^{-3}$ is used because ITU-T Recommendation G.706 [20] states that with this value it is almost impossible to distinguish whether Cyclic Redundancy Check errors are caused by the false frame alignment or by transmission bit errors. For the threshold value of the frame alignment loss probability the (1) is rewritten as:

$$P_{ALT}(n_C) = \left[1 - 0{,}993 \cdot \left(1 - \beta \cdot n_C\right)\right]^3. \qquad (2)$$

In the case of real MWR equipment, the values of bit error rate are obtained through corresponding monitoring but for the research object simulation can be calculated with the following expression [18] considering the Binary Phase Shift Keying implemented in the microwave radio path:

$$\varepsilon_i = \frac{1}{2}\left(1 - erf\left(\sqrt{\frac{2 \cdot \frac{10^{0{,}1 \cdot p_c}}{R}}{4{,}002 \cdot 10^{-21} \cdot k}} \Big/ \sqrt{2}\right)\right), \qquad (3)$$

where

p_c – signal power level at an input of MWR receiver,

R – bit rate of MWR,

k – noise coefficient of the MWR receiver.

The series of $\{P_{AL}(i)\}$ values may have significant fluctuations in long-term perspective. These fluctuations can be made smoother with the help of an exponential moving average obtained as follows [19]:

$$Q(i) = Q(i-1) + \alpha \cdot \left(P_{AL}(i) - Q(i-1)\right), \qquad (4)$$

where

α – coefficient that characterizes a weight of current observation and belongs to the range of $0 < \alpha \le 1$.

It is necessary to detect an increasing or decreasing trend in the series of $\{P_{AL}(i)\}$ values before performing extrapolation. The trend detection is carried out with the help of the Foster-Stuart method [19]. This method associates every $P_{AL}(i)$ value with two variables u_i and l_i. If a current $P_{AL}(i)$ is the biggest one in a series then $u_i = 1$ while $l_i = 1$ if the current $P_{AL}(i)$ is the smallest one in the series. Otherwise $u_i = l_i = 0$. Trend in the series of $\{P_{AL}(i)\}$ values can be proved by testing the following inequality:

$$\frac{\sum_{i=1}^{n} u_i - l_i}{\sigma_2} > t_\alpha; \qquad (5)$$

where

σ_2 – mean-square error of the $\sum_{i=1}^{n} u_i - l_i$ value,

t_α – value of Student t-statistics.

If the inequality (5) is fair then trend in the series of $\{P_{AL}(i)\}$ values is proven with the certain confidence probability.

If the quantity of available P_{AL} values is insufficient for the polynomial extrapolation or there is no trend found in the P_{AL} values then the exponential moving average extrapolation is used to detect the possibility of a frame alignment loss. The possibility of a frame alignment loss is detected with the help of the following inequality:

$$Q(\mathrm{n})+t_{\alpha}\cdot s\cdot\sqrt{1+\frac{\alpha}{2-\alpha}}>P_{ALT}(n_C), \qquad (6)$$

where

s – mean square deviation from frame alignment loss probability series obtained considering f degrees of freedom.

If a trend in the series of $\{P_{AL}(i)\}$ has been proven and the quantity of available P_{AL} values is sufficient ($n \ge n_{\min}$; where $n_{min} = f(L, \lambda)$ according to [19]) for the polynomial extrapolation then the order λ of a polynomial is determined with the help of the method of sequential differences.

The next step is to use the least squares method [19] to obtain the statistical estimations a_j $j=\overline{0,\lambda}$ of polynomial coefficients. The general form of an extrapolation polynomial is $\hat{P}_{AL}(\mathrm{i})=a_0+a_1\cdot i+a_2\cdot i^2+\cdots+a_{\lambda}\cdot i^{\lambda}$.

The purpose of long-term forecasting of frame alignment losses is to determine a time instant in a long-term perspective when a frame alignment loss may occur. This can be done by finding a minimum value of i that makes the following expression fair.

$$P_{ALT}(n_C)\le a_0+a_1\cdot i+a_2\cdot i^2+\cdots+a_{\lambda}\cdot i^{\lambda}+t_{\alpha}\cdot s. \qquad (7)$$

The minimum value of i that fits expression (7) refers to the time instant t_{cr} of possible frame alignment loss.

It should be noted that simulation involves time shift from event to event where the new event refers to obtaining a new ε_i value.

Fig. 2 depicts the developed method for long-term forecasting of frame alignment losses using bit error rate monitoring in a mobile backhaul network with CESoETH implemented.

Let us take a look at the developed method operation example considering the following initial conditions: 1) p_c changes from –123 dBW to –124.67 dBW; 2) $k = 9$, 3) $R = 2$ Mbit/s; 4) $n_C = 2$; 5) BPSK modulation is used in MWR path; 6) the value of ε_i is updated every second considering Nokia FlexiHopper [21] MWR; 7) trend in the series of $\{P_{AL}(i)\}$ is proven with the confidence probability of 0.95; 8) quantity of values in the series of $\{P_{AL}(i)\}$ is $n = 23$; 9) simulation lasts for 70 seconds; 10) α = 1 because there is no need to apply smoothening.

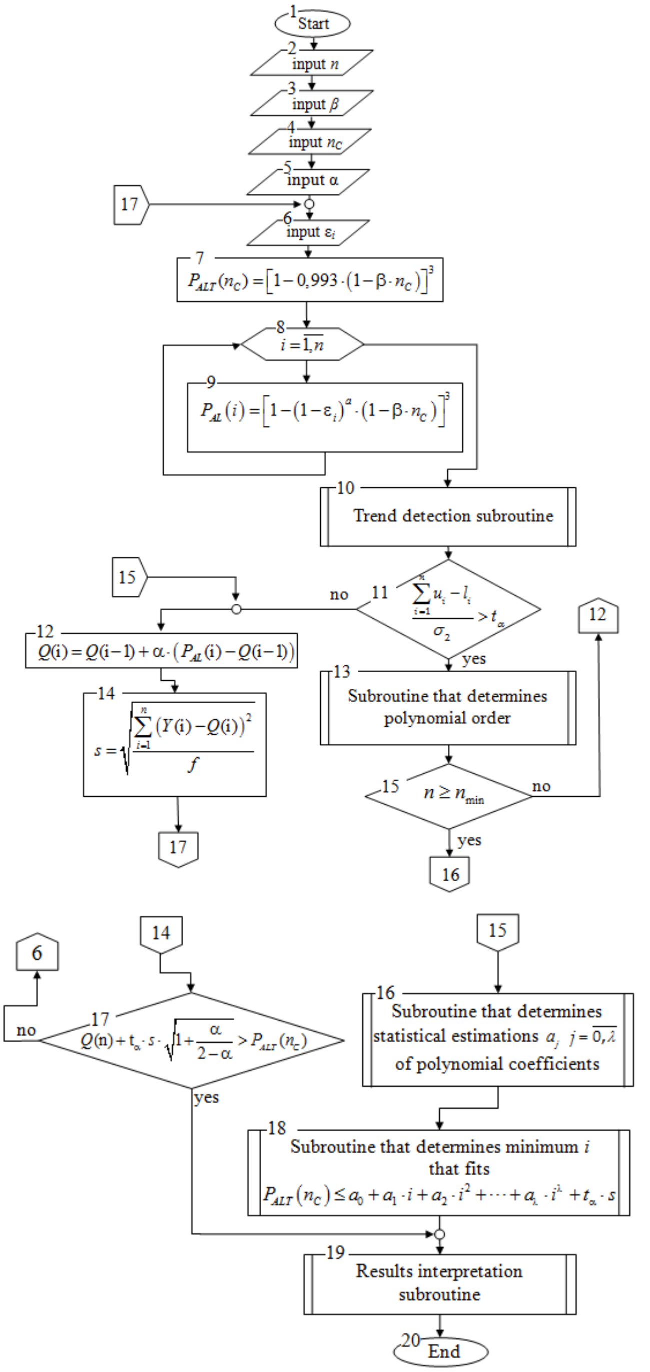

Fig. 2. Algorithm of long-term forecasting of frame alignment losses using bit error rate monitoring in a mobile backhaul network with CESoETH.

The algorithm uses exponential moving average extrapolation till the 23-rd second of simulation. During this period frame alignment loss has not been detected. After the 23 seconds of simulation the algorithm has the quantity of P_{AL} values sufficient for the polynomial extrapolation and trend has been already proven. At this time the algorithm obtains the order $\lambda = 3$ of the polynomial. Then the following statistical estimations of the polynomial coefficients are obtained: $a_0 = 3{,}184\times10^{-10}$; $a_1 = 3{,}616\times10^{-11}$; $a_2 = 2{,}037\times10^{-12}$; $a_3 = 1{,}430\times10^{-13}$. This allows to predict frame alignment loss after 68-th second. The actual frame alignment loss happens between 68-th and 69-th second of simulation as it is shown in the Fig. 3.

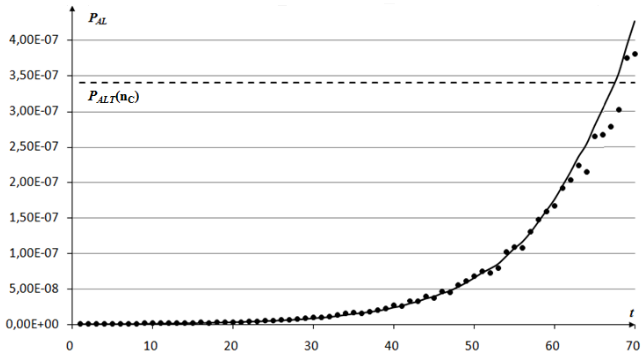

Fig. 3. Long-term forecasting of frame alignment losses.

V. CONCLUSION

This article has proposed and formalized with the algorithm the method for long-term forecasting of frame alignment losses using bit error rate monitoring. Being the part of frame alignment losses predictive monitoring implementation for mobile backhauls using CESoETH, the developed method for long-term forecasting of frame alignment losses allows to detect in a long-term perspective the time instants when frame alignment losses are supposed to happen. This allows engineering personnel to make a forehanded decision about the necessary actions preventing the emergency situation or easing possible consequences. Besides, the results of long-term forecasting of frame alignment losses can correct a decision about the volume of TDM data encapsulated into an Ethernet frame based solely on the results of the short-term forecasting of frame alignment losses in mobile backhaul using CESoETH.

The proposed algorithm of long-term forecasting of frame alignment losses along with the method of short-term forecasting of frame alignment losses based on monitoring the bit error rate is acting as an implementation of predictive monitoring of frame alignment loss probability in the case of CESoETH applied in a mobile backhaul network.

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