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LONG-TERM MONITORING OF ROUTES UNAVAILABILITY FOR INFORMATION AND COMMUNICATION NETWORKS

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ДОВГОСТРОКОВИЙ МОНІТОРИНГ НЕГОТОВНОСТІ МАРШРУТІВ У ІНФОКОМУНІКАЦІЙНІЙ МЕРЕЖІ

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ДОЛГОСРОЧНЫЙ МОНИТОРИНГ НЕГОТОВНОСТИ МАРШРУТОВ В ИНФОКОММУНИКАЦИОННОЙ СЕТИ

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Abstract. The article represents an approach to long-term monitoring of routes unavailability for information and communication networks based on the TCP/IP stack. The proposed approach allows the identification of the necessity of a route reconstruction or reconfiguration before QoS significantly suffers, which can be a part of a preventive maintenance strategy. Being the bases of the proposed approach, the statistical prediction techniques including the polynomial extrapolation and autoregressive integrated moving average allow to obtain prediction results with the preset probability. In addition, the proposed method allows the performance of an automatic network infrastructure and routes discovery. This work also explains the interaction between software modules of the proposed method implementation. The proposed method represented by this work is recommended to be used in the wired networks of access and aggregation/distribution where usually a few (if any) backup routes are available and, thus, it is more sensible to avoid a malfunction than to react on it after it happens.

Key words: preventive maintenance, long-term monitoring, network routes, unavailability.

Анотація. У статті показано підхід до довгострокового моніторингу неготовності маршрутів інформаційних та комунікаційних мереж, які використовують стек протоколів TCP/IP. Запропонований підхід може бути частиною стратегії превентивного технічного обслуговування мережі оскільки дозволяє виявити необхідність реконструкції або реконфігурації маршрутів до того, як суттєво знизиться якість обслуговування користувачів. Після виявлення загрози зниження якості обслуговування через надлишкову неготовність маршрутів мережі, система моніторингу, яка використовує запропонований метод, генерує відповідне повідомлення для інженерного персоналу або адміністратора мережі, що дає останнім часом, необхідний для вживання запобіжних заходів, з метою недопущення деградації якості обслуговування. Запропонований метод реалізовано у вигляді програмного продукту, який є сумісним із існуючими апаратними та програмними засобами моніторингу. Основною областю застосування даного методу є провідні мережі доступу або агрегації/розподілу, де, зазвичай, резервні маршрути або зовсім відсутні або їх кількість суттєво обмежена, і тому більш доцільно уникнути аварійної ситуації, ніж реагувати на неї після того, як вона матиме місце. Методи статистичного прогнозування, а саме: поліноміальна екстраполяція та інтегрована модель авторегресії і ковзного середнього, які покладені в основу запропонованого підходу, дозволяють отримати результати прогнозування із наперед відомою ймовірністю. Окрім того, не має потреби в адаптації реалізації методу до конкретної мережі, тому що додатково передбачено

автоматичне розпізнання мережної інфраструктури та маршрутів. При формуванні статистичних вибірок для довгострокового прогнозування використовується метод "ковзного вікна", а розмір вибірки динамічно змінюється в залежності від періоду упередження прогнозу та необхідної точності прогнозування. Дана робота пояснює принципи математичної обробки результатів моніторингу, склад та взаємодію між програмними модулями реалізації запропонованого методу.
Ключові слова: превентивне технічне обслуговування, довгостроковий моніторинг, маршрути мережі, неготовність.

Аннотация. В статье представлен подход к долгосрочному мониторингу неготовности маршрутов инфокоммуникационных сетей, использующих стек протоколов TCP/IP. Предложенный подход позволяет выявить необходимость реконструкции или реконфигурации маршрутов до того как существенно снизится QoS, что может быть частью стратегии превентивного технического обслуживания. Методы статистического прогнозирования, а именно: полиномиальная экстраполяция и интегрированная модель авторегрессии и скользящего среднего, которые положены в основу предложенного подхода, позволяют получить результаты прогнозирования с заранее известной вероятностью. Предложенный метод дополнительно позволяет автоматически выполнить распознавание сетевой инфраструктуры и маршрутов. Данная работа объясняет взаимодействие между программными модулями реализации предложенного метода. Вместе с тем, метод, показанный в данной работе, рекомендуется к применению в проводных сетях доступа или агрегации/распределения, где, как правило, резервные маршруты или вовсе недоступны или их число сильно ограничено и поэтому более целесообразно избежать аварийной ситуации, чем реагировать на нее после того, как она произойдет.
Ключевые слова: превентивное техническое обслуживание, долгосрочный мониторинг, маршруты сети, неготовность.

Modern information and communication networks are quality of service (QoS) enabled and capable of providing a wide range of services. However, the process of providing many services with certain QoS requirements faces many challenges. For example, inconsistent routing may significantly affect all the aspects of service performance and, finally, decrease the degree of satisfaction of a user of the service.

Under normal operation conditions, routers of an information and communication network are likely to experience "inconsistent routing tables and routing loops" [1] during a convergence caused by a topology change due to link or node malfunction and/or unavailability. Despite that convergence is a "natural" part of a routing protocol operation, it is clear that inconsistency of routing tables and routing loops contradict the definition of availability performance given in [2]. As stated in [3], convergence time varies depending on network load, and, also, between 45% and 70% of faults in networks are caused by aging telecommunication equipment. These facts illustrate the task of long-term analysis and prediction of network routes availability/unavailability with the consideration of how convergence time changes during network operation.

The purpose of this work is to propose a method of long-term analysis and prediction of network routes unavailability aimed at identifying the necessity of network's reconstruction. The main idea of the method is to inform the network administrator about the necessity of a network's reconstruction in advance, before QoS significantly suffers due to insufficient network availability.

Recent works on the topic show its relevance. The authors of [4] provide a powerful tool to estimate the relationship between quality of experience (QoE) (for audio/video) and routes availability through simulation of connections and disconnections in a mobile ad hoc network (MANET). Unlike [4], our approach is suitable for wired networks of access and aggregation/distribution. While the work [4] allows the estimation of current QoE for audio/video traffic, the method proposed in this work is aimed at identifying long-term trends in routes availability regardless of the type of transported traffic.

The work [5] proposes a mathematical model to estimate the probability of route availability between two arbitrary nodes of MANET at the stage of network planning. While [5] can be considered as a guide to plan a reliable MANET, the approach proposed in this paper focuses on identifying the reconstruction necessity of wired access and aggregation/distribution network during long-term operation.

Unlike the work [6], our method focuses on tracking dynamics of exact network routes' unavailability in time. The purpose of such an approach is to inform the network administrator/owner about the necessity the reconstruction or reconfiguration of the exact routes. This is significant because the low availability of some routes may contribute to major QoS issues while overall network performance can still be satisfactory.

In contrast to approach given in [7], the proposed method is focused on finding long-term trends in availability dynamics of exact routes, but not in the states of definite networking devices.

The works [8, 9] introduce approaches of availability-aware network design and analysis while the proposed method is designed to enhance functionality of routes availability monitoring on existing information and communication networks.

The approach [10] considers solution to the problem of failures identifications during the operation of local computer networks. The approach is based on the Holt-Winters method for the short-term prediction. Unlike [10], the method given in this paper is more specific (it is applied to routes availability only) and has a long-term orientation.

The work [11] aims to review traffic forecasting methods for wireless mesh networks. The only approach that hypothetically can be adopted for our task is the wavelet-based neural network. However, it is not a good option because prediction accuracy, in this case, depends on the examples used during neural network learning process. Another drawback is that a system based on neural networks requires a prior learning process while telecommunication companies usually expect solutions to be capable of full functionality straight "out of the box".

The stated above task can be solved by adopting the method described in [12]. Precisely, only one in three prediction-time horizons, among the mentioned in [12], will be used – the long-term horizon.

The method [12], as well as its long-term part adaptation represented in this paper, can be applied to large-scale transport networks. However, it is more sensible to apply the long-term routes unavailability prediction method (LTRUPM) to the networks of access and aggregation/distribution because, unlike transport networks, they do not have many backup routes. This means the unavailability of a route may contribute to major QoS problems.

Since the parameter that is a subject to predictive monitoring is route unavailability, it makes sense to clarify the definition of this term. The problem is that the ITU terminology database does not contain the definition of route availability or unavailability in context of a wired network. Thus, for the LTRUPM we can adopt the route unavailability definition provided in [13] i.e. "unavailability of all possible routes between the two nodes". It worth noting that "a node" in the case of LTRUPM refers to a router or an L3 switch. Route unavailability is further expressed through route unavailability coefficient (RUC) that is obtained as route unavailability time divided by an observation period.

Long-term term predictive monitoring [12] considers two significant parameters. They are a prediction horizon and a threshold value corresponding to the reconstruction necessity. Both parameters are supposed to be defined by a network administrator or engineering staff of the exact network with the help of an expert method depending on current network policies and priorities.

Formulating the LTRUPM in the form of steps sequence, we have

Step 1. Perform network topology discovery and identify all the network routes using the routing protocol.

Step 2. Use SNMP agent of the equipment to keep track of unavailability or load of the equipment and hence the routes.

Step 3. Form series of RUC values for each route.

Step 4. Test a hypothesis of having a trend in the series. It should be mentioned that the series must be formed according to the principle of "sliding window"[12].

Step 5. If the hypothesis is fair then a trend must be formalized and extrapolated in order to compare a predicted value of RUC with the threshold corresponding to reconstruction necessity.

Otherwise, the comparison with the threshold should be done in order to make sure that QoS has no risk of suffering due to low availability value.

Step 6. If the predicted value of RUC is greater than the threshold, an LTRUPM implementation forms a message in order to warn a network administrator or engineering staff about reconstruction necessity at some route.

The above steps three to five require mathematical processing of the data obtained from monitoring tools. More is shown in the detail of the mathematical model of the data processing.

At the step 3, the series $\{F(j)\}$ (where *j* number of a sample in the series) of RUC values is formed according to principle given in [14], i.e. the size n_{min} of series is defined by prediction horizon L_D and the extent of an extrapolation polynomial λ. It is worth noting that for LTRUPM we consider $1 \le \lambda < 6$ in order to avoid ill-conditioning of matrices while using the Least Square Method.

To test a hypothesis of having a trend in the series $\{F(j)\}$ a Foster-Stewart method is used, which allows the identification of the trend in average value and in variance [14]. The Foster-Stewart method [14] considers that every j-th value is matched to

$$u_j = \begin{cases} 1, \text{if } F(j) > F(p);\ p = \overline{1, j-1}; \\ 0, \text{otherwise.} \end{cases}$$
$$l_j = \begin{cases} 1, \text{if } F(j) < F(p);\ p = \overline{1, j-1}; \\ 0, \text{otherwise.} \end{cases} \quad (1)$$

Then the following sums are calculated:

$$S_F = \sum_{j=1}^{n_{min}} \left(u_j + l_j\right);$$
$$d_F = \sum_{j=1}^{n_{min}} \left(u_i - l_i\right). \quad (2)$$

According to [14], the trend-assuming hypothesis is accepted if the following expression is fair:

$$\frac{d_F}{\sigma_{F2}} > t_{\alpha F} \vee \frac{\left|S_F - \mu_F\right|}{\sigma_{F1}} > t_{\alpha F}; \quad (3)$$

where μ_F denotes the expectation that S_F; σ_{F1} is a mean square error of S_F; σ_{F2} is a mean square error of d_F; and $t_{\alpha F}$ is a Student's coefficient.

The task of identifying the extent of a polynomial for extrapolation can be accomplished with the method of sequential subtraction. In accordance with [14], the method of sequential subtraction can be formalized as follows:

$$\begin{aligned} g_i &= F(j) - F(j-1); \\ g_i^{(2)} &= g_i - g_{i-1}; \\ &\vdots \\ g_i^{(k)} &= g_i^{(k-1)} - g_{i-1}^{(k-1)}. \end{aligned} \quad (4)$$

Starting from $k = \lambda + 1$ the value of $\sigma^2(k) = \frac{\frac{1}{n_{min} - k} \sum_{i=1}^{n_{min}-k} \left(g_i^{(k)}\right)^2}{C_{2k}^{k}}$ stays approximately the same, which allows finding the value of λ.

The next step is to estimate coefficients a_χ $\left(\chi=\overline{0,\lambda}\right)$ of the extrapolation polynomial. This task can be fulfilled with the help of the Least Square Method through solving the following system.

$$\begin{cases} \sum F(j)=a_0\cdot n_{min}+a_1\cdot\sum j+a_2\cdot\sum j^2+\dots+a_\lambda\cdot\sum j^\lambda; \\ \sum F(j)\cdot j=a_0\cdot\sum j+a_1\cdot\sum j^2+a_2\cdot\sum j^3\dots+a_\lambda\cdot\sum j^{\lambda+1}; \\ \vdots \\ \sum F(j)\cdot j^\lambda=a_0\cdot\sum j^\lambda+a_1\cdot\sum j^{\lambda+1}+a_2\cdot\sum j^{\lambda+2}\dots+a_\lambda\cdot\sum j^{\lambda+\lambda}. \end{cases} \quad (5)$$

After solving (5), it is possible to formalize the route unavailability trend in the form of

$$Tr(j)=a_0+a_1\cdot j+a_2\cdot j^2+\dots+a_\lambda\cdot j^\lambda . \quad (6)$$

However, the expression (6) cannot be used for extrapolation because it does not consider the a_χ $\left(\chi=\overline{0,\lambda}\right)$ estimation error. The results of the route unavailability forecast must be represented as follows:

$$F(j)=Tr(j)+e(j), \quad (7)$$

where $e(j)$ is a random item having the constant dispersion and equal to zero expectation. This item can be represented as a mean square deviation:

$$s_F=\sqrt{\frac{\sum_{j=1}^{n_{min}}\left(F(j)-F_{PR}(j)\right)^2}{f}}, \quad (8)$$

where f denotes degree of freedom selected as specified in [18].

Considering the expressions (6) – (8), the predicted RUC value can be written in the following manner:

$$F_{PR}(j+L_D)=Tr_{PR}(j+L_D)\pm t_\alpha\cdot s_F\cdot K_D, \quad (9)$$

where $Tr_{PR}(j+L_D)$ denotes an extrapolated trend value; t_α is the Student's criteria; $K_D=f\left(L_D,n_{min}\right)$ is calculated according to [14].

If the trend-assuming hypothesis cannot be confirmed with the Foster-Stewart method, it makes sense to apply that of Box and Jenkins [15] in order to obtain a predicted value of route unavailability in the form of

$$\begin{aligned} F_{PR}(j+L_D)&=a_1F(j-1+L_D)+a_2F(j-2+L_D)+\ldots+a_pF(j-p+L_D)+e(j)-\\ &-b_1e(j-1+L_D)-b_2e(j-2+L_D)-\ldots-b_qe(j-q+L_D), \end{aligned} \quad (10)$$

where a_α $\left(\alpha=\overline{1,p}\right)$, b_β $\left(\beta=\overline{1,q}\right)$ are the parameters of the autoregressive integrated moving average (ARIMA) model while the *p* and *q* denote the order of auto regression and moving average, correspondingly.

The figure 1 illustrates the idea of prediction where the series uses a "sliding window" approach. Here the T_F denotes the observation period used (as the denominator) to determine RUC.

At the step 6, the predicted value of RUC $F_{PR}(j+L_D)$ is compared to the F_P RUC threshold value. If the following relation is violated, then a warning message is generated in order to inform the network administrator about the route reconstruction/reconfiguration necessity that should be accomplished before t_{rec}.

$$F_{PR}(j+L_D)<F_{P.} \quad (11)$$

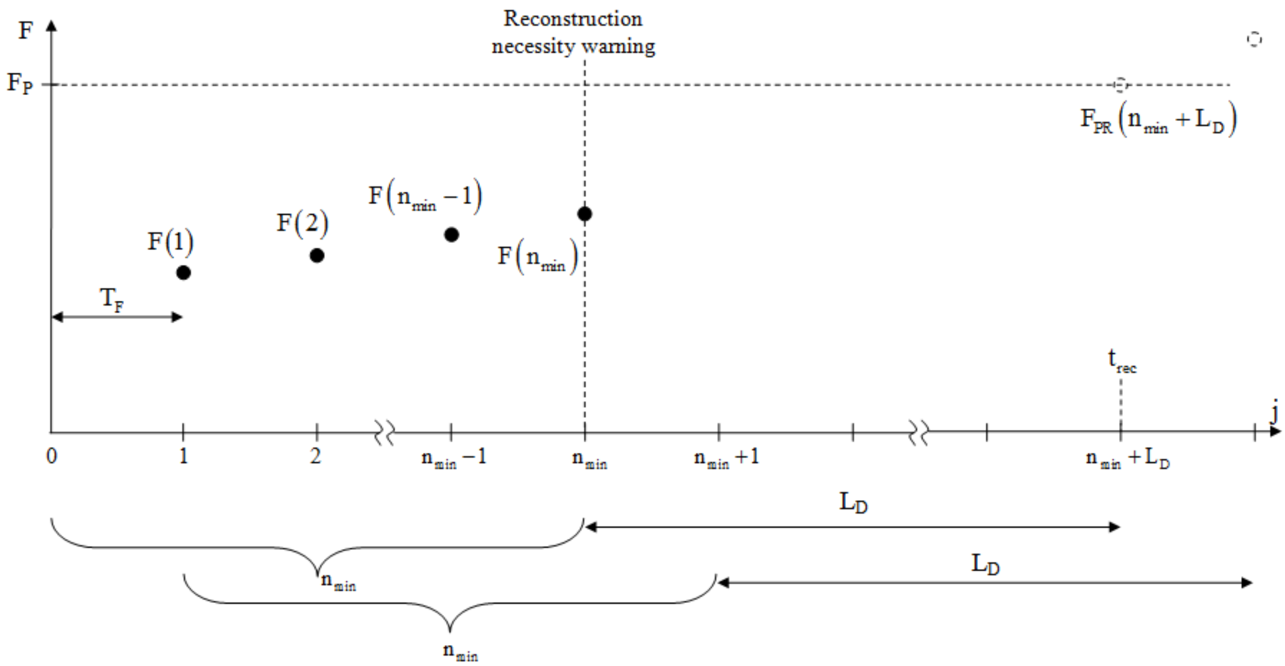

Figure 1 – The "sliding window" approach to series forming

It is worth mentioning that the "oldest" sample is removed from the series when a new one is generated.

Software modules of the LTRUPM. Interaction between software modules of LTRUPM implementation is shown in the figure 2.

A user interface module is intended for input and output functions while interacting with the network administrator. It requires the RUC threshold unavailability values F_{P1}, F_{P2}..F_{Pm} of the corresponding routes as input data. The user interface module initiates operation of a network discovery and routes unavailability monitoring module. This module discovers network infrastructure and provides routes statistics (RS) to be displayed by the user interface module.

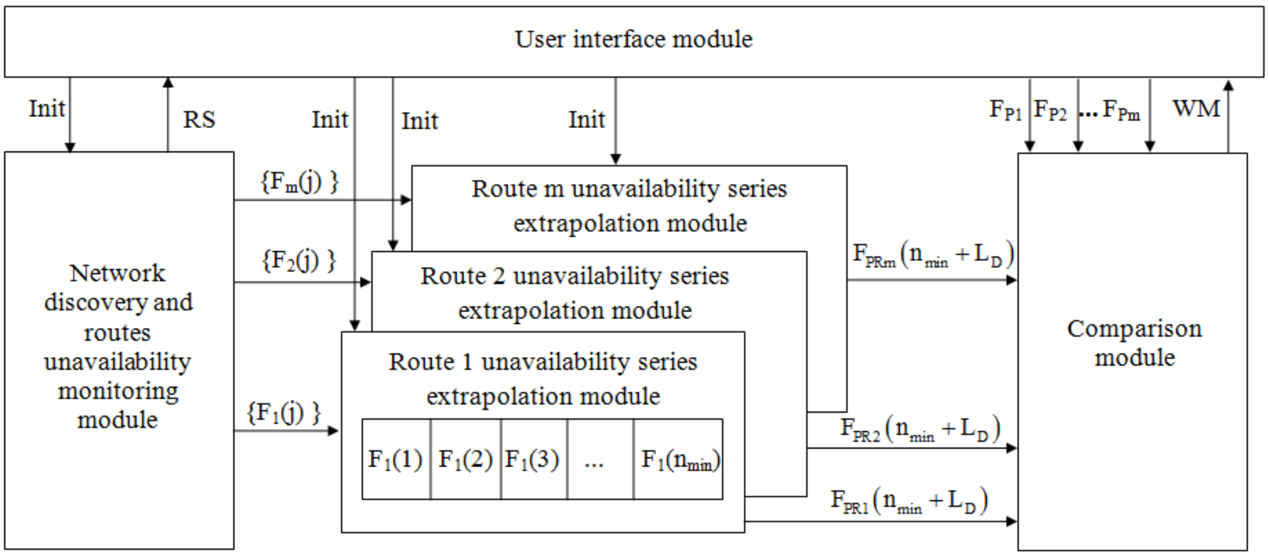

Figure 2 – Software modules of the LTRUPM

After network infrastructure discovery, the user interface module initiates as many processes of RUC series extrapolation after the routes have been discovered. Every such process receives values of the corresponding route RUC and forms a series for extrapolation. The results of extrapolation are further provided to a comparison module. The comparison module compares RUC extrapolation results with the corresponding threshold values obtained from the user interface module. If any predicted value exceeds its threshold, this module generates a warning message (WM) for the user interface module. After receiving such a message, the network administrator has enough time to reconstruct/reconfigure the route before QoS suffers dramatically.

This work represents a method of long-term analysis and prediction of network routes unavailability (expressed through RUC) aimed at identifying the necessity of a network's reconstruction. The prediction is based on polynomial extrapolation and ARIMA model, which allows obtaining the prediction results with preset probabilities and there is no need for supervised learning or any other kinds of adaptation to an information communication network.

The proposed LTRUPM allows a network administrator to recognize long-term routes availability degradations caused by traffic growth and/or equipment aging before these factors significantly affect QoS. The main feature of the proposed LTRUPM, compared to the examined solutions, is that it allows a network administrator to take preventive measures before QoS dramatically suffers. Thus, the LTRUPM is a tool for preventive network maintenance.

The LTRUPM represented by this work is recommended to be used in the wired networks of access and aggregation/distribution where usually a few backup routes are available and, thus, it is more sensible to avoid a problem than to react on it after it occurs.

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