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# Detection of Link Failure in the Node of Telephone Network with Alternate Routing

***Abstract**. In this paper we present detector of faulty links in non-hierarchical telephone network with alternate call routing, as, for, example, in telephone networks of Electric Power Utility. The operation principle of the detector is traffic measurement on links. The main detector properties are determined: alarm detection, failure detection credibility and the detection time. The last two of three mentioned properties are inversely proportional.*

***Streszczenie.** W artykule opisano detektor błędnych połączeń w bez-hierarchicznych sieciach telefonicznych ze zmiennym routowaniem, na przykładzie sieci telefonicznej Electric Power Utility. Określono główne właściwości detektora, wpływające na czas wykrycia błędu. (**Wykrywanie błędów połączeń w węzłach sieci telefonicznej ze zmiennym routowaniem**)*

**Keywords:** telephone network, alternate routing, link failure, probability of false alarm
**Słowa kluczowe:** sieć telefoniczna, zmienne rout'owanie, błędne połączenie, prawdopodobieństwo fałszywego alarmu

## Introduction

Telephone network, which should have high availability, (as is telephone network of Electric Power Utility), is designed in one level and it is called non-hierarchical network. The high availability of this network is achieved using all available transmission links, [1], and the possibility of alternate routing of telephone calls, which is the important property of this network. Alternate routing has some problems as the consequence. The first one is the possibility of network loop creation, and the second one is more difficult detection of faulty links between network nodes. The reason is that users establish connections using alternate routes, and the unusable link can be unnoticed. In this short paper we present the method of faulty link detection using traffic flows. Telephone traffic analysis is well-known method for event discovery in network. As presented in [2], [3], the faulty channels in classic telephone network can be detected very efficiently using the analysis of call distribution in the channel group.

## Model, assumptions and designations

Let us observe the part of the non-hierarchical network, Fig. 1. In this figure network nodes are designated by 1, 2, 3, 4, 5. Network nodes operate as local exchanges, where the users are connected, but they also have the function of transit nodes. The links between network nodes are identified by designations J, B, C, D, E, F, G, H.

Arrivals of telephone calls to each node and on each link form Poisson process. The time duration of speech connection is the random variable and it has negative exponential distribution (with the mean value $t_m$).

Traffic handling in the network is arranged very efficiently and it can be supposed that there is no traffic loss, i.e. that offered traffic $A$ is equal to the carried traffic $Y$. Traffic $A$ can be presented by the product of call intensity, $\lambda$, and the mean time of connection duration, $t_m$, $A=\lambda \cdot t_m$.

We consider one node in the network in Fig. 1. Let us suppose that this node is connected by $M$ links to the adjacent nodes. When all links are faultless, the sum of outgoing and incoming traffic of the node is $A$, and traffic of node users, which loads the link $i$ ($i$=1,2,3,...,$M$) is $A_i$. The total number of outgoing and incoming telephone calls, realized by node users during time interval $t$, is $N(t)$, and the number of calls from node users and to node users realized by the link $i$ during time interval $t$ is $N_i(t)$.

In the time of one link failure, the values of traffic and call numbers will be designated by the sign ('): $A'$, $A_i'$, $N'(T)$, $N_i'(T)$.

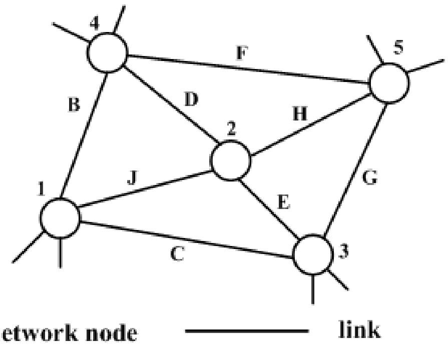


Fig.1. Illustration of the part of non-hierarchical network

Telephone connection establishment starts by the initial message: SETUP, (ISDN, [4], and QSIG signalling, [5]), IAM (Initial Address Message, CCSNo7 signalling, [6]) and INVITE (SIP, [7]). Successful establishment of the connection is acknowledged from the called side by the signalling message: CONNECT (ISDN and QSIG), ANM (ANswer Message, CCSNo7) and 200 OK (SIP).

When measuring or calculating link traffic, the conversation time, i.e. call holding time, is supposed to be time interval between the messages of conversation beginning (signalling messages CONNECT, ANM or 200 OK) and conversation finishing (signalling messages RELEASE (ISDN), DISCONNECT (QSIG), REL (RELease, CCSNo7), BYE (SIP)).

## Link failure

Link failure can be caused by the hardware or software malfunction. The failure can be in the signalling part of the network node and link, or in the part for voice transmission. If signalling part is faultless, but the voice transmission is not satisfactory, then the procedure of connection establishment finishes correctly, but the connection interrupts quickly. The consequence is great number of successive short seizures. The link in this state can be detected and blocked (or excluded) using methods presented in [2] and [3]. That's why we shall consider here only the state of faulty link, which can not be seized successfully.

When all links are faultless, one connection establishment from the user (u), connected to the node (exchange) 2, using the route u2H5···, is presented in Fig. 2.a). (The connections are realized using the route with minimum number of transit nodes when all links are faultless).

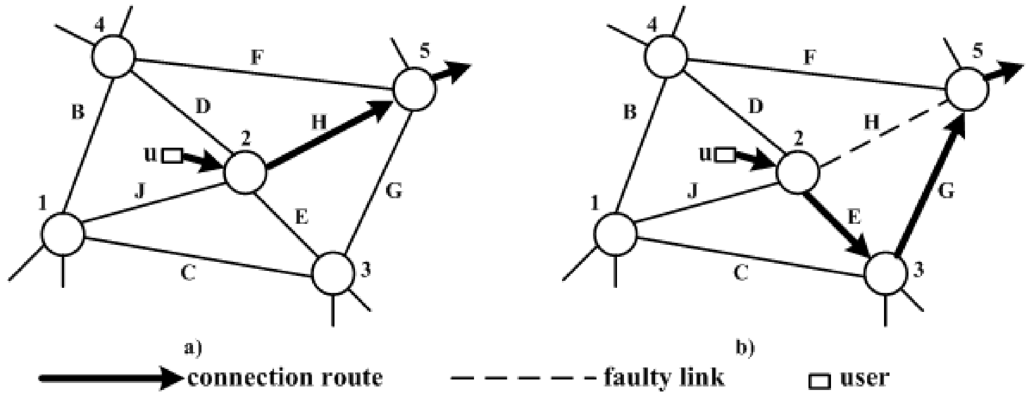


Fig.2. Connection realization when all links are faultless (a) and when one link (H) is faulty (b)

The connection, that passes the considered network part when link H is faulty, is presented in Fig. 2.b). This connection uses the route u2E3G5···. It is obvious that this connection can be established also using the route u2D4F5···. The incoming connections to the user can be presented similarly in the case of correct and faulty link.

In the networks with alternate routing the outgoing and incoming traffic of one node are overflowed from the faulty link on the correct links connected to the same network node. According to the example in Fig. 2.b), the traffic of the considered call will load the link E instead the link H.

Fig. 3 presents one network node with links and users. All links are faultless in Fig. 3.a), and link *i* is faulty in Fig. 3.b). The traffic values $A_i$ and $A_i'$ ($i$ = 1,2,...,$M$) are the sum of outgoing and incoming traffic of the link *i*, without transit traffic.

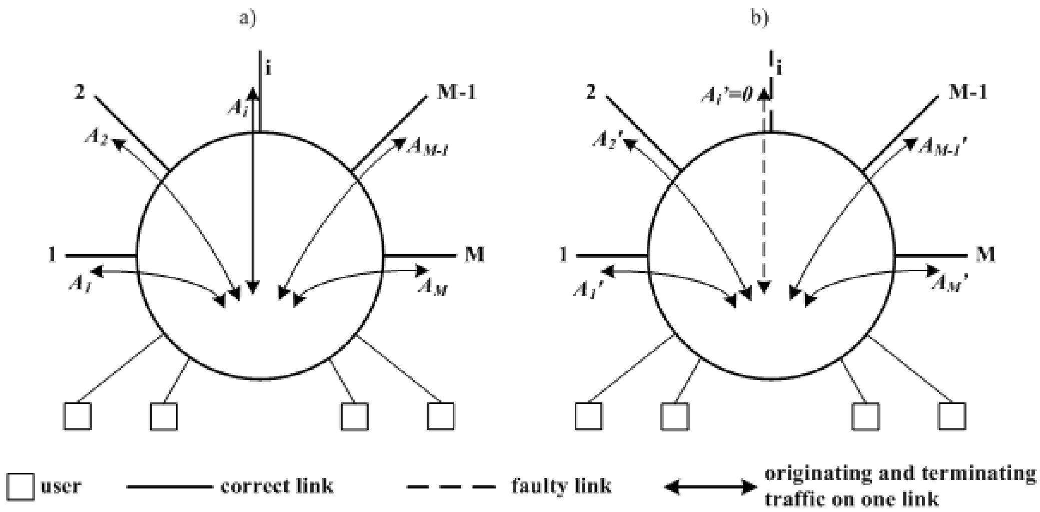


Fig.3. Network node with links and users when all links are faultless (a) and when link *i* is faulty (b)

It can be concluded that link failure does not have influence on the sum of outgoing and incoming traffic intensity in node, i.e. *A=const*. If link *i* is faulty, it can be written:

(1) $$\begin{aligned} A &= A_1 + A_2 + ... + A_{i-1} + A_i + A_{i+1} + ... + A_M = \\ &= A_1' + A_2' + ... + A_{i-1}' + 0 + A_{i+1}' + ... + A_M' = A' \end{aligned}$$

and the same is valid for the number of outgoing and incoming connections from and to the node before and after the failure:

(2) $$\begin{aligned} &N(T) = N_1(T) + N_2(T) + ... + N_{i-1}(T) + N_i(T) + \\ &N_{i+1}(T) + ... + N_M(T) = N_1'(T) + N_2'(T) + ... \\ &... + N_{i-1}'(T) + 0 + N_{i+1}'(T) + ... + N_M'(T) = N'(T) \end{aligned}$$

Let *N(T,M-1)* presents the mean number of outgoing and incoming connections of the users connected to the considered node, which can be established during the time interval *T* on all links except the considered link *i*. Link *i* is faultless, i.e.:

(3) $$\begin{aligned} &N(T, M-1) = N_1(T) + N_2(T) + ... \\ &... + N_{i-1}(T) + N_{i+1}(T) + ... + N_M(T) \end{aligned}$$

Similarly, let *N'(T,M-1)* present measured connection number on all links when link *i* is faulty, i.e.:

(4) $$\begin{aligned} &N'(T, M-1) = N_1'(T) + N_2'(T) + ... \\ &... + N_{i-1}'(T) + N_{i+1}'(T) + ... + N_M'(T) \end{aligned}$$

From equations (2), (3) and (4) it follows:

(5) $$N'(T, M-1) = N(T, M-1) + N_i(T)$$

i.e.:

(6) $$N'(T, M-1) > N(T, M-1)$$

From simple relations in (in)equalities (1) and (6) we can conclude:
- there are no calls on the faulty link;

- call number on other links increases as the consequence of alternate routing of outgoing and incoming calls, related to the considered no

**Link failure detector**

Let us consider one network node and link $i$ ($i$ = 1,2,3,…,$M$-1,$M$). The mean values of call number for each link, connected to the considered node, are determined on the base of long-term measurements. Based on these values, we can calculate mean values of call number on all links except link $i$, $N(T,M\text{-}1)$, for each link. Link failure detector consists of timer and the counter of total number of established outgoing and incoming calls in the node, where the considered link is connected. Link functionality is tested in time intervals $T_i$. Time intervals $T_i$ are selected in such a way that probability of no seizure on the link during these time intervals can be negligible, if the link is faultless. The duration of this time interval $T_i$ is determined for each link separately. For example: traffic, measured on link $i$ for long time period, is $A_i$, and the mean length of telephone connection is $t_{mi}$. The calculated mean call arrival rate is $\lambda_i$. The time interval of link $i$ testing, $T_i$, will be in the bounds $1/\lambda_i \le T_i \le 10/\lambda_i$, depending on desirable credibility of detector presentation and desirable time of detector reaction.

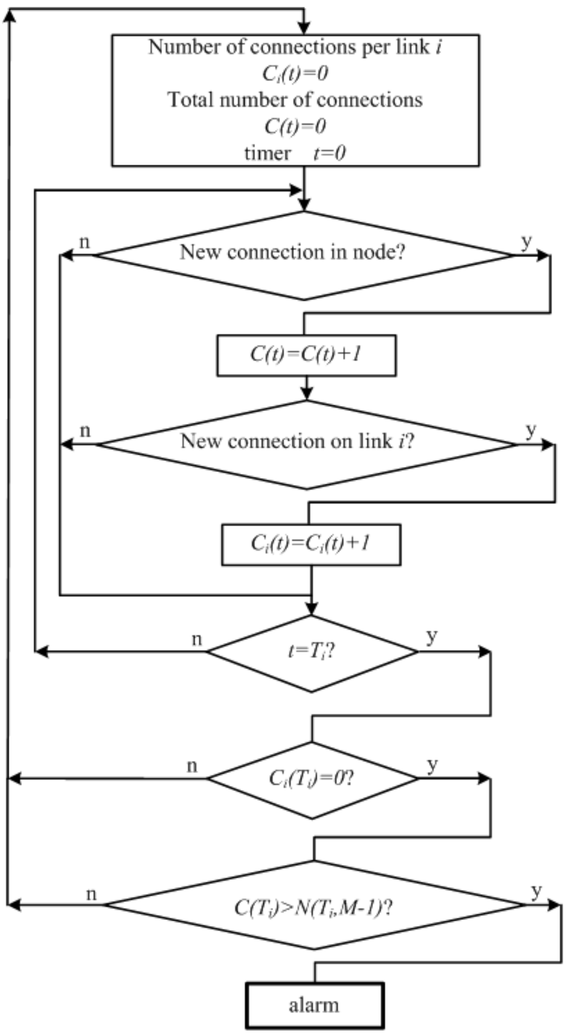


Fig.4. Flow-chart of the link failure detector

At the beginning of time interval $T_i$, the counters of telephone connection number on link $i$ and the counters of total number of outgoing and incoming connections of the considered node are set to zero: $C_i(t)$=0, $C(t)$=0.

At the end of time interval $T_i$, alarm on link is declared if the conditions $C_i(T)$=0, $C(T)>N(T,M\text{-}1)$ are satisfied simultaneously. If one of these conditions is not satisfied, the next testing cycle is started.

The detector functions according to flow-chart, presented in Fig. 4.

So, alarm on the link is declared, if there are no realized connections on the link, and the sum of the number of outgoing and incoming calls in the node does not decrease. If these two events happen, and link is faultless, alarm is false, and the calculation of its probability is presented in the following chapter.

**Probability of false alarm and time of detector reaction**

False alarm is the event that happens if no connections are established on correct link $i$ during time interval $T_i$, and simultaneously the sum of the number of outgoing and incoming calls in network node does not decrease.

The probability of $N$ calls arrival during time interval $T$ is expressed by Poisson distribution:

$$P(N,\lambda,T) = \frac{(\lambda \cdot T)^N \cdot e^{-\lambda \cdot T}}{N!} \tag{7}$$

where $\lambda$ is call arrival rate.

Probability that no connections are realized using link $i$ during time interval $T_i$ is, therefore:

$$P_i(0,\lambda_i,T_i) = e^{-\lambda_i \cdot T_i} \tag{8}$$

Probability that during the same time interval $T_i$ greater call number than the mean number $N=N(M\text{-}1,T_i)$ is realized on other (M-1) links, may be expressed as:

$$P_i(n>N,T_i) = \sum_{k=N+1}^{\infty} P(k,\lambda,T_i) \tag{9}$$

and the probability of false alarm is:

$$P_{fa} = P_i(0,\lambda_i,T_i) \cdot P_i(n>N,T_i) \tag{10}$$

Considering the symmetry of Poisson distribution in relation to the mean value, we can adopt that $P(n>N,T_i) \approx 0.5$, and the probability of false alarm on link $i$ is equal to half the probability that no connections are realized on that link.

$$P_{fa} \approx 0.5 \cdot e^{-\lambda_i \cdot T_i} \tag{11}$$

***Example 1***: Let us suppose that traffic load measured for long time period on one of E1 links, i.e. on one group of 30 speech channels (for example link H in Fig. 2.b)), is 15 Erlang, and that the mean telephone connection duration is 90 seconds. Call arrival rate is $\lambda$=10 calls/minute. Let us assume that testing period is $T$=1 minute. For these parameters is:

$$P_{fa} \approx 0.5 \cdot e^{-\lambda \cdot T} \approx 0.000022 \tag{12}$$

***Example 2***: Let us suppose that traffic load measured for long time period on one-channel Power Line Carrier links is 0.5 Erlang, and the mean telephone connection duration is 90 seconds. Call arrival rate is $\lambda$=0.3333 calls/minute. Let us assume that testing period is $T$=10 minutes. For these parameters is:

$$P_{fa} \approx 0.5 \cdot e^{-\lambda \cdot T} \approx 0.0178 \tag{13}$$

False alarm probability, $P_{fa}$, as the function of testing time interval $T$, is presented in Fig. 5. As time units are measured using mean time between two calls, ($1/\lambda$), Fig. 5 indirectly presents dependence of false alarm probability on the offered load. We can remark that satisfactory detector credibility ($P_{fa}\leq 0.01$) is achieved for $T\geq 4/\lambda$.

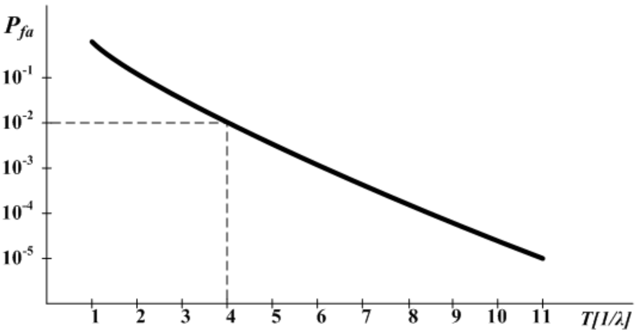


Fig.5. False alarm probability as the function of testing time interval $T$

The time of detector reaction is expressed by the mean time from failure to failure detection, $T_{da}$. It is clear that link failure happens in random moment, $t_f$, Fig. 6.

Link failure can not be detected in testing period $T_{k-1}$, as the condition, presented by the equation (8), is not satisfied. This condition is satisfied in the next testing period $T_k$. The time of failure detection is equal to the time interval from link failure to the end of that testing interval, increased by one testing period, i.e. $t_{da}=t_d-t_f$, Fig. 6. The mean value of this time is, obviously, $T_{da}=1.5\cdot T$.

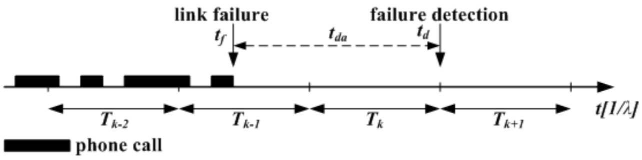


Fig.6. Illustration of failure detection moment after link failure

***Example 3***: In the case from example 1 it is obvious that the mean detection time is, with great credibility, equal to the mean connection time, i.e. $T_{da}$=1.5 minutes.
***Example 4***: In the case from example 2 it is obvious that the mean detection time is $T_{da}$=15 minutes with smaller detector credibility than in Example 1.

Fig. 7 presents mean time of faulty link detection, $T_{da}$, as the function of traffic on the link, $A$, when the probability of false alarm is $P_{fa}\approx 0.01$.

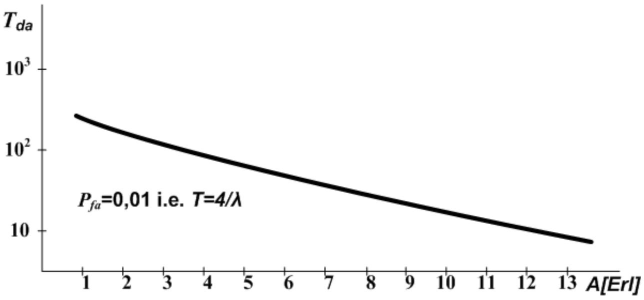


Fig.7. Mean time of false link detection as the function of traffic load

Considering Fig. 7, we can conclude that failure detection has the same property as traffic measurement: when traffic load is increased, the detection (measurement) credibility increases, and the detection (measurement) time decreases, [8].

Note: detection time can be decreased by resetting all counters for considered link after finishing each connection. Alarm is declared under the same conditions.

**Conclusion**

Detector of faulty link in telephone network with alternate routing (that is used in Electric Power Utility) rapidly detects link failure. The user can not detect this faulty link, because the connections are established using alternate routing. Detector proclaims link failure, if it is detected that traffic load does not exist on the considered link, and that it increases on the remaining links of the same network node, where the considered link is connected. We suppose that traffic on the link exists, if the connections finish with the signalling messages CONNECT, ANM or 200 OK, sent from the called party to the calling party. If the connections are established successfully, but are quickly interrupted, because quality of transmitted speech signal is not satisfactory, these failures can be detected using the methods presented in [2] and [3].

The main features of presented detector are the credibility, expressed by the probability of false alarm, and the mean time of failure detection. The probability of false alarm can be decreased as desired by the extension of testing interval. The credibility of detector indication is increased, if we take into account the indications of two detectors, located in the nodes on both ends of the considered link. The time necessary for failure detection is inversely proportional to the credibility and the traffic load on the link.

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