Mihailo STANIĆ, Aleksandar LEBL, Dragan MITIĆ, Žarko MARKOV

Institute for Telecommunications and Electronics IRITEL A.D. BELGRADE

Detection of Pre-alarm State in Mixed Telephone Network of Electric Power Utility

***Abstract**. We describe the operation of ISDN or IP faulty link detector in mixed telephone network of Electric Power Utility. Basic principle of this detector is increased seizing of Power Line Carrier link that is parallel to ISDN or IP link. Main indicators of detector efficiency: the probability of detection of false failure, the probability of detection miss and mean time to failure detection are calculated, verified by computer simulation and discussed.*

***Streszczenie.** W artykule opisano metodę wykrywania błędnego połączenia IP albo ISDN w mieszanej sieci telefonicznej. Zasada detekcji opiera się na zwiększeniu rozmiaru połączenia Power Line Carrier równoległego do ISDN albo IP. (**Detekcja stanu alarmowego w mieszanej sieci telefonicznej stosowanej w układach typu EPU**)*

Słowa kluczowe: mieszana sieć telefoniczna, IP, ISDN
Keywords: Mixed Telephone Network, Electric Power Utility, Power Line Carrier link, IP, ISDN

Introduction

When the telephone network of Electric Power Utility (EPU) is designed, the main demand is very high reliability. All available resources are used for its achievement. The most important resources are non-hierarchical (i.e. one-level) network architecture and the use of all link types regardless of their technology. Non-hierarchical network allows the alternate routing. Different types of links (optical cables, metal cables, radio) increase the network availability, as mentioned in [1] and [2]. The increased network availability of mixed network is paid by use of gateways or interfaces. The gateways and interfaces solve the problem of different signaling types (CAS, ISDN, IP) and different speech signals form (analog, digital, packet). In this paper we point out how the mixed EPU network, besides the interworking problems, has one useful property used in failure surveillance.

Model, designations and assumptions

We consider two nodes of mixed EPU network, Fig. 1. Mixed network consists of telephone exchanges (TE) and links that may be IP, ISDN or Power Line Carriers (PLC). (PLCs are links based on transmission of speech and data over high voltage power lines. They were dominant links in old EPU network. In Ref. [2] PLCs are called, insufficiently precisely, E&M analog lines).

Telephone exchanges TE1 and TE2 are connected by ISDN or IP link and by PLC link. Setting up the telephone connections between TE1 and TE2 is made according to selection rule (SR), which gives the priority of seizing to the ISDN (Fig. 1.a) or IP (Fig. 1.b) link before PLC. This SR is consequence of better speech signal quality and shorter connection set-up time on ISDN or IP link than on PLC. In normal operation, the traffic load of PLC is very small and equal to traffic on last channel in the group with sequential hunting beginning from the first channel. Accordingly, the PLC may be seized in two cases. The first case is failure on ISDN or IP link and the second case is too high traffic load. (It is clear that the selection rule is performed in such a way to minimize the collision probability on ISDN link).

The number of ISDN channels or the greatest number of telephone connections over IP link is N. The state with j simultaneous connections is denoted by $\{j\}$, $j=0,1,2,\ldots\ldots N, N+1$. The probability of state $\{j\}$ in the group of K channels with offered traffic A is denoted by $P(j,A,K)$.

The normal state (operation) is one with all correct links between exchanges TE1 and TE2.

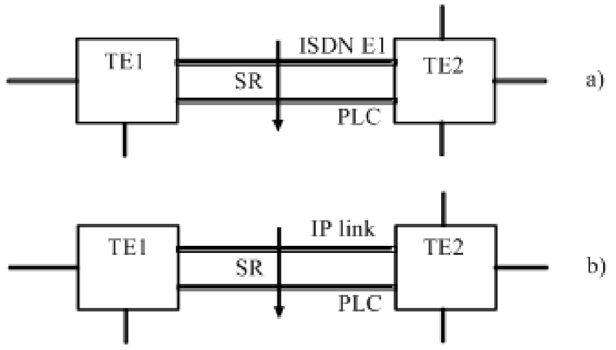

Fig.1. Model of two network nodes connected by ISDN (a) or IP (b) link and PLC

The alarm state is one with all faulty trunks between exchanges TE1 and TE2.

The pre-alarm state is one with faulty ISDN or IP link but with correct PLC.

Telephone calls, offered to links between TE1 and TE2, make Poisson process. The call intensity (number of offered calls per unit of time) between TE1 and TE2 is λ. Mean interarrival time of calls is $T_{ia}=1/\lambda$.

The duration time of conversations has negative exponential distribution with mean T.

Interarrival time and call duration time are random variables with negative exponentialy distributed probability of duration, so they have memoryless property.

Offered traffic between exchanges TE1 and TE2 is $A=\lambda\cdot T$.

Blocking probability (call congestion) in the group with K channels and offered traffic A is calculated by well known Erlang formula $B=E(A,K)=P(K,A,K)$, [3]. Carried traffic is $Y=A\cdot(1-B)$.

Pre-alarm detector

The pre-alarm detector is algorithm that detects the seizing of PLC, counts the number of seizures, measures the duration of seizures and declares the pre-alarm state, i.e. the failure on ISDN or IP link. The purpose of pre-alarm detector is to detect the failures on links before alarm state. The information of pre-alarm state is (1) sent to maintenance centre and (2) used in the exchanges to serve only high priority calls.

The pre-alarm detector is based on call statistics and different readings are possible. Link may be in correct and faulty state. The detector may detect or not detect the pre-alarm state. The Fig. 2 presents all the possible events.

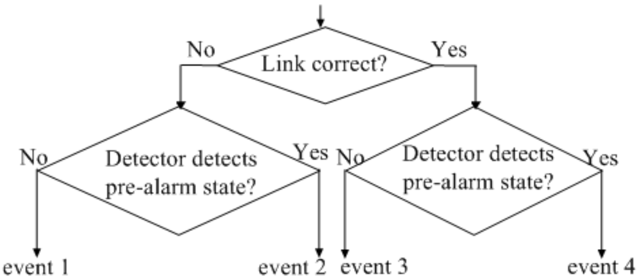

Fig.2. All possible events of a detector

The possible events are:
event 1: link faulty, detector does not detect the pre-alarm (miss of detection),
event 2: link faulty, detector detects the pre-alarm state,
event 3: link correct, detector acknowledges it,
event 4: link correct but detector detects pre-alarm state, i. e. false pre-alarm state.

The probability of event 1 (miss probability) and probability of event 4 (probability of false pre-alarm state) are the probabilities of faulty readings of detector and they must be as small as possible.

The basic characteristics of detector efficiency are: miss probability, P_{miss}, probability of false pre-alarm, P_{fpa}, and mean time from failure to detection of pre-alarm state, T_{dpa}.

The calculation principle of detector model is as follows: in normal operation state the Erlang group of *N+1* channel with offered traffic *A* is observed, in pre-alarm state one-channel Erlang model with same offered traffic *A* is analyzed.

The simplest calculation is done in the case of small traffic load. The model with *N* ISDN channels and PLC is considered, Fig 1.a. When ISDN link becomes faulty, PLC will be seized by first incoming call. That event may be information of pre-alarm state. But PLC may be seized in the rare case of correct ISDN link if all ISDN channels are seized by great traffic load in the instant of new call attempt. The probability of this event is the probability of false pre-alarm state and it equals to the probability of all *N+1* channels being busy:

(1) $$P_{fpa} = E(A, N+1)$$ ....

This detector with small traffic load is called the trivial or one-step detector. In this case every seizing of PLC is declared as (true or false) pre-alarm state.

The probability P_{fpa} is too small so we may believe that every seizing of PLC is signal of failure of ISDN link.

Example: we observe primary ISDN link (*N=30*) and if *A* ≤ *13* Erlangs, then $P_{fpa} \leq 0.00001$. Every seizing of PLC may be considered as reliable information that ISDN link is faulty.

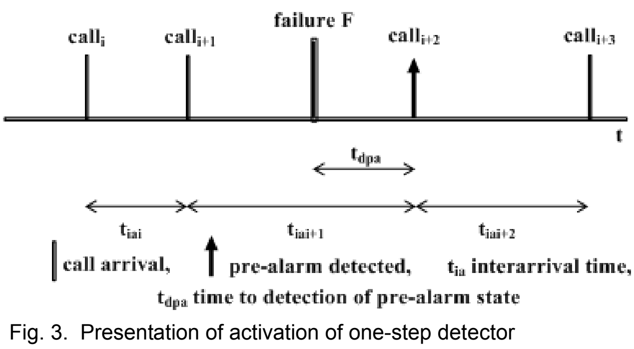

Fig. 3. Presentation of activation of one-step detector

The mean time to detection of pre-alarm state for one-step detector may be calculated as follows. We observe the process of call arrivals (call$_i$) and failure on the link (F), Figure 3.

The time interval from failure to its detection, t_{dpa}, is obviously time interval from failure to next call arrival. Call arrivals and failure happen in random moments, so the mean time to detection of pre-alarm state equals to the mean interarrival time due to memoryless property of interarrival time.

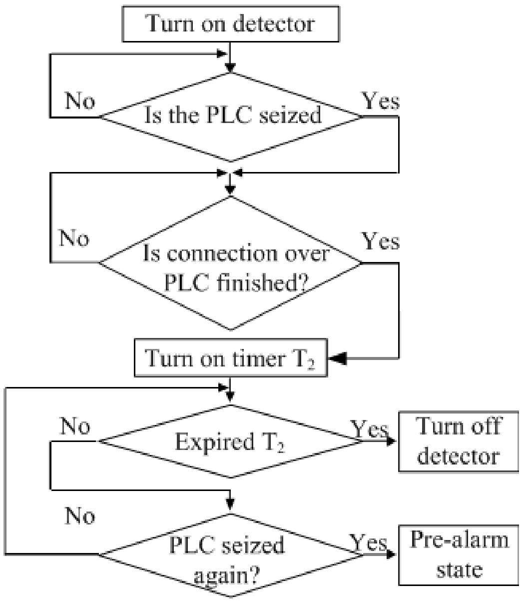

Fig. 4. Flow-chart of two-step detector operation

Mean interarrival time is $T_{ia}=1/\lambda$, so the mean detection time is $T_{dpa}=1/\lambda$. Example: if the mean conversation time is *T=120s*, and if *A=13* Erlangs, call intensity is $\lambda=390$ calls per hour. Mean detection time is $T_{dpa} \approx 9.2s$.

Good property of one-step detector is impossibility of miss. Bad property of one-step detector is dependence of the probability of false pre-alarm on the offered traffic load.

The case of great traffic load is more complex. If the traffic load increases, the probability of false pre-alarm increases also, because the probability of state *{N+1}* increases.

Example: on the primary ISDN link (*N=30*) offered load is 26 Erlangs, $P_{fpa} = E(26, 31) \approx 0.053$ i.e. every twentieth call seizes the PLC and P_{fpa} is non negligible. Mean detection time is $T_{dpa} \approx 4.6s$.

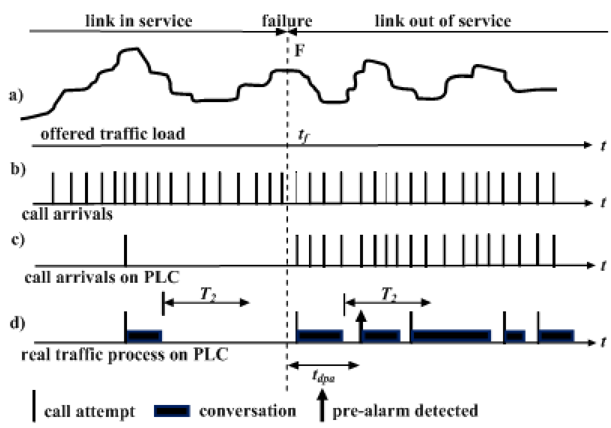

Fig. 5. Symbolic presentation of traffic process and two-step detector activation: a) (hypothetical) offered load, b) total call arrivals, c) call arrivals to PLC, d) detector activation

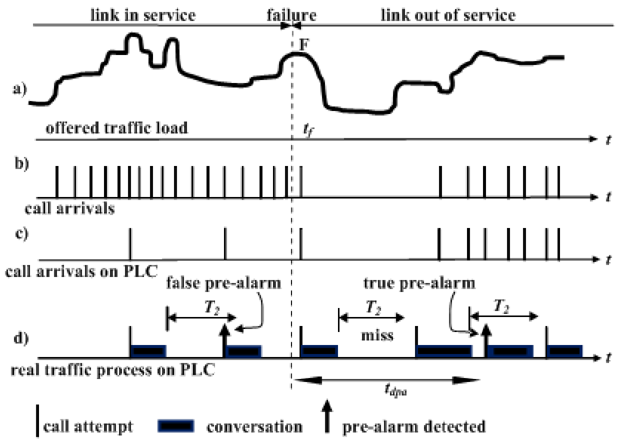

Fig. 6. Symbolic presentation of: a) (hypothetical) offered load, b) total call arrivals, c) call arrivals to PLC, d) false pre-alarm, miss and true pre-alarm (two-step detector)

The probability of false pre-alarm may be reduced by so-called two-step detector: after first seizing and release of PLC, the timer T_2 is turned on. If the PLC is seized again in the time interval T_2, the state of pre-alarm is declared, Fig. 4. Two-step detector is the main theme of this paper. (We may continue to turn on the timer T_2 and count *k-1* successive seizing of PLC. After, *k* successive seizures, pre-alarm state is declared. Thus probability of false pre-alarm decreases, but both miss probability and detection time increase. This detector may be called multi-step or k-step detector.)

The random process on ISDN or IP link and PLC between TE1 and TE2, before and after failure is presented in Fig. 5. Activation of two-step detector is also presented.

The random processes, the detection of false pre-alarm and detector miss are presented in Fig. 6. It can be seen that miss is compensated in second attempt, and that false pre-alarm detection cannot be cancelled.

The probability of false pre-alarm in two-step detector, P_{fpa2}, is the probability of two successive seizure of PLC in the normal operation. This probability may be estimated in the following way:

(2) $$P_{fpa2} \approx P_{fpa} \cdot P_2(\lambda_N, T_2)$$

where $P_2(\lambda_N, T_2)$ is the probability of at least one seizure of PLC in normal state, at time interval T_2, after first seizure. Here λ_N is the intensity of entering the state *{N+1}*. Intensity of entering the state *{N+1}* may be approximately calculated from blocking probability (time congestion) and mean duration time of state *{N+1}*. The time interval T_2 should be several interarrival times, because the probability of new call in time interval T_2 should be very high.

(3) $$P_2(\lambda_N, T_2) = 1 - e^{-\lambda_N \cdot T_2}$$

It is clear that for multi-step (*k*) detector we estimate the probability of detection of false pre-alarm in the same way

$$P_{fpak} \approx P_{fpa} \cdot P_2(\lambda_N, T_2) \cdot P_3(\lambda_N, T_2) \cdot \ldots \cdot P_j(\lambda_N, T_2) \cdot$$
$$\ldots \cdot P_k(\lambda_N, T_2) = P_{fpa} \cdot (1 - e^{-\lambda_N \cdot T_2})^{k-1}$$

where $P_j(\lambda_N, T_2)$ is the probability that at least one seizure happens in the *j*-th consecutive time interval T_2, *j=2,3,...,k*. The probability P_{fpak} decreases with increased *k*, but miss probability and mean time to detection increase.

Calculation of mean time to alarm can be done in two ways: if the failure happens when PLC is seized or if it is free. The second case is more probable and the obtained results are more conservative. That's why it is used in this paper.

Mean time from the failure to detection for two-step detector consists of three components:
- mean time from failure to first seizure,
- mean conversation time,
- mean time from releasing the PLC to second seizure.

Because the failure, the call attempts and call ends happen in random instants, we have

(4) $$T_{dpa} = T_{ia} + T + T_{ia} = 2 \cdot T_{ia} + T$$

Example: *N=30*, *A=26* Erlangs, *T=120s*, $T_2=5/\lambda$ (that ensures at least one call attempt in T_2 with probability greater than 0.99). We have $\lambda=780$ calls per hour, mean interarrival time $T_{ia}=4.6s$, $T_2 \approx 23s$, $Y_{N+1}=0.3562$ Erlangs, $\lambda_{N+1}=10.686$ calls per hour i.e. *0.002968* calls per second, $P_2(Y_{N+1}, T_2) = 0.06619$ and probability of false pre-alarm $P_{fpa2} = P_{fpa} \cdot P_2(Y_{N+1}, T_2) = 0.0035$. Mean detection time is $T_{dpa} = 2 \cdot T_{ia} + T = 129.26s$.

As we expect, increasing of the credibility of detector reading demands longer detection time. Second property of two-step detector is great impact of conversation time duration on detection time.

In the case of multi-step (*k*) detector, mean time to detection is:

(4') $$T_{dpa} = T_{ia} + (k-1) \cdot (T + T_{ia})$$

Calculation (4') is, again, based on the assumption that failure happens when PLC is not seized.

The probability of miss for two-step detector may be calculated in the following way: after the failure, total traffic load (*A*) is offered to the only correct channel i.e. to PLC. After the first seizure of PLC, the detector turns on, and after release of PLC, the timer T_2 turns on. The miss in failure detection will happen if no calls arrived in the time interval T_2 after first seizure, Fig. 6. The probability of this event is $e^{-\lambda T_2}$.

The probability of miss is approximately

(5) $$P_{miss} \approx e^{-\lambda \cdot T_2}$$

It is mentioned that the value of T_2 should be chosen in such a way that the probability of at least one call arrival during T_2 is very high (close to unity). Because of that, the probability of miss is quite small. Example: if *N=30*, *A=26* Erlangs, *T=120s*, $T_2=5/\lambda$, we have $P_{miss}=0.0067$.

Dependencies of basic properties of two-step detector

The dependence of probability of false pre-alarm, P_{fpa2}, probability of miss, P_{miss}, and mean detection time T_{dpa}, on offered traffic load, *A*, for two-step detector are presented in Fig. 7.

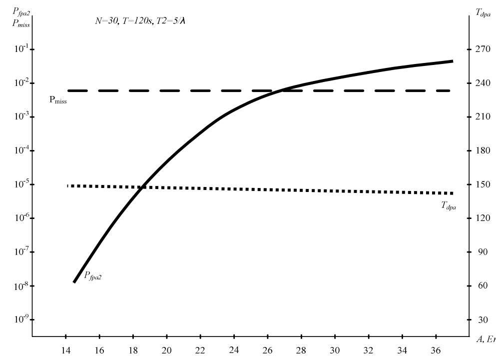

Fig. 7. Probability of false pre-alarm, probability of miss and mean time to detection of two-step detector as functions of offered traffic

It may be seen that miss probability does not depend on traffic load, because it is defined as probability of no calls in the five interarrival times, i.e. $P_{miss}=e^{-5\lambda/\lambda} = e^{-5}$, according to eq. (5).

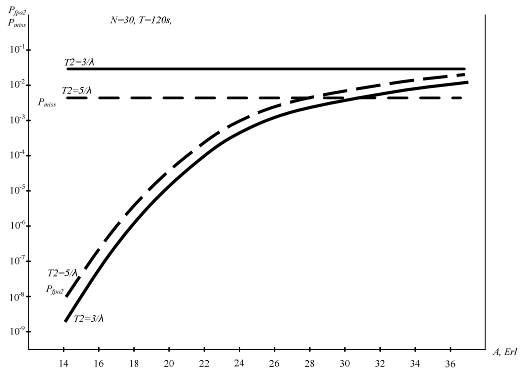

Fig. 8. Decreasing of false pre-alarm probability may be obtained by increasing of probability of miss (two-step detector)

Mean detection time is dominantly dependent on mean conversation time. It is clear because in eq. (4) interarrival time is much smaller than conversation time, for observed traffic values.

The probability of false pre-alarm increases with increasing the traffic load. It is normal because the greater traffic load increases the probability of two calls on PLC in normal state. Intuitively is clear that probability of false pre-alarm may be decreased by reducing the interval T_2. It is, also, clear that this reduction increases the probability of miss. One such example for two-step detector is presented in Fig. 8. In this example time interval T_2 is reduced so that probability of at least one new call in interval T_2 is cca 0.95, $T_2 = 3 \cdot T_{ia} = 3/\lambda$. Full lines in Fig. 8 show the probability of false pre-alarm and miss probability for the case $T_2=3/\lambda$. Dashed lines in Fig. 8 show the probability of false pre-alarm and miss probability for the case $T_2=5/\lambda$.

Case with IP link

IP exchanges (voice routers) exist in some nodes of telephone network of EPU. They establish the connections over IP links. Parts of IP exchanges are gateways or interfaces that enable use of PLCs to connect IP exchanges, Fig. 1b). In principle, the number of telephone connections over IP links may be limited due to limited DSP resources in IP exchange. The greatest number of simultaneous connection over IP link, N, may be calculated starting from offered traffic load. Like in the case of ISDN link, the PLC will be seized in two cases: if IP link is out of service or if the offered traffic needs more than N connections. Therefore, the detector of pre-alarm state may be used in the case of IP link. Calculation is the same as in the case of ISDN link.

Realization

Pre-alarm detector is used to detect failures on ISDN and IP links in mixed EPU telephone network, monitoring the seizures of PLC. Question is: is it correct to suppose that failure happens only on ISDN or IP link and not on PLC? Obviously, it isn't. But, the correctness of PLC may be tested periodically by artificial short seizures. Duration of these seizures is so short that they are undetected by detector. This is the justification for assumption that failures do not happen simultaneously on PLC and on ISDN (IP) links.

Great convenience of described detector is monitoring only the seizures of PLC. In that way no modification in exchanges is needed.

In this paper one channel PLC is observed. There exist two- or three-channel PLCs. In this case the detection principle is same. Calculation is almost the same. The only difference is in shortened detection time. Namely, the timer T_2 starts after the seizure of first PLC channel, not after its releasing as in Fig. 4. As the failure and the call arrivals are random variables (with memoryless property), the mean detection time will be $T_{dpa} = 2 \cdot T_{ia}$.

Information of pre-alarm state may be sent to maintenance center by Internet and GPRS, not only by EPU telephone network. In this way the availability of surveillance becomes higher.

Conclusion

The detector of pre-alarm state in EPU network is simple tool of failure detection on ISDN or IP links. The main advantage of this algorithm is that failure is detected when connection may be established over PLC. First consequence of failure detection is transfer of this information to the maintenance center over different routes. Second consequence may be restricted calls serving: after detected failure only priority (dispatcher) calls may be served.

Basic indicators of detector efficiency are: the probability of false pre-alarm, probability of miss and mean time to detection. There exist one-, two- and multi-step detectors. We concluded that two-step detector have good efficiency, because the probabilities of false pre-alarm and miss may be reduced to values of order of magnitude 10^{-3}. The probability of false pre-alarm may be decreased while increasing probability of miss and vice versa. Detection of false pre-alarm, theoretically, cannot be avoided. On the contrary to detection of false pre-alarm, the detection miss is corrected in the next attempt after some longer detection time.

Mean time to detection is quite short and, in the case of one PLC, depends on conversation time.

The numerical results for the detection time, probability of false alarm and the probability of detection miss are verified by the simulation of telephone traffic in the group with full availability and the sequential hunting of free channel, using the well-known roulette or Monte Carlo method, [4], [5].

ACKNOWLEDGEMENTS

The study was carried out within the Project TR32007: "Multiservice optical transport platform with OTN/40/100 Gbps DWDM/ROADM and Carrier Ethernet functionality". It was financed by the Ministry of Science and Technology, Republic of Serbia.

REFERENCES

[1] Iibuchi R., Kaneko H., Fukugawa S., Matsumoto M., Suzuki S. and Seino K : "Construction of IP Network in Rural Areas", Paper no D2-03 B02, 2009 CIGRE Colloquium, Fukuoka, Japan, October 2009.

[2] Krajnovic, N : "The Design of a Highly Available Enterprise IP Telephony Network for the Power Utility of Serbia Company", IEEE Communications Magazine, Vol.47, No.4, pp.118-122, April 2009.

[3] Akimaru H. and Kawashima K : "Teletraffic, Theory and Applications", Springer-Verlag, 1993.

[4] Olsson, K. M.: "Simulation on computers. A method for determining the traffic-carrying capacities of telephone systems", TELE, Vol. XXII, No.1, 1970.

[5] Kosten, L.: "Simulation in teletraffic theory", 6th ITC, Münich, 1970.

Authors: *mr Mihailo Stanić, dipl. Ing., IRITEL A.D., Batajnički put 23, 11080 Belgrade, Serbia, (phone 381-11-3073485; e-mail: mihailo@iritel.com; dr Aleksandar Lebl dipl.ing., IRITEL A.D., Batajnički put 23, 11080 Belgrade, Serbia, (phone 381-11-3073403; e-mail: lebl@iritel.com; dr Dragan Mitić dipl.ing., IRITEL A.D., Batajnički put 23, 11080 Belgrade, Serbia, phone 381-11-3073425; e-mail: mita@iritel.com; prof. dr Žarko Markov, dipl.ing., IRITEL A.D., Batajnički put 23, 11080 Belgrade, Serbia, phone 381-11-3073403; e-mail: Zarko.Markov@iritel.com.*