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THE SIMULATION OF COMPUTER NETWORKS FOR RAILWAY CONTROL AND MANAGEMENT

The paper treats about simulation of package transmission in computer systems (interlocking and dispatcher monitoring) applied in railway. Modelled systems from the EU railways: specialised three computer interlocking SELMIS, dispatcher system WSKR, remote control of Warsaw Underground and GSM-R based ERTMS structure for train monitoring are simulated with respect to total delay time. For simulation Network Simulator NS-2 in Linux environment is applied. The results of simulation are compared with analytical theory of queues by using Markov processes.

SYMULACJA SIECI KOMPUTEROWYCH W SYSTEMACH STEROWANIA I ZARZĄDZANIA RUCHEM KOLEJOWYM

Praca dotyczy symulacji transmisji pakietowej w komputerowych systemach zależnościowych i dyspozytorskich. Modelowane systemy stosowane na kolejach europejskich: trzykomputerowy system zależnościowy SELMIS, system kontroli dyspozytorskiej WSKR, system zdalnego sterowania w Warszawskim Metrze i przyszłościowy system nadzorowania pociągu ERTMS/GSM-R, zostały poddane symulacji pod kątem całkowitego czasu opóźnienia. Dla celów symulacji został zastosowany Network Simulator NS-2 pracujący w środowisku LINUX. Wyniki symulacji zostały porównane z analitycznymi rozwiązaniami uzyskanymi z teorii kolejek opartej na procesach Markowa.

1. INTRODUCTION

The computer network used for railway transport management and control apply different transmission methods based both on radio and cable standards. The examples of new generation of computer network for EU railway applications, especially GSM-R based on ERTMS structure for train monitoring are analysed and modelled with respect to typical net parameters such probability of correct connection and delay time. The main aim of this work is safety characteristics of such networked systems assuming Markov process modelling the exploitation of multicomputer systems.

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In the paper the modelling and simulation the typical network systems is presented: three coupled processor structure of ESTW interlocking computer, LAN remote control system for Warsaw Underground and future wireless GSM-R railway control system corresponding to ERTMS/ETCS. The proposed approach give possibility of simple estimation of probabilistic and time parameters necessary for safety analysis.

2. THE COMPUTER NETWORK IN RAILWAY TRANSPORT APPLICATIONS

The safety transmission applied in railway control and management requires following assumptions:

- High reliability related to special net technologies including redundancy of links or nodes (fail safe systems must ensure by-pass element instead the failed),
- Appropriate quality of connections with respect to assumed bandwidth low failure rate and low constant delay (co-operation of control and dispatcher system may share the same bandwidth),
- Security related to cryptography and correction/detection codes (protection against unauthorised access and interference),
- Appropriate capacity in bauds corresponding to complicated functionality of new management systems in large area.

The existing computer networks in railway system apply the cable connections and simple radio transmission. There are ATP/ATC system with radio connections (via balises and beacons) and centralised interlocking systems (including dispatcher systems) with remote control many local systems, The new generation of computer network apply the wireless technology corresponding to GSM-R standard. The European project ERTMS/ETCS (European Railway Traffic Management System/European Train Control System) is designed to optimal control of train in UE area (Fig.1). Such system integrates existing ATP/ATC systems, interlocking systems with dispatcher systems. Using additionally the specially designed for railways GSM-R mobile communication system (and in the future the satellite positioning GPS) gives the possibility of optimal train control (flexible block distance for line with heavy traffic or wireless control and monitoring of train for lines with light traffic). The ERTMS/ETCS system is very good example of system with many different messages generating queues and delays with important influence for safety [1].

The simulation model may be applied to typical computer networks used for many years in European and Polish railways[1].

The special bus connection assure the fail safe operation, with complex monitoring and fault recovery is realised in program way. This SELMIS three computer structure from Fig. 3.a with bus topology is elaborated by ALCATEL for centralised interlocking ESTW system. The implementation assures the checking of all bus signals, synchronisation and diagnostics of faulty modules. The dispatcher system WSKR for local management has been installed in Kraków-Tarnów line in the form from Fig.4.a. (dispatcher centre with duplex structure based on main computer and hot stand-by computer) and 5.a (local dispatcher subsystem and train number monitoring with single ring topology).

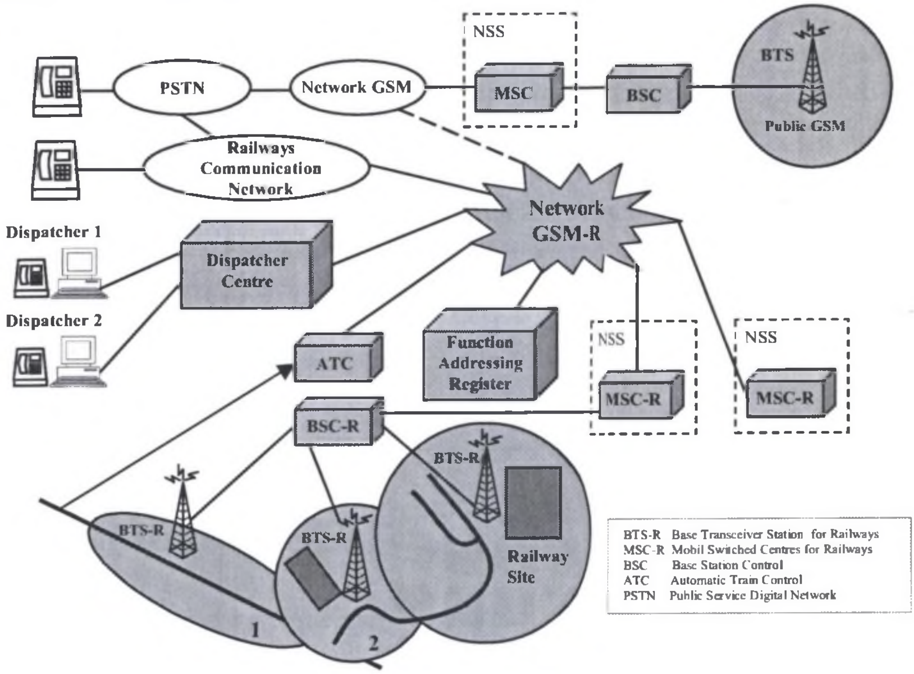

Fig.1. The ERTMS/ETCS system with many transmission subsystems

3. THE CHARACTERISTICS OF PACKAGE TRANSMISSION IN COMPUTER NETWORKS

In the analysis of package transmission in the cable or radio transmission three basic parameters are assumed. First parameter of the network is failure rate – the probability of failed transfer the message. In the existing networks the typical value of this parameter is less than 1/1000. The second parameter, capacity in bits per second corresponds to quantity of transmitted messages.

The very important third parameter – delay is defined as time necessary to transfer the package from one node to assumed node. In the network with commutation of packages delay depends of number of packages number of nodes in the network and service time the given package during transfer. The service time may be treated as a sum of several elements:

- Propagation time in each link related to transmission medium and transfer technology,
- Serialisation time defined as length of package in bits/ interface rate in bits per second,
- Processing time in the node of network connected with efficiency of node processor,
- Output buffer delay time related to number of messages incoming to the node.

The propagation time and serialisation time have typical physical restrictions connected with IP technology (the minimal values may be observed in the wide band networks), processing time may be minimised using efficient active network devices and algorithms, the output buffer delay time may be optimised using advanced queue algorithms instead FIFO (First In First Out). In the network with constant link rate is impossible to transfer the different messages with different rates, but some messages may be transfer earlier and in consequence some delays for given messages (such audio or video) may be shorter than for others.

The flow control in package networks is related to overload protection – the maximal number of packages in the transportation layer must be limited corresponding to:

- Node to node control, eliminating the overload problem in the nodes,
- Flow control between source and destination, completing the messages in the destination,
- Transport layer control, assuring the o-operation of communicating terminals,
- Access management, corresponding to decision of access to the given network.

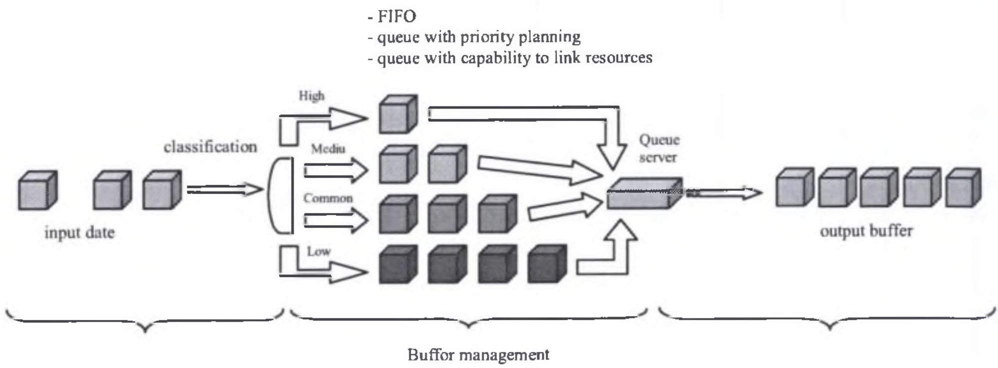

Fig.2. The advanced queue algorithm structure

The queue algorithm structure is shown on the Fig.2. The advanced queue management use the following algorithms

- Priority planning, where some messages in assumed protocols have priorities corresponding to appropriate output buffers,
- Guaranteed bandwidth with cyclic service, where each application has assured minimal part of bandwidth and corresponding buffers.

Additionally the scheme from Fig.2 is very convenient for overload protection. The congestion may be eliminated using RED (Random Early Detection) by random elimination of packages and more slowly transfer from some, less important sources (weighted random discarding). The lost of some packages may be characterised by appropriate probability.

The delay problem in the network may be modelled using Markov process methodology applied to the mass service theory. Corresponding to the Markov process assumption about Poisson distribution of events connected with new messages (and exponential distribution of times related to these events) the mean delay time or single link is determined by Little relations [5]:

$$T = \frac{N}{\lambda} = \frac{\ell/\lambda}{1-\ell} = \frac{1/\mu}{1-\ell} = \frac{1}{\mu - \lambda} \tag{1}$$

Where

$N = \frac{\ell}{1-\ell}$ - mean number of packages

$\ell = \lambda / \mu$ - system load

For the part of net connected with n links the mean delay for the network is equal to

$$T_i = \frac{1}{\mu C_i - \lambda_i} \tag{2}$$

For mean delay of package in network with n nodes and m lines the following relations are applied:

$\gamma = \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij}$ - common traffic between each pair nodes

$\lambda = \sum_{i=1}^{m} \lambda_i$ - common movement in all lines

Mean delay for stage is a weighted sum of all individual delay described by (2), and means delay time per line T_o is equal to.

$$T_o = \sum_{i=1}^{m} \frac{\lambda_i T_i}{\lambda} \tag{3}$$

The mean delay time of package T_p is greater because many packages must reach several stages. T_p may be expended with respect to $\bar{n} = \lambda / \gamma$ mean number of stages per packet.

$$T_p = \bar{n} \sum_{i=1}^{m} \frac{\lambda_i T_i}{\lambda} = \bar{n} \sum_{i=1}^{m} \frac{\lambda_{i/\lambda}}{\mu C_i - \lambda_i} \tag{4}$$

The above formula may be used for comparison with simulation experiment results to verify the assumptions about message generation process.
For ESTW the analytical results are: $T_o = 1.27$ ms, $T_i = 0.0000065$ ms ÷ 0.00000708 ms, $T_p = 1.3$ ms, $\bar{n} = 1.02$. However For WSKR the analytical results are: $T_o = 0.0093$ ms, $T_i = 0.0000068$ ms ÷ 0.0000078 ms, $T_p = 0.0104$ ms, $\bar{n} = 1.12$

4. THE SIMULATION OF TRANSMISSION PROCESS OF COMPUTER NETWORK

The described process of transfer the packages in presented railway systems (ESTW, WSKR) has been simulated in Network Simulator-2/Linux program. The evaluating part of the program is implemented in C++. Before simulation starting the network topology and parameters (capacities, rates, frequency and bandwidth, protocols, buffer delays, and routing algorithms) must be determined. NS-2 gives the possibility of modelling all types of links: via cable, radio and satellite. It has also the possibility of modelling the disconnecting of link.

The Fig.3.b, Fig.4.b and. Fig.5.b show the simulation with failed link respectively to the presented railway systems.

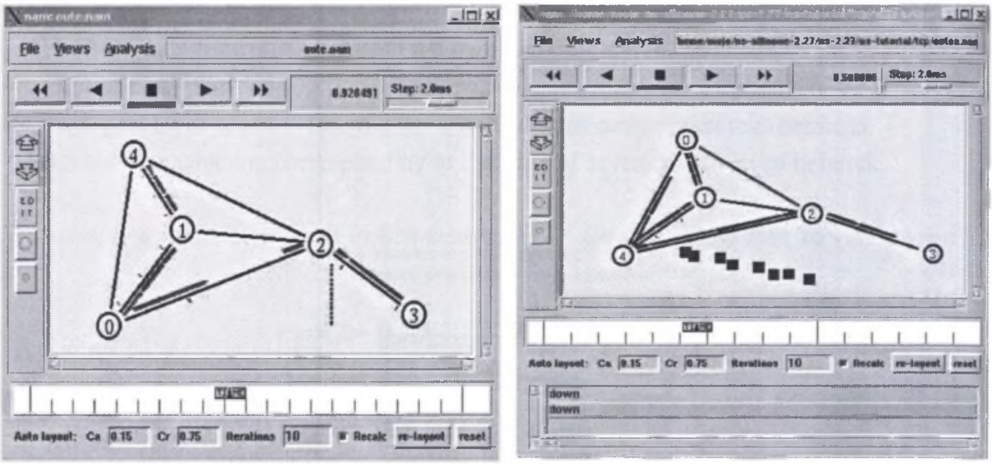

Fig.3. The model of ESTW three computer system (a) and failed link model (b)

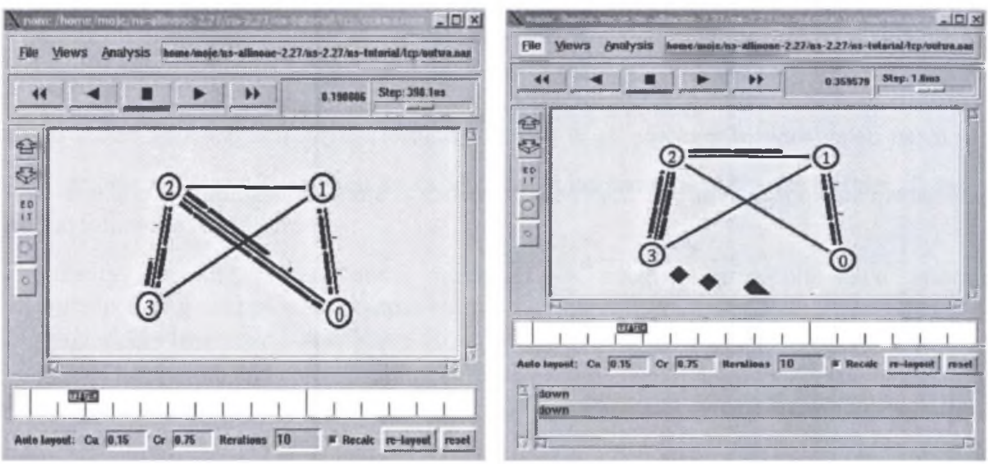

Fig.4. The model of WSKR centre (a) and failed link model (b)

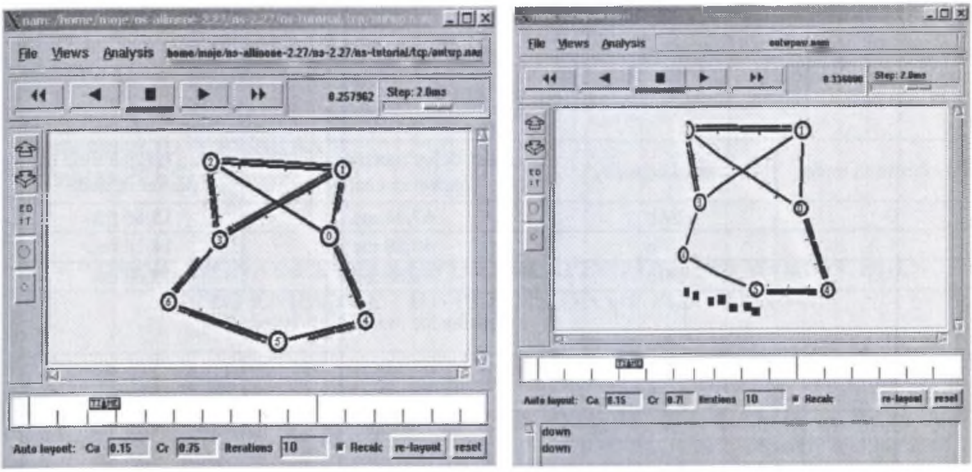

Fig.5. The model of line subsystem PIP (a) and failed link model (b)

For all examples the influence of service time of package to total delay time of transmission is analysed.

For ESTW the duplex links, 2Mb/s capacity for input line and 1MB/s for output line, 10ms delay in each channel, 1040 bytes for TCP and 40 bytes for ACK package are assumed. In the 1.5 s of simulation time the 1932 packages were transmitted The Table 1 contains the results of the simulation.

Table 1

Results for failed link model without queue

link between nodes	channel capacity	mean delay transmission of packet in channel	mean service time of packet in node
0-2	2Mb	1.04 ms	14.16 ms
4-1	2Mb	1.04 ms	13.11 ms
1-0	2Mb	14.72 ms	14.16 ms
2-3	1Mb	1.04 ms	14.16 ms
Results for model with queue			
0-2	2Mb	1.04 ms	14.16 ms
4-1	2Mb	1.04 ms	14.16 ms
1-0	2Mb	14.72 ms	14.16 ms
2-3	1Mb	20.34 ms	18.32 ms
Results for model with failed link			
0-4	2Mb	9.36 ms	14.16 ms
2-4	2Mb	0 ms	14.16 ms
1-0	2Mb	14.72 ms	14.16 ms
4-1	2Mb	14.72ms	14.16 ms
2-3	1Mb	0 ms	14.16 ms

For WSKR centre assumptions similar to ESTW give the results of simulation from Table 2 (1880 transmitted packages during 1.5 s).

Table 2

Results for WSKR

link between nodes	channel capacity	mean delay transmission of packet in channel	mean service time of packet in node
0-1	2Mb	67.36 ms	15.66 ms
1-2	2Mb	40.88 ms	14.16 ms
2-3	2Mb	58.88 ms	13.62 ms
Results for model with failed link			
0-1	2Mb	67.36 ms	15.66 ms
2-3	2Mb	58.88 ms	13.62 ms
3-1	2Mb	0 ms	14.16 ms
2-0	2Mb	23.24 ms	14.16 ms

5. CONCLUSIONS

Presented simulation experiments are necessary for assessment of new systems in design, laboratory or field tests and earlier, conditional exploitation. Obtained results – total delay time has an important influence into the system safety measures required by European standardisation and railway organisations such CENELEC and UIC. These results may be in nearest future verify by test and exploitation results, but simulation determines the limits of system possibilities corresponding to railway traffic and real parametrs of applied transmission systems. The simulation results for presented examples are less different than analytical values obtained from (1) and (2), because in theory of queues.

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