

A Data Transfer Model of Computer-Aided Vehicle Traffic Coordination System for the Rail Transport in Ukraine

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Abstract. This paper gives a general layout of subsystem operation used for the rolling stock traffic coordination. A principle of selection of information technologies applied for the realization of the communication and data transfer system has been described. GSM and GPRS technologies that are used for the transmission of navigation information on a vehicle locus and for the information exchange in the system have been described. To provide a required level of transmission capacity through the frequency reuse the guard period between the base transceiver stations has been calculated. To calculate the GPRS channel capacity and that of information exchange via the Internet GPRS network an algorithm for the simulation modeling of packet arrival in the prescribed time space has been constructed. Using this algorithm an experiment was carried out for different intensity values of packet arrival to the system.

Keywords. Traffic coordination, information technologies, transmission capacity, algorithm, simulation model, communication channel

Key terms. Development, Model, MathematicalModel

1 Introduction

The traffic control automation is a topical and up-to-date problem of the rail transport in Ukraine. An important part of this problem is the development of algorithms for the coordination and control of the large amount of rolling stock, situated in a zone of railway traffic control points. An important requirement set to such algorithms is to provide safe and regular traffic of the whole collection of trains and to make optimal decisions from the economic standpoint.

To provide safe traffic for rolling stocks at the stage of departure or arrival a certain (permissible minimum) time interval should be provided, which is always taken into consideration while making a train timetable. Despite this fact the train timetable is sometimes disturbed due to many reasons and situations arise when the rolling stocks are found to be undivided by the safe time interval and the groups of conflict-

ing trains are formed. In the case of high traffic intensity the groups of conflicting trains at stations or at a train overtaking locus can be rather large. On the other part the malfunction of train timetable can result in subsequent traffic disturbance (train delay, train overtaking conflicts, etc.) The above problems can be resolved through the automation of operative traffic control of rail transport. The experience gained by foreign countries [1,2] shows that the efficient solution of traffic control with regard to the rail transport is only possible if the latest information technologies are used.

The use of inexhaustible potential of railway information systems for the benefit of entire transport system of the country allows to reduce control costs required for the management and realization of domestic and international traffic. This also provides a considerable improvement in the quality of transport and logistics-related services and safety of traffic.

The examples of computer-aided systems that can fully or partially solve the above problems are the European Train Control System (ETCS) [3], American Positive Train Control (PTC) [4] and ILSD-U system [5] used by Russia.

A specific feature of the developed computer-aided system used for the rolling stock (RS) traffic coordination is the introduction of contemporary satellite technologies, communication and data transfer systems into a routine work of rail transport in Ukraine. The information exchange technology can be described as follows.

A GPS/GPRS –modem receives the navigation information from satellites, after that using the GPRS technology the coordinates, current speed and other information are transmitted via the operator's server of mobile communication to the database server. The RS locus data are transmitted to the workstation of railway station dispatcher and to the workstation of railway dispatcher.

The data should be processed in a real time mode. An important aspect is that a time interval during which these data gain currency should be taken into consideration. This fact considerably constrains not only the algorithm used for the solution of coordination problem but also data transfer technologies.

This paper consists of several sections. First of all, the technologies used for the data collection, processing and transfer will be described. Then, we will estimate the channel data transfer capacity and do appropriate computations that prove the obtained results.

2 Data Transfer, Processing, and Collection Technology

At the present time the railway adopts the computer-aided system (CAS), which includes the following basic subsystems: onboard intellectual system, which provides positioning, control and information support for the rolling stock; surface intellectual system (SIS), which provides control and coordination in a real time mode; communication and data transfer system based on the mobile GSM communication; navigation charts that reflect a real railway infrastructure. The SIS structure and CAS system on the whole are given in Fig.1.

A special place in SIS is occupied by the information system designed for the rolling stock traffic coordination, which is the subject of this research. The navigation

data collection system is used for the automatic identification of a rolling stock locus and also for securing the safety of traffic. The information about a rolling stock locus is required for the optimal use of traffic and carrying capacity of railways and for the elimination of dangerous situations (dangerous passing approach, passing the traffic lights with forbidden signals, siding motion, exceeding the allowable speed in the places of its restriction, etc.) A locus of each RS is transmitted to the traffic control service via the navigation system for further data processing and traffic control. The basic principles of monitoring are the safety of traffic, time fulfillment of a transportation schedule and costs minimization.

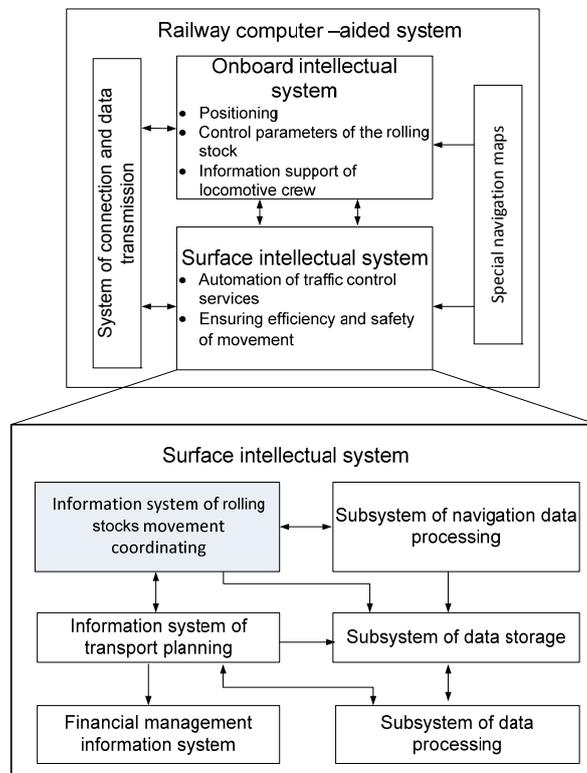


Fig. 1. CAS and SIS structures

In order to create the appropriate computer-aided communication and data transfer system for the rail transport the adoption of communication standard is required to meet the entire system operation requirements, in addition to the use of satellite navigation. The required communication system should provide high safety, reliability and solutions proved in practice and it should also be an innovative and high performance system. The costs required for the total system deployment should be reduced to a minimum.

Taking into consideration the European experience gained in the realization of similar data transfer systems telecommunication technologies should be developed meeting the GSM-R standard (Global System for Mobile Communications-railway)[6,7], which engineering and economic efficiency has been proved not only by tests but also by real application for different railway systems in developed European countries. However, at this stage of the development of information technologies in Ukraine we can make to the conclusion that the realization of formulated problem is possible and it is highly recommended to use the GSM mobile communication standard. The GPRS technology is recommended for the data transfer.

The GPRS networks split the transmitted information into individual packets that are delivered from a transmitter to a receiver. If errors have been detected the received packets can be transmitted once again. The original message is designed by the receiver party using the obtained packets. The data transfer in packet-switching networks differs from the data transfer in channel-switching networks in the way that the required channel resource is allocated exclusively for the time of transmission of appropriate information packets. The rest of the time it is at disposal of a network. In the case of GSM/GPRS networks this allows us to use one physical channel for the transmission of packets to several subscribers and to simultaneously allocate several physical channels for the transmission of packets to one subscriber. The packets are transmitted aside from each other in different directions.

The GPRS defines the effective use of a channel resource. The same physical channel is provided for the group of subscribers to receive messages sent from the base transceiver station (BTS) to a mobile station (MS) and packets are transmitted as soon as they arrive depending on the volume of information and the priority of subscribers. Each packet contains an identifier or address, which is used for the delivery. A subscriber is continuously connected to the packet network, which provides for him a virtual channel. It becomes a real (physical) radio channel during the packet transmission. The rest of the time this physical channel is used for the transmission of packets of other users.

Due to the fact that the same channel resource is used by several subscribers and during the communication session the packets of different users can simultaneously arrive the waiting list of transmitted packets can be originated, which will result in the communication delay. The allowable value of packets delay is one of the attributes defining the quality of a subscriber service.

The paper [8] defines three classes of delay depending on the delay norms and packet length. The top priority is assigned to the Class 1, the normal priority is given to the class 2 and the class 3 enjoys the least priority. The delays have not been defined for the Class 4, because the service of packets of this class is performed adhering to the "best effort" principle.

The intensity values of packets arrival can be selected on the basis of statistical research. A statistics shows that a number of packets arriving per time units to the input of GPRS circuit changer can vary in a wide range from hundreds of packets/s at input sites to several thousands of packets/s at backbone sites.

To provide the appropriate level of data throughput we use the basic principle of the construction of cellular communication networks, which is based on the frequency

reuse [8]. The main essence of it consists in that the neighboring (adjacent) cells of a mobile communication system use different frequency systems and in non-adjacent cells located at sufficient distance from each other the used frequency bands are repeated. In practice the cities and regions with a solid cellular coating use clusters in which each cell is divided into the three sectors, using the directional radiation antenna with the directional pattern width of 120° .

The base stations that allow frequency reuse are located at a distance D from each other. This D distance is measured between the centers of hexagonal cells and it is called a guard interval.

Proceeding from geometrical reasons the parameter D can be defined as follows:

$$D = R\sqrt{3\eta},$$

where R is a radius of circle circumscribed around the regular hexagon; η is a coefficient of the frequency reuse. The $\frac{D}{R}$ ratio is defined as a reduction factor of channel noises.

Thus, for the optimal frequency reuse and an increase in the GPRS channel capacity in Ukraine the guard interval should be:

$$D = 15\sqrt{3} \cdot 3 = 45 \text{ (km)}$$

3 Case-Study for Capacity Evaluation

The developed computer-aided system used for the rolling stock traffic coordination should take into consideration, while transmitting the navigation information to the mobile operator server, not only the capacity of GPRS channels but also that of cable or fiber-optic channel of the Internet network, which is used for the transmission of data to the database server.

By analogy to the mobile communication it is necessary to consider a problem related to the average duration of delays in the packet switch.

The term "packet switch" implies here a concentrator (statistical multiplexor), a virtual packet switch (network X*25, Frame Relay, and ATM network) and a router (IP network). The packet switch can be represented as an element with many input and output channels (switch/router). Using the Kendall notation such network elements can be presented by queuing systems of G/G/1 or G/G/n type (arbitrary probabilistic distributions describing the incoming stream of customers (in our case packets or protocol blocks) and the time of their serving time. (Let us note that models with one server, i.e. G/G/1 are often used for the analysis of packet switches).

Let's assume that in the general case applications arrive to the system input in compliance with the Poisson distribution law, whose service time is an arbitrary value. Then the average queue length in the system with the infinite buffer size (M/G/1) is calculated using the classic Khintchine-Pollaczek formula [9]:

$$\bar{t}_q = \frac{\bar{q}}{\lambda} = \bar{t}_s \times \left[1 + \rho \frac{1 + C_s^2}{2(1 - \rho)} \right] \tag{1}$$

where \bar{q} is an average queue length in the considered system (including protocol blocks PB);

$\rho = \frac{\lambda}{\mu}$ is the M/G/1 system load intensity, $\rho < 1$;

λ, μ are the intensity values of the PB arrival and service in the system, accordingly;

\bar{t}_s is an average time of PB service in the system;

$C_s^2 = \frac{D(t_s)}{(\bar{t}_s)^2}$ is a quadratic coefficient of service time variation equal to the ratio of service time variance and squared expectation value.

The values required for computations using formula (1) were obtained through the simulation modeling of data transfer in the Internet network, which algorithm is given in [1].

A one-channel queuing system (QS) of the M/G/1 type has been taken as an example. The arrival of the Poisson stream of applications with the constant service time τ_j has been simulated. The numerical experiment, which was carried out, allows us to come to the conclusion that there is no loss of data packets.

The constructed graphs show the time of the arrival of customers in a queue and the time of channel teardown from the previous application at the application arrival intensities of $\lambda = \frac{1}{10}$ (see Fig.2.a) and $\lambda = \frac{1}{20}$ (see Fig.2.b)

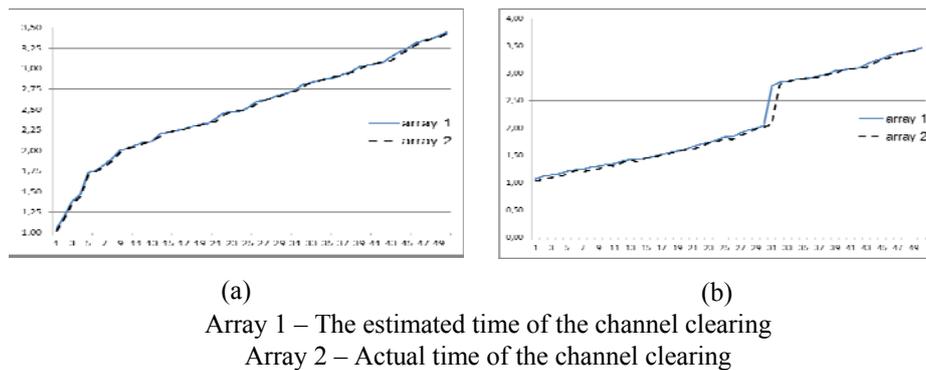


Fig. 2. QS simulation with an intensity of $\lambda = \frac{1}{10}$ and $\lambda = \frac{1}{20}$

The given Figures show that an increase in intensity of arriving customers does not result in the lack of channel capacity. This proves the correct choice of information

technologies for the realization of computer-aided system used for the rolling stock traffic coordination.

To define the data transfer channel capacity in the Internet network the network duration and delay should be calculated.

Due to the fact that the data transfer channel-switching center services packets it can be simulated using the system with a constant service time of a M/D/1 type.

$$\bar{t}_q = \bar{t}_s \times \left(1 + \frac{\rho}{2(1-\rho)} \right).$$

$$\text{At } \lambda = \frac{1}{10} \text{ and } \mu = \frac{1}{5}$$

$$\rho = \frac{\lambda}{\mu} = \frac{1}{2}$$

Let t in the given example be equal to 0,05. As a result we get:

$$\bar{t}_q = 0,05 \times \left(1 + \frac{1}{2} \right) = 0,075,$$

which corresponds to the first service class.

$$\text{At } \lambda = \frac{1}{20} \text{ and } \mu = \frac{1}{15}$$

$$\rho = \frac{\lambda}{\mu} = \frac{3}{4}$$

Let t in the given example be equal to 0,05. As a result we get:

$$\bar{t}_q = 0,05 \times \left(1 + \frac{3}{2} \right) = 0,125,$$

which corresponds to the first service class.

4 Conclusions

Today the railways are the major branch of the economy of Ukraine and they serve as a basis of the Ukrainian transportation system. Due to the rapidly changing demands for freight services and carriage of passengers a permanent control over the required amount of rolling stocks should be investigated. The proper amount of such vehicles can be defined through the traffic analysis.

The information on the timetable of railway traffic and actual amount of rolling stocks involved in traffic serves as a source information for further computations of the capacity of a communication and data transfer system of the computer-aided system. This will provide the fulfillment of actuality condition of obtained data and the solution of the traffic coordination problem in a real time mode.

To provide the functioning of computer-aided system on the whole the following algorithms should be realized. The algorithm used for the determination of the amount of conflicting trains is the first step towards the problem solution. It allows for the detection of those rolling stocks for which conflict-free conditions are not observed due to different reasons (timetable violation, technical malfunction, etc.). A decomposition algorithm is required for the reduction of dimension of a solved problem that would allow the reduction of time interval of data acquisition. The obtained data are used for the generation of control action and for the reduction of loading for the used transmission channel, providing thus the observance of principles of control in a real time mode. An algorithm of the problem related to the coordination of rolling stock traffic allows for the elaboration of such control actions that provide not only the elimination of a definite conflict but also the fulfillment of conflict-free conditions for the definite rolling stock in the future. An algorithm of data transfer in a real time mode is the basis of information exchange between the rolling stock and the database server. Our further research is targeted at the development of algorithmic support of communication and data transfer system to solve the problem on the coordination of traffic of rolling stocks.

This paper gives the description of GSM and GPRS technologies that are used for the transmission of navigation information on the locus of rolling stocks and also for the information exchange in the system. It has been noted that in order to provide the required capacity level we applied the main principle used for the construction of cellular communication networks, i.e. the frequency reuse. The cluster structure with a template of 3/9 has been constructed and the guard interval between the BSs used for the mobile communication in Ukraine has been calculated.

To calculate the capacity of GPRS channels and that of information exchange channel in the GPRS Internet network the algorithm of simulation modeling of arriving packets during the prescribed time interval has been constructed. On the basis of this algorithm we carried out an experiment for different intensity values of packets arrival to the system. Using the analysis data we can come to the conclusion that an increase in the intensity of arriving customers causes no lack of channel capacity.

Our further research is targeted at the development of an algorithm for the data processing in a real time mode, and also at the development and testing of the information system designed for the rolling stock traffic coordination. We will also delve into the computation of efficiency estimates to evaluate the introduction of information technologies into the rail transport operation.

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