Service quality management in multipath access solutions for transport telematics solution

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ABSTRACT

ITSs (Intelligent Transport systems) are associated with serious expectations and getting ITS applications in the real practice is understood as essential potential to significantly faster resolve many transport challenges. Research is concentrated on the promotion of ITS architecture in real ITS practice and using it for solving the different ITS optimization tasks. In this paper main afford is oriented to the communications key support of the ITS architecture.

KEYWORDS: Intelligent Transport System, Transport telematics, Multipath seamless communications access service, Bayes statistics, Laplace density function

1. Introduction

ITSs (Intelligent Transport systems) are associated with serious expectations and getting ITS applications in the real practice is understood as essential potential to significantly faster resolve many transport challenges. Research is concentrated on the promotion of ITS architecture in real ITS practice and using it for solving the different ITS optimization tasks. In this paper main afford is oriented to the communications key support of the ITS architecture.

2. Telematic requirements communications solution

ITSs (Intelligent The first step in addressing the ITS architecture requirements is the analysis and establishment of performance parameters in designed telematics

applications, in co-operation with the end-users or with organizations like Railways Authority, Road and Motorways Directorates, Airport and Air-transport Authorities, Government etc.

The methodology for the definition and measurement of following individual system parameters is being developed in frame of the ITS architecture and it is described in [1] - [5].

Substantial part of the system parameters analysis is decomposition of system parameters into individual subsystems of the telematics chain. This step represents analysis of requirements on individual functions and information linkage so that the whole telematic chain should comply with the above defined system parameters.

The completed decomposition of system parameters enables application of the follow-up analysis of telematic chains according to the various criteria (optimization of the information transfer between a mobile unit and processing centre, maximum use of the existing information

and telecommunication infrastructure, etc.). It is obvious that quantification of requirements on relevant telecommunication solutions within telematic chains plays one of key roles in this process.

Mobility of the communication solution represents one of the crucial system properties namely in context of specific demand on availability and security of the solution. Monitoring and management of the airport over-ground traffic was one of our key projects where our own approach to system solution was designed and tested. This application is characterized by strict regulation and successful tests of ITS system under heavy airport conditions can be understood as the representative telematic reference.

Data transmission capacity can act due to possible high density of moving objects and limited wireless capacities critical system requirements, which can be resolved either by application of broadcasting regime of data distribution or by selective individually reduced frequency of positional data distribution. Distance between objects or moving objects density in area represents simple but effective criteria for such individual data distribution management.

Following communications performance indicators quantify communications service quality (see e.g. [6] - [10]):

- Availability – (Service Activation Time, Mean Time to Restore (MTTR), Mean Time Between Failure (MTBF) and VC availability),
- Delay is an accumulative parameter and it is effected by either interfaces rates, frame size or load/congestion of all in line active nodes (switches),
- Packet/Frames Loss (as a tool which not direct mean network failure),
- Security.

Performance indicators applied for such communications applications must be transformable into telematic performance indicators structure and vice versa. Indicators transformability simplifies system synthesis. Additive impact of the communications performance indicators vector *tci* on the vector of telematics performance indicators Δtmi can be expressed as

$$\overrightarrow{\Delta tmi} = TM \cdot \overrightarrow{tci}$$

where: TM represents transformation matrix. It is valid, however, only under condition that probability levels of all studied phenomena are on the same level and all performance indicators are expressed exclusively by parameters with the same physical dimension – typically in time or in time convertible variable (see e.g. [7]). Transformation matrix construction is dependent on the detailed communication solution and its integration into telematic system. Probability of each phenomena appearance in context of other processes is not deeply evaluated in the introductory

period, when specific structure of transformation matrix is identified. In [7] - [10] are presented details of proposed iterative method. Method is designed as broadly as possible with clear aim to be applied in the widest possible range of telematic application. This method can be also successfully used for identification of decision processes criteria, i.e. tolerance range of each performance indicator. Such information represents necessary (but not sufficient) condition to let processes decide which access technology is in defined time period the best possible alternative.

3. Calm

Family of standards ISO TC204, WG16.1 "Communications Air-interface for Long and Medium range" (CALM) represents concept of identification of the best available wireless access solution in given time and area. Process of the alternative wireless access solution substitution is understood as the second generation of the handover principle known in its first generation namely from the cellular mobile systems. Each handover process is predestinated by set of performance indicators range identified for decision processes implemented in the control unit. CALM standards have implemented Policy-Based Management (PBM) approach. This concept has been traditionally and successfully applied in the IP based terrestrial networks. Such approach, however, has got remarkable limits for wireless networks discussed later in this paper.

Details of CALM architecture are described e.g. in [11] and [13]. Handover in CALM is implemented on the L2 of the TCP/IP model. Alternative approach based on standard IEEE 802.21 - see e.g. [14] - expects integration of the L2 switching into handover process, as well, even though with this system approach we identified remarkable advantages against the "CALM" alternative.

Authors solution is based on L3 routing and this approach we would like to categorized as "intelligent routing". Such approach offers advantage of the exclusively SW based implementation and no special HW requirements on OBU (On Board Unit) installed in the vehicle.

4. Mutli-path access solution structure

Second generation handover action can be determined by evaluation of the performance indicators set like Bit Error Rate (BER), Packets Lost Ratio (PLR) or packet Round Trip Delay (RTD) as well as remarkable number of other e.g. "radio" parameters with different level of influence on the final decision. Decision to switch to the alternative path is so complex issue with high number of input

parameters. Number of inputs can be limited, if significant parameters are identified, and all other known parameters can be accepted as insignificant. Such afford to identify the key performance indicators has been basis for our specific studies of all available telecommunications technologies used in the transport telematics.

Adaptive communications control system has following architecture:

- 1-st layer – Cellular Layer (CL) - represents feed-back control processes of parameters like transmitted power, type of applied modulation etc. Goal of processes on this layer is to keep given set of managed parameters like e.g. Bit Error Rate (BER) or Round Trip Delay (RTD) within required limits.
- 2-nd layer – the first generation of handover (1HL) represents seamless switching process between cells of the same mobile network. Such approach is applied in mobile systems like GSM, UMTS, Mobile WiMax or Mobile WiFi (802.11r). 1HL layer typically shares resources with CL layer (delivered usually as one system) so that there is no risk of contra-productively simultaneously operated processes on both layers - of course only - if it is correctly designed and operated. These solutions are, however, mostly designed as "close" ones, i.e. nothing like APIs are available.
- 3-rd layer – the second generation of handover (2HL) is mostly dependent only on identification of the service performance indicators. It is for sure that the effective management on the 2HL layer can be much easier reached if 1HL and LC layers are opened for relevant information exchange with layer 2HL.

Critical issue can be identified in potential simultaneous processing on the different layers of the processes. Such activities can be contra-productive, and, all potential decisions and actions should be well synchronized.

5. DOTEK

Decision processes representing basis for adaptability of communications wireless services have not been deeply enough resolved issue in ISO CALM standards. CALM standards recommend on Policy-based Management (PBM) approach. This concept has been traditionally applied in the IP based networking and we can only state its remarkable success.

L3 routing based on "deterministic decisions" was applied in project of the communication module for transport telematics - DOTEK. "DOTEK approach" ensures the best wireless access solution selection from the set of available wireless services and it is based on system parameters benchmarking derived from the telematic application requirements recorded in form of required parameters range into the "decision" table.

The main objective of the DOTEK project was motivated by the CALM family of standards. However, principal difference if compared with "CALM approach" was implementation of the "intelligent" routing principles replacing L2 switching used in case of CALM solution. DOTEK project was focused mainly on the following areas:

- Analysis and selection of available wireless services applicable for different transport telematics services.
- Design of comprehensive management including decision algorithm for selection of optimal data transfer technology.
- Provisioning of the continuous monitoring and evaluation of given services quality necessary for the correct decision to select appropriate service.
- "Table based" processing of the decision in order to ensure proper operation of telematics applications.

An important part of communication module is to monitor current system parameters and communication technologies in order to assess their current situation and decide about their suitability for use according to the specific requirements of telematic applications. Telecommunication technologies are described by system parameters like:

- availability,
- delays (latency),
- packet/frames loss,
- signal to noise ratio (SNR),
- received signal strength indication (RSSI),
- bit error ratio (BER),
- security level,
- etc.

For the pilot implementation basic three monitored system parameters were chosen:

- signal to noise ratio,
- packet latency,
- packet loss.

In case of further implementation it will be possible to include other system parameters if relevant impact is identified.
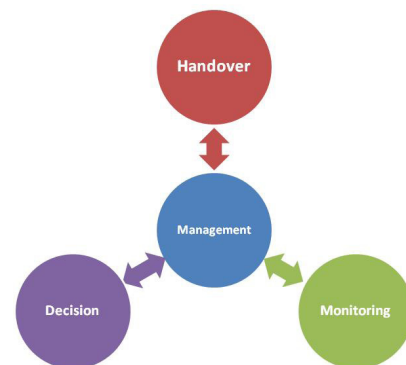

Fig. 1. General system architecture
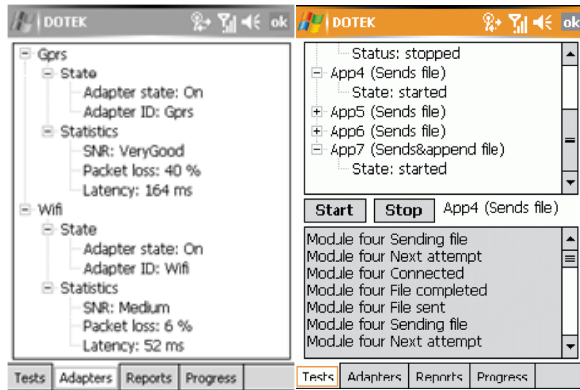**Source: [own work]**

Fig. 2. Screenshots from testing application
Source: [own work]

Implemented decision algorithm supports appropriate access wireless service selection. It is based on application of relevant data requirements recorded in the "decisions tables". Current status of available telecommunications technologies including the one in use must be continuously available. Cost of each applied access wireless telecommunication service use to be required to be taken in account, as well.

Decision to implement described simplified "Extended PBM" approach was done on based on evaluation of currently available research R&D man power resources. Full adaptive version described below was out of team capacity as well as of allocated resources. With this implemented version was successfully tested this "extended PBM approach". System successfully passed test scenarios for verification its basic functionalities. Results of measured times needed for the second generation handover are presented in the Table 1.

Project DOTEK was successfully finalized and obtained results were integrated into existing on-board unit (OBU) tested with four telematic applications implemented - EFC, fleet management, e-Call and navigation. Results – i.e. developed software has got modular structure, and, therefore it can be integrated into other compatible systems. Correctly integrated modules can provide relevant management of applied communication solutions. Presented pilot implementation, as presented in Table 1 handover time, is applicable in wide range of transport telematics solutions.

Table 1. Results of test scenario - time of handover

Test no.	Handover time [ms]
1	208
2	137
3	41
4	108
5	362

6. Adaptive decision process

Below presented approach can be understood as the "conservative" approach based on Bayes statistics with well known limits given by CPU capacity consuming complex mathematical implementations. Authors are driven by fact that applied services are operated as wireless access solutions with parameters not being available in the terrestrial solutions (like SNR). Complex mathematical solution can require remarkable capacity of the applied CPU. It could be expected that combination of classical mathematical solution with approach like POETRY can appear. However, dynamically increasing CPU power of communication micro-chip systems will diminish requirement on reduction of CPU capacity needs and complex statistical mathematical approach will be kept at least for more demanding alternatives.

Following paragraphs describe our approach to the decision processes. Proposed methodology is based on following principles - see [22] or [23]:

Measured parameters are processed by Kalman filter. Such process separates reasonable part of present noise and also allows prediction of the individual parameters in near future behavior.

Set of measured parameters is extended by deterministic parameters like identification communicated with tall collection, economical parameter, corporate policy etc. All together it is presented as parameters vector x.

Based on time lines of vector x it is feasible to classify the best possible technology selection. Classification algorithm is trained using time lines of training vectors x extended by assignment to the relevant class, i.e. selected path.

Success of classification is related to the size and quality of the training data lines.

This solution does not necessarily require 2HL control system with the other layers ones, nevertheless, more stable, efficient and precise decision is obtained if such communication is at least partially possible.

Let us define the classification problem as an allocation of the feature vector:

$$\mathbf{x} \in R^{D}$$

to one of the C mutually exclusive classes knowing that the class of x takes the value in

$$\left\langle \Omega = \left\{ \omega_1, ..., \omega_C \right\} \right\rangle$$

with probabilities $P(\omega_1)$, ..., $P(\omega_C)$, and x is a realization of a random vector characterized by a conditional probability density function

$$p(\mathbf{x}\,|\,\omega), \quad \omega \in \Omega$$

This allocation means the selection of best fitted tele-communication technology based on knowledge of x vector.

A non-parametric estimate of the ω-th class conditional density provided by the kernel method is:

$$\hat{f}(\mathbf{x}\,|\,\omega) = \frac{1}{N_\omega \cdot h_\omega^D} \cdot \sum_{i=1}^{N_\omega} K\left(\frac{\mathbf{x} - x_i^\omega}{h_\omega}\right), \qquad (1)$$

where $K(..)$ is a kernel function that integrates to one, is a smoothing parameter for ω-th class, N_ω stands for sample count in class ω and

$$\mathbf{x}_1^\omega, ..., \mathbf{x}_{N_\omega}^\omega$$

is the independent training data. The density estimate defined by (1) is also called the Parzen window density estimate with the window function $K(..)$.

Choice of a particular window function is not as important as the proper selection of smoothing parameter. For our case we use the Laplace kernel defined by the following Laplace density function:

$$f_L(x;\mu,\sigma) = \frac{1}{2\cdot\sigma} \cdot \exp\left(-\frac{|x-\mu|}{\sigma}\right), \qquad (2)$$

where

$$x \in R, \ \mu \in R, \ \sigma \in (0, \infty).$$

The product kernel is used with a vector of smoothing parameters $\boldsymbol{h}_\omega = (h_{1\omega}, ..., h_{D\omega})$ for each class ω. The product kernel density estimate with Laplace kernel is then defined as:

$$\hat{f}(\mathbf{x}|\omega) = \frac{1}{N_\omega} \sum_{i=1}^{N_\omega} \prod_{j=1}^{D} \frac{1}{2\cdot h_{\omega,j}} \exp\left(-\frac{|x_j - x_{i,j}^\omega|}{h_{\omega,j}}\right). \quad (3)$$

Smoothing vectors $\boldsymbol{h}_\omega$ are optimized by a pseudo-likelihood cross-validation method using the Expectation-Maximization (EM) algorithm - see [21].

To rank the features according to their discriminative power the standard between-to within-class variance ratio is employed. This method is based on the assumption that individual features have Gaussian distributions. The feature vector

$$\mathbf{x} \in R^D$$

takes value to one of C mutually exclusive classes

$$\Omega = \{\omega_1, ..., \omega_C\}$$

The probabilistic measure of two classes separability for the feature d (d-th component of feature vector) is defined as:

$$Q_{d,i,j}(d, \omega_i, \omega_j) = \frac{\eta \cdot (\sigma_i + \sigma_j)}{|\mu_i - \mu_j|}, \qquad (4)$$

where ωi and ωj are classes and symbol $\eta = 3.0$ denotes the real constant specifying the interval taken into account (probability that observation of normally distributed random variable falls in $[\mu\text{-}3.0.\sigma, \ \mu\text{+}3.0.\sigma \ ]$ is 0.998). The smaller is the value of the measure $Q_{i,j,d}$, the better is separation of the inspected classes made by the feature d. For $Q_{i,j,d} < 1$, both classes are completely separable. The measure is similar to the widely used Fisher criterion.

For multi-class problems, the two-class contributions are accumulated to get a C-class separability measure Q(d) for the feature d:

$$Q(d) = \sum_{i=1}^{C} \sum_{\substack{j=1 \\ i \neq j}}^{C} Q_{d,i,j}(d, i, j). \qquad (5)$$

All the features in the training data are then sorted according to their Q(d) measures. The function Q(d) is similar to the significance of the of d-th component of the measured feature vector. The subset of n first features is selected as an output of this individual feature selection method. The drawback of the method is the assumption of unimodality and the fact that just linear separability is taken into account. On the other hand, the individual feature selection method based on the between-to within-class variance ratio is very fast.

Presented classification approach is effectively applicable for relevant decision processes used to select the best possible alternative access from the set of available paths. Decision can provide evaluation of both random as well as deterministic processes and introduced approach enables continuous decision processes parameters training.

Presented method allows solutions implementations with limited information flows between layer 2HL and layers 1HL and CL. Presented solution is, however, open for any future changes in information resources. Such changes can lead to the principal decision processes parameters improvement. Due to its self training procedure of the new information resources integration is smooth and relatively simple.

It is important to stress that optimized number of the representative key performance indicators can lead to the significant reduction of required CPU capacity.

7. Conclusion

Due to regular complexity of telematic services covered areas (wide area coverage, several classes of services

with different system requirements) we focused our afford on wireless access solution designed as seamless switched combination of more independent access solutions of the same or alternative technology.

Decision processes representing basis for adaptability of the communications wireless services are quite rarely resolved and published. Most of present implementations are based on Policy-based Management (PBM). This concept has been traditionally applied in the IP based networking and we can only state its remarkable success. Implemented "Extended PBN based" decision processes were presented as well as principle parameters describing system behavior

Our final goal is, however, based on application of Bayes statistics. Set of measured parameters can be so flexibly extended by deterministic parameters like economical parameter, corporate policy etc. Based on self trained classification processes it is feasible to classify the best possible selection i.e. assigning data vector to one of set of classes. Classification algorithm is trained using time line of training data vectors extended by correct assignment to the relevant class, i.e. selected path.

Optimized number of the representative key performance indicators can, however, principally reduce requirement on CPU capacity. That is the reason why detailed study of each applied telecommunications technology has been accomplished in our laboratory to identify specific representative key performance indicators for each technology potentially applied in the system.

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