Adaptive wireless access environment in transport solutions

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ABSTRACT

This paper presents new attitude to adaptive control of the multi-path and multi-technology technology wireless access communications solutions. Presented approach is response on transport processes management requirements to provide complex seamless communication services in the selection of different modes coverage and guaranteed quality. Such solutions are related to communications of the vehicle to infrastructure as well as vehicle to vehicle. Such communications networking must include inter-vehicle communication interconnect, as well. CALM based system represent relevant data routing/switching with vertical RM OSI compatible communications architecture, however, with horizontal hierarchical management structure. Genuine decision processes in defined communications CALM routing/switching structures are, however, in literature discusses quite rarely. Decision processes measurable i.e. precisely enumerated system requirements are qualified by the performance. Based on application analysis performance indicators are demarcated into the acceptable tolerance ranges. In this paper we propose decision processes based on Bayes statistics as “classical” alternative to e.g. concept of Policy-based Management (PBM) traditionally and widely applied within the IP based networks.

In proposed alternative measured data are processed by Kalman filters to separate reasonable part of noise and to predict individual parameters behavior in its near future. Than self-trained classification algorithm processes filtered measured data which are combined with deterministic parameters like the services economy, company policy etc. Training data block represent parameters vectors time line extended by correct decisions, i.e. assignment to the appropriate class. Even though these tools are designed specifically for the multi-path communications system, such principles are open for future penetration into whole telematic system adaptive management. These results were obtained within projects e-Ident1, DOTEK2 and SRATVU3 which are elaborating results of project CAMNA4.

Keywords: Intelligent Transport System, Telematics, Performance Indicators, Satellite Navigation System. Seamless communications access service, handover, Bayes statistics, Kalman filter, classification process, Fisher criterion, Expectation-Maximization algorithm, self-training processes

1. INTRODUCTION

In order to be able to speak about a system it is necessary to describe it minimally as a final automaton defined by mapping the system inputs with respect to internal state plus mapping the inputs and internal state with respect to the system outputs. A subsystem must be describable through an identical methodology like a system; in its substance a subsystem is a system to be described at a more detailed distinguishing level. A system shows both a structure and architecture while the structure is usually much more detailed than the architecture. The architecture defines the basic arrangement of subsystems and functional blocks in the space. Functional block is used if it is not possible to define the given block as a system or a subsystem. The architecture is more global and its objective is to be arranged and intelligible as clear as possible. The structure goes up to systems elements, and it is more complex and more complete but less clearly arranged. For that reason architecture approach is used within our Intelligent Transport Systems (ITS) studies.

A process reflects the chained events within a system. An event may mean a change of a system state brought about by an initiation on inputs (transfer of input values) or initiation of internal system state or “only” in the course of the external time. A set of all activated processes at possible environmental conditions defines the system behavior. ITS (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. The ITS architecture reflects several different views of the examined system and can be divided into:

• Reference architecture - defines the main terminators of ITS system (the reference architecture yields to definition of boundary between ITS system and environment of ITS system),
• Functional architecture - defines the structure and hierarchy of ITS functions (the functional architecture yields to the definition of functionality of whole ITS system),
• Information architecture - defines information links between functions and terminators (the goal of information architecture is to provide the cohesion between different functions),
• Physical architecture - defines the physical subsystems and modules (the physical architecture could be adopted according to the user requirements, e.g. legislative rules, organization structure, etc.),
• Communication architecture - defines the telecommunication services between physical devices (correctly selects set of communications service),

2 DOTEK – Communication module for transport telematic applications –grant 2A-2TP1/105 of MPO.
3 SRATVU – “System Requirements and Architecture of the universal Telematic Vehicle Unit” is grant 2A-1TP1/138 of MPO.
4 CAMNA – “Joining of the Czech Republic into Galileo project” grant 802/210/112 of Ministry of Transport of the Czech Republic.
Organization architecture - specifies competencies of single
management levels (correctly selected organization
architecture optimizes management and competencies at all
management levels).

It must be taken in consideration that ITS systems usually cover
widely spread areas and the ITS solutions are usually
principally dependent on the relevant quality communications
services availability. We concentrate afford on the ITS
communications support, quantification methods of ITS system
demand on the communication solution performance parameters
indicators (see 2.1) as well as design of structures and processes
how these frequently extremely demanding requirements can be
fulfilled.

2. COMMUNICATIONS SOLUTION

2.1 Telematic sub-system requirements

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,
etc.

The methodology for the definition and measurement of
following individual system parameters – performance
indicators is being developed in frame of the ITS architecture
(see [1] - [5]):

• Reliability - the ability to perform required function under
given conditions for a given time interval.
• Availability - the ability to perform required function at the
initialization of the intended operation.
• Integrity - the ability to provide timely and valid alerts to
the user when a system must not be used for the intended
operation.
• Continuity - the ability to perform required function
without non-scheduled interruption during the intended
operation.
• Accuracy - the degree of conformance between a
platform’s true parameter and its estimated value, etc.
• Safety - risk analysis, risk classification, risk tolerability
matrix, etc.

Substantial part of the performance indicators analysis is
composition of system parameters into individual sub-
systems of the telematic 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 frequently very
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, but transparent 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
represent simple but effective criteria for such individual data
distribution management.

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

• Availability –
  o Service Activation Time,
  o Mean Time to Restore (MTTR),
  o Mean Time Between Failure (MTBF) and
  o VC availability,
• Delay is an accumulative parameter effected by
  o interfaces rates,
  o frame size, and
  o load / congestion of all in line active nodes (switches).
• Packet/Frames Loss (as a tool which not direct mean
  network failure) and
• 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 telematic performance indicators $\Delta mi$ can be expressed as

$$\Delta mi = TM : tci,$$

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 – in described
case in time or to 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. However, each $TM$ element is consequently
evaluated in several steps process based on the detailed analysis
of the particular telematic and communications configuration
and its appearance probability in specific context of the whole
system performance. This approach represents subsequent
iterative process managed with goal to reach stage where all
minor indicators (relations) are eliminated and the major
indicators are identified under condition that relevant telematic
performance indicators indicators are kept within given
tolerance range.

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
“CALM” criteria, i.e. tolerance range of each performance
indicator, to let decide which alternative access technology is in
applied in the widest possible range of telematic application.

2.2 Communications solution structure

Figure 1 presents typical telecommunications chain diagram,
originally applied within the pilot project Airport Praha (see e.g.
[7]). This structure was, however, later generally accepted as
a typical architecture of ITS telematic solutions. On Board Units
(OBU), GNSS Sensing System (SS) and set of Wireless Units
(WL) are installed in the moving object. SS applies now
exclusively GPS (Global Positioning System with no SLA
publically available), but there is expected to come the

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\begin{align*}
\text{Reliability} &= \text{the ability to perform required function under} \\
\text{Given conditions for a given time interval.} \\
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\text{Initialization of the intended operation.} \\
\text{Integrity} &= \text{the ability to provide timely and valid alerts to} \\
\text{The user when a system must not be used for the intended} \\
\text{Operation.} \\
\text{Continuity} &= \text{the ability to perform required function} \\
\text{Without non-scheduled interruption during the intended} \\
\text{Operation.} \\
\text{Accuracy} &= \text{the degree of conformance between a} \\
\text{Platform’s true parameter and its estimated value, etc.} \\
\text{Safety} &= \text{risk analysis, risk classification, risk tolerability} \\
\text{Matrix, etc.} \\
\end{align*}
\]
European Galileo GNSS with guaranteed quality of service. OBU represents not only control but also display and human communication services and WiL represents i-th cellular technology of the wireless complex solution. Terrestrial communication part consist of set of mobile cellular Base Stations (BS) (i-th bases station of the j-th cellular system) integrated by the terrestrial network based on L3/L2 switches/nodes (TN) interconnected with Servers (S). E2E (End to End) service is provided based on IP protocol, L2 switching is Ethernet protocol based.

![Diagram of Telematic telecommunication scheme in chain](image)

**Figure 1. Telematic telecommunication scheme in chain diagram**

If it is possible one core access wireless technology would be typically selected as the core solution to be combined with alternative solutions when needed. We will discuss principles of procedures which support selection of the best possible communications solution quantified by performance indicators and by some other parameters e.g. like service cost, company policy, as well. Technical implementation is described by standard under development (ISO TC204, WG16.1) CALM, even though there are available also alternative solutions e.g. based on L3/L2 switching principles.

### 2.3 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 parameters range identified for decision processes managed by control unit. Criteria for the “best possible” solution include indicators like Bit Error Rate (BER), packet Round Trip Delay (RTD), level of received radio signal (compared with the other base stations being just available), but also cost of provided service etc. Mathematically resolved control system can take in account not only the absolute values of selected indicators, but also specific parameters combinations trends.

Handover to alternative solution can be in principle evoked also by identification of more suitable alternative - e.g. by appearance of alternative service with more suitable cost conditions even though existing alternative has been technically sufficient and safe.

Communications CALM media are:

- Cellular systems including 2G and 2.5G GSM and UMTS,
- DSRC (5.8GHz) used worldwide for road tolling and access control,
- Millimeter wave technology (62-63GHz) used in conjunction with radar signal at similar frequencies,
- Satellite communications exclusively applied for emergency and “special applications”,
- Mobile Wireless Broadband (MBB) with cell usually much larger than UMTS cells – today namely communications systems based on IEEE Std. 802.16e and coming IEEE Std. 802.20,
- IR (Infra Read) communications solutions,
- WiFi (IEEE 802.11 based) different alternatives - a, b, g, n,
- M5 based on standard IEEE 802.11p,
- IEEE 802.15.x based solutions: Bluetooth – 15.1, UWB (Ultra Wide Band) - 15.3, ZigBee - 15.4,
- W-USB (Wireless USB)
- ISO 15628 applications developed as application layer of European DSRC (5.8GHz). However CALM can support the only limited set of services,
- Other media to come.

Details of CALM architecture are described e.g. in [11] and [12]. CALM applies exclusively still not widely enough spread IPv6 protocol which allows due to its extensive abilities to continuously remotely trace active applied alternative. Handover is accomplished on the L2 of the TCP/UDP/IP model, i.e. out of TCP/IP competences. Handover competences given to this L2 is the only suitable alternative for most of the wireless solutions.

### 3. CONTINUOUS ACTIVE ACCESS PATHS EVALUATION AND DECISION PROCESS ON POTENTIAL SEAMLESS SWITCHING TO THE ALTERNATIVE PATH

Second generation of handover processes is sited in the top layer of the hierarchical adaptive communications control system with following architecture (there is not any relation to the RM OSI model):

- 1-st layer – Cellular Layer (CL) - represents feed-back control processes of parameters like transmitted power, type of applied modulation or redundancy of applied channel coding. Goal of processes on this layer is to keep given set of managed parameters like Bit Error Rate (BER) or Round Trip Delay (RTD) within required limits.

- 2-nd layer – the first generation of handover (1HL) - represents support of process of the seamless switching between different cells of the same provider network. Such approach is applied in technologies like GPRS, EDGE, UMTS, Mobile WiMax (IEEE 802.16e), but also in new amendment IEEE 802.11r designed within family of standards IEEE 802.11 (WiFi). This layer use to share information with CL layer (offered usually as one system) so that there is no high risk of contra-productively operated processes on these two layers - of course only in case it is correctly designed and operated.

- 3-rd layer – the second generation of handover (2HL) - is mostly dependent only on identification of the service performance indicators. Cellular systems are not usually designed as the open systems with appropriate application interfaces (API) so that there is not mostly available potential interconnection with management of these lower layers. It is for sure that the effective management on the 2HL layer can be much easier reached if 1HL an LC layers share relevant information with managed layer 2HL.

Communications access systems used in transport telematics are designed based on technologies like GPRS, EDGE, UMTS, WiFi (IEEE 802.11a, b, g, e, n, p (applied namely in US as M5) and r), WiMax (IEEE 82.16d,e), DSRC, IR, and set of WPAN (Wireless Personal Access Network) technologies like Bluetooth (based on IEEE 802.15.1), UWB (IEEE 802.15.3 today namely in version 802.15.3c and ZigBee (applying MAC layer defined by IEEE 802.15.4). Satellite communications can be integrated for specific applications, as well, even though satellite services frequent appearance is namely for economical reason not expectable in short time horizon and even long term expectations are not very clear.
Only some of presented systems have cellular architecture. In case system is not cellular we can omit 1HL layer of presented model. Some specific technologies (WPAN, Ir, RFID systems) operate exclusively on short distance. However, this communication tools are within ITS quite frequently applied in “nomadic” regime for specific mostly static applications like data transfer between Car and Infrastructure at hot spots, in parking areas etc.

CALM standard resolves described above issue by vertical system decomposability compatible with RM OSI principles to the individual subsystems for each communications access path, however, management keeps strictly the horizontal layers architecture see Fig. 2. Relevant information needed for qualified decisions (incl. of those from layers 2HL, 1HL and CL) are between layers shared exclusively via the control system structures. We evaluated this approach best available one, however, connected with quite extensive R&D representing remarkable time period.

As a response on an urgent need of acceptable solution authors proposed alternative approach based on L3/L2 TCP/IP switching which is operated in specific configuration and settings. This solution is understood as the only interim and in functionality limited substitution, however, with much less time demanding R&D and so much faster in implementation.

3.1. Multi-path adaptive switching as classification process

Decision processes representing basis for adaptability of communications wireless services have not been deeply resolved issue. We can find implementations and related papers mostly 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. This approach can be combined with Model Driven Architecture employing models, and precisely Object management Group (OMG) Model Driven Architecture (MDA). Authors of such approach [14] integrated language- and middleware-neutral features into adaptive services. So called POETRY service creation framework described in [14] applies PBM method to describe and control internal logic of the adaptive services and simultaneously method based on MDA model is used to describe the adaptive service informatics model.

Our presented approach is based on a bit more “conservative” approach based on Bayes statistics with well known limits given by CPU capacity consuming complex mathematical implementations. Nevertheless, our main driver is based on fact, that we are operating in area of radio signals of the wireless access solutions with continuous in time character of some critical performance indicators (like intensity of signal). We understand as advantage to decide not only based on status of the performance indicators, but also on evaluation of the performance indicators selection trends. As already mentioned complex mathematical solution can easily swallow remarkable capacity of the applied CPU. We could so expect in future that combination of classical mathematical solution with approach like POETRY is expected and we are open to such approach and already study such alternatives. With increasing CPU capacity of available communication micro-chip systems, however, in many cases solutions based on “conservative” statistical mathematical approach will most probably remain as more effective and stable alternative.

Following paragraphs describe one of the potential approaches to the decision processes. Proposed methodology is based on following principles - see [15] or [25]:

- Measured parameters a processed by Kalman filter. Such process separates reasonable part of present noise and also allows prediction of the individual parameters 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 \( \mathbf{x} \).
- Based on time lines of vector \( \mathbf{x} \) it is feasible to classify the best possible technology selection. Classification algorithm is trained using time lines of training vectors \( \mathbf{x} \) 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. To minimize contra productive actions on different layers it is necessary to centralize all layers decision in one decision center - see on Fig. 2 the management information flow within CALM architecture. An alternative solution is in synchronization of different layers decisions centers.
Let us introduce the vector $x$ as the vector carrying information about the values of performance parameters in sample time. The items of vector $x$ are either deterministic or random processes with help e.g. of Kalman filtering described e.g. in [22] or [23].

Let us define the classification problem as an allocation of the feature vector $x \in R^D$ to one of the $C$ mutually exclusive classes knowing that the class of $x$ takes the value in $\{\Omega = [\alpha_1, \ldots, \alpha_C]\}$ with probabilities $P(\alpha_1), \ldots, P(\alpha_C)$, respectively, and $x$ is a realization of a random vector characterized by a conditional probability density function $p(x|\alpha)$, $\alpha \in \Omega$. This allocation means the selection of best fitted telecommunication technology based on knowledge of $x$ vector.

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

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

(1)

where $K(\cdot)$ is a kernel function that integrates to one, $h_\omega$ is the smoothing parameter for the $\omega$-th class conditional density. The density estimate defined by (1) is also called the Parzen window density estimate with the window function $h_\omega$.

It is a well-known fact that the choice of a particular window function is not as important as the proper selection of smoothing parameter. We use the Laplace kernel defined by the following Laplace density function:

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

(2)

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

The product kernel is used with a vector of smoothing parameters $h_\omega = (h_{\omega_1}, \ldots, h_{\omega_D})$ for each class $\omega$. The product kernel density estimate with Laplace kernel is then defined as

$$ f(x|\omega) = \frac{1}{N_\omega} \prod_{j=1}^{D} h_{\omega_j} \exp \left( \frac{|x_j - x_{\omega_j}|}{h_{\omega_j}} \right). $$

(3)

Smoothing vectors $h_\omega$ are optimized by a pseudo-likelihood cross-validation method using the Expectation-Maximizations (EM) algorithm (see [15] - [16]).

To rank the features according to their discriminative power the between-to-within-class separability measure $Q(d)$ for the $d$-th component of feature vector $x$ is defined as

$$ Q(d) = \sum_{i=1}^{C} \sum_{j=1}^{C} Q_{ij}(d, i, j), $$

(5)

where $Q_{ij}(d, i, j)$ is a significance measure of the $d$-th component of a 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 is based on evaluation of both random as well as deterministic processes. Introduced approach enables continuous decision processes training.

Presented method allows implementation to be started with no information flow between layer 2HL and layers 1HL and CL even though such tool can be understood as overestimated approach for limited number of measured parameters. This solution is deliberately to be applied for future extensions in information resources to let decision process principally improve by application of potentially available information from layers 1HL and CL. Such growth in number of status information resources can be than smooth and relatively simple to be implemented.

4. CONCLUSIONS

Due to regular complexity of by telematic services covered areas (wide area coverage, several classes of services with different system requirements) we concentrated our afford on wireless access solution designed as seamless switched combination of more independent access solutions of the same or alternative technology.

Process of access solution switching has been subject of intensive R&D and family of standards (still under ISO process) CALM developed to transport applications represents promising response on the ITS requirements.

Decision processes representing basis for adaptability of the communications wireless services have not been deeply resolved and published topic. We can find implementations and related papers mostly 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. Our approach is based on a “conservative” approach based on Bayes statistics with well known limits given by CPU capacity consuming complex mathematical implementations. Set of measured parameters can be effectively 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. Success of classification is related to the size and quality of the training data lines so that self training process is feasible to be prolonged into application period, as well.

Presented method theoretically allows implementation started with no information flow between control layer 2HL and the lower layers 1HL and CL. In such case this tool can be than understood as overestimated approach. Nevertheless, this method is primarily designated for extended number of
information resources originated from all control layers to let decision process be stable, precise and efficient. To minimize contra-productive actions on different control layers it is necessary to centralize all layers decision in one decision center or to provide efficient synchronization of decisions centers of different layers.

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