Adaptive Wireless Multipath Access Solution for Transport Telematics

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***Abstract* —**Intelligent Transportation Systems solutions require availability of the selectable range of wireless telecommunications services with guaranteed coverage and service quality. Even though publically available mobile wireless data services can usually offer acceptable service coverage and reasonable pricing, providers' portfolios mostly do not include guarantee of any data services quality. Private solutions can frequently guarantee relevant quality of provided service, however, such solutions are not typically ready for the wide area mobile coverage. Authors of this paper propose mobile solution alternative with more efficient quality as well as wide area coverage management based on the dynamical seamless handover of the best possible service from the set of just accessible different wireless alternatives. In contrary to the proposed standards ISO TC204, WG16.1 (CALM) or IEEE 802.21 based on the L2 switching and Policy-based Management (PBM) authors introduce alternative in category of the "intelligent" routing, i.e. solution based and implemented exclusively on the routing L3. Success of proposed solution is strongly dependent on efficient adaptive decisions processes which are managing selection of the best possible alternative between the available ones. Such approach has got remarkable advantage in relatively simple system integration based dominantly on the SW implementation with no or very limited additional requirements on mostly off shelf available hardware.

***Keywords*—** Intelligent Transport System, Transport telematics, Multipath seamless communications access service, Bayes statistics, Laplace density function, adaptive approach.

I. INTRODUCTION

ITSs (Intelligent Transport systems) are associated with serious expectations and getting ITS applications in the real practice is understood as approach with essential potential to solve significantly faster growing transportation challenges.

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 sub-systems 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 center, 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.

II. TELEMATIC REQUIREMENTS ON TELEOMMUNICATIONS SOLUTION

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 was 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.

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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 $\overrightarrow{tci}$ on the vector of telematics performance indicators $\Delta\overrightarrow{tmi}$ can be expressed as $\Delta\overrightarrow{tmi} = TM \cdot \overrightarrow{tci}$, 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.

III. TELECOMMUNICATIONS SOLUTION STRUCTURE

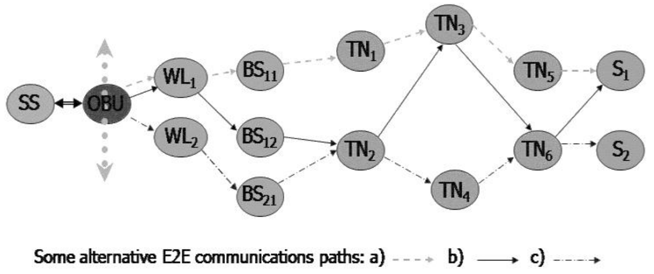


Figure 1. Telematics telecommunication scheme - chain diagram

Fig. 1 presents typical telecommunications chain diagram, firstly applied within authors pilot project Airport Praha (see e.g. [7]). This structure we later accepted as the ITS telecommunications solutions general architecture. 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 services. However, it is expected that coming European Galileo GNSS as well as 2nd generation of GPS will provide publically available paid services with guaranteed service quality. OBU represents not only control but also display and HMI (Human Machine Interface) and WL_i represents i-th cellular technology of the wireless complex solution. Terrestrial communication part consist of set of mobile cellular Base Stations (BS_{ij}) (i-th bases station of the j-th system) integrated by the terrestrial network based on L3/L2 switches/nodes (TN_i) interconnected with Servers (S_i). E2E (End to End) service is provided based on IP protocol, supported by L2 Ethernet protocol based switching.

In the following paragraphs we will present principles of the best available wireless communications solution selection based on evaluation of their performance indicators as well as other relevant parameters like service cost, corporate policy. Presented decisions processes are effectively useable to select the best possible alternative are effective if applied on IP layer (i.e. L3) of the TCP/IP communication model i.e. in contrary to most of discussed alternatives implemented on L2. Before this solution is presented analysis of three mostly applied wireless solutions of the key wireless technologies analysis are introduced and their principle performance indicators measured in our laboratories are provided.

IV. GSM DATA SERVICES PERFORMANCE

There is a common understanding that GSM mobile network can provide fast and reliable data service with very reasonable signal coverage and very high level of availability. However, practical ITS implementation identified quite a remarkable problem with performance of GSM data services applied within telematic applications.

Our study has been concentrated on identification of the critical internal performance indicators and study of their impact on the data services performance. All measurements were done exclusively within one GSM cell.

Principle change of service parameters caused by either too high number of customers or e.g. overloaded IP network caused e.g. by lack of routers CPU/memory capacity cannot be identified directly – providers do not offer such information to theirs even top clients. Changes of the services performance indicators can be identified only indirectly by parameters like PLR (Packet Lost Ratio) or RTD (Round Trip Delay).

Data channel capacity CC can be calculated as $CC = B.\log_2(1 + C/I)[b/s]$, where B is the bandwidth of the channel in Hz, parameter C/I is ratio C - total channel signal power in used bandwidth measured in mW and I - total noise power in applied bandwidth measured in mW. *C/I* typically used in GSM terminology is in Shannon – Hartley theorem known as S/N, i.e. the signal-to-noise ratio (SNR) or the carrier-to-noise ratio (CNR) of the communication signal and the Gaussian noise interference expressed as a linear power ratio.

In GSM architecture bandwidth is constantly set to 200 kHz. Parameter C/I so represents the critical parameter which influences GSM data services technology performance expressed by performance indicators:

(i) Data channel capacity,

(ii) Packets loss ratio (PLR) and

(iii) PDD (Packet delivery delay) or RTD (Round Trip Delay).

Above mentioned parameters can be routinely identified on the IP layer using services of L3 (IP layer).

A. Methodology of experiment

Each of available 2.5th GSM generation data services i.e. CSD, HSCSD, GPRS and EDGE was individually studied. GSM laboratory was equipped by locally manageable fully calibrated base station with adjustable transmitter output power C. Additionally signal noise with adjustable level I was generated by external calibrated noise generator. Power of the base station was set for each measurement period on defined level C and power of noise I generated by additional noise generator was changed in defined limits step by step.

Service quality measurement was processed using L3 (IP) layer tools. Each individual measurement was generated by "ping -n 100 -l 10 ftp.address", where n represents number of transmitted packets (n=100) and l represents packet size (l=10B). Small packet size was reasonable for identification of minimal time of service response.

Black line in graphs represents minimal RTD [ms], dark grey stands for average RTD a light grey corresponds with average PLR [0% – 100%].

B. CSD measurement results

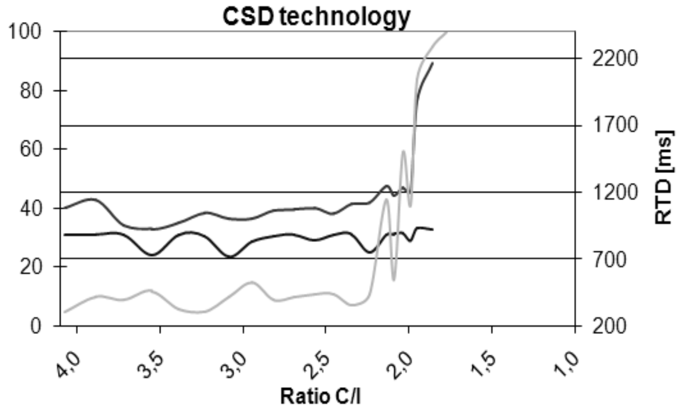


Fig. 2. PLR and RTD - CSD technology

Fig. 2 shows that CDS technology offers data service with delay in the sub-second range. Service has relatively low sensitivity to signal to notice ratio. However, it must be stressed that CSD is circuit switched technology with all well known disadvantages of this approach in the field of data services.

C. HSCSD measurement results

Results obtained for CDS technology measurement displayed on Fig. 3 are valid for HSCDS technology, as well. The only difference is in channel capacity due to fact that increase of the capacity is exclusively reached by increasing of the applied time slots number.

D. GPRS

Fig. 2 shows that GPRS technology provides better delay than CDS (350 ms), however, only for small values of signal to noise ratio). With increasing intensity of interference GPRS service delay rapidly grows. Relatively high sensitivity packet loss on C/I can be identify, as well. For C/I above 2.69 packets loss is above 75%! Results identified mainly that GPRS technologies are applicable for "less demanding" applications where long delays and high potential of packet losses are not critical or it can be combined with alternative technology based on CALM principles.

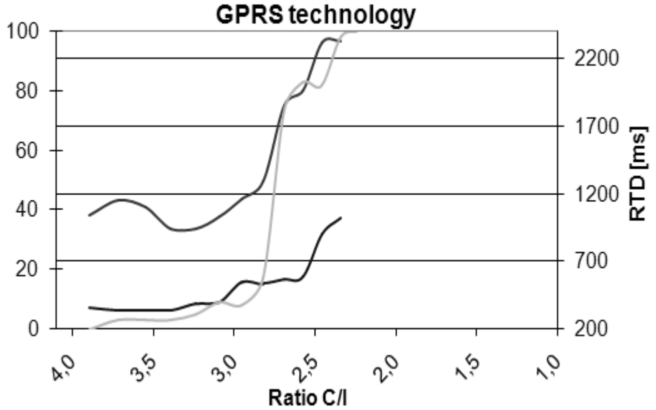


Fig. 3. PLR and RTD - GPRS technology

E. EDGE measurement results

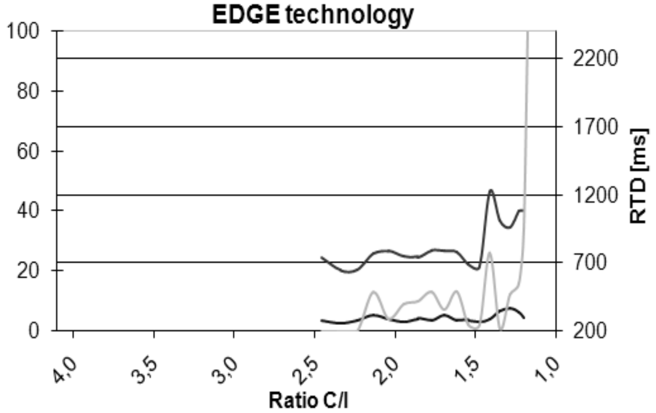


Fig. 4. PLR and RTD - EDGE technology

Fig. 4 describes fact that EDGE technology is better acceptable for telematics applications than GPRS, because of remarkable improvement in both delay and packet loss. Minimal delay was in this case within interval from 258ms to 365ms and high packet loss starts, when value of C/I ratio is above 1.2. This technology so could appear even with more demanding telematic solutions if service provider can guarantee appropriate priority of service provisioning.

F. GSM date services summary

GSM service providers have kept their focus on the core business - mobile voice services and data services are provided as more or less complementary products with not guaranteed services quality. This disadvantage could be resolved by partial network capacity dedication (e.g. via virtual operator's services) to the "special" services portfolio with efficient services quality management. However, status of auspicious “virtual operators” does not have good chance to be accepted due to strong “self-defense” afford of the powerful mobile operators.

Originally expected data services with global coverage based on the 3rd generation mobile data service (UMTS) don’t have potential to reach namely rural areas. Beyond 3rd generation solutions (LTE) are very promising future solutions (expected latency approx. 10ms), however, such services cannot be expected sooner than in a few years.

V. WIMAX (IEEE 802.16D) ALTERNATIVE

Remarkable potential can be recognized in combination of all key GSM service providers as well as different alternative wireless access data services. Management can be based on the “CALM” or alternative principles with implemented effective classification and decision processes. Mostly alternative services are dedicated to fill the services gaps when/where globally available GSM wireless network cannot provide service on required quality level.

Technology based on IEEE 802.16d/e standards known as (Mobile) WiMax represents one of the most promising substitutions. This technology (in version “d”) was studied in detail in project CAMNA. Research team had unique opportunity to test WiMax technology in “real life” pilot application - see e.g. [7], [8] and [9]. Basic results of WiMax measurement are in Table 1. Even though results are in different structure due to different method applied to identify WiMax technology performance, dynamic parameters can be quite easily compared.

TABLE 1.
OBTAINED PARAMETERS OF THE WIMAX ACCESS

Site	Visibility	RTD [ms]	SNR [db]
1	LOS	45.6	33
2	LOS	47.1	32
3	NLOS	44.6	-26
4	NLOS	44.8	-27

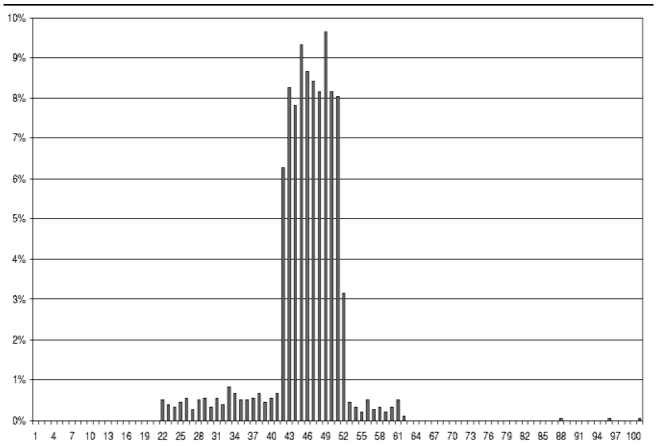


Fig. 5. RTD spectra of LOS - SNR =+33db

RTD presents “Round Trip Delay” in ms, SNR is “Signal to Noise Ratio” in dB, LOS represents “Line Of Sigh” and NLOS stands for “Non LOS”. RTD results are displayed on Fig. 5 and 6. RTD is in average approx. 50ms , i.e. more than ten times faster than GPSR and EDGE.

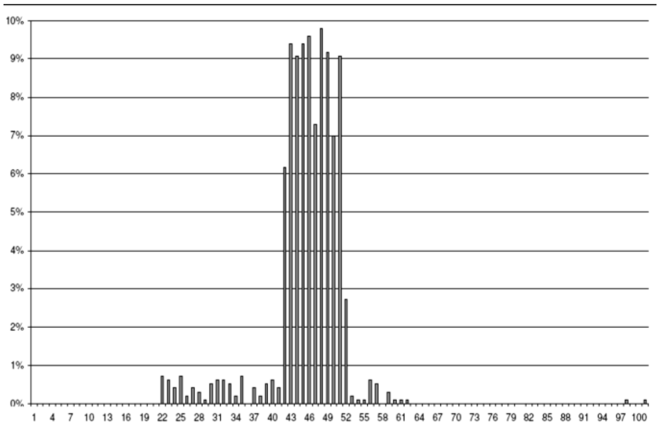


Fig. 6. RTD spectra of NLOS - SNR=-27db

VI. WIFI (IEEE 802.11) ALTERNATIVE

WiFi technology based on IEEE 802.11 represent very dynamically growing area with possibility to be much more frequently applied in the ITS applications. Main WiFi focus was on the low end of the mass access Internet market operated in “non-licensed” frequencies bands. This standards, however, nowadays trends via new Amendments to the professional applications. Appendixes like “e”, “p” offer quality management operated in licensed bands. Most of WiFi amendments have not been yet officially accepted and published, however, we can expect WiFi solutions as cheaper imposing competitor to e.g. more complex and more expensive WiMax services.

Basic system parameters study was focused on latency and packet lost ratio in dependency on SNR. Goal was to obtain representative set of data for this technology evaluation.

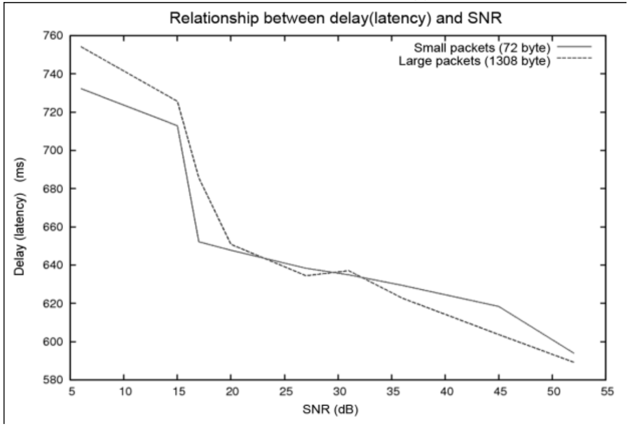


Fig. 7. WiFi – Packet delay vs. SNR.

SNR values 20 dB represents the critical value. However, both Delay and Packet loss are dependent on the other parameters - namely the network load. Collision access protocol has limited possibility to manage service quality – even only 30% traffic load can cause latency up to several hundred of ms. Appendix IEEE 802.11e will, however, offer QoS (Quality of Service) management tools simultaneously with much higher efficiency of available bandwidth usage.

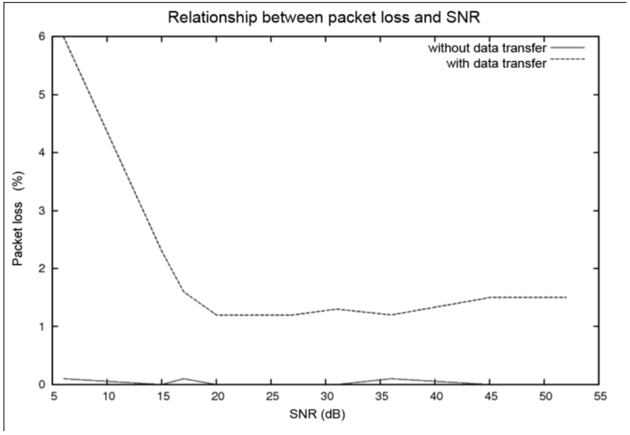


Fig. 8. Packet loss vs. SNR

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.

VII. CALM

Details of CALM architecture are described e.g. in [11] and [13] and description of proposed CALM architecture is introduced on Fig . 9 describing complexity of this approach. CALM executive processes are implemented on the L2 of the TCP/IP model. Alternative approach based on standard IEEE 802.21 - see e.g. [14] - accepts the L2 switching as executive layer, as well. IEEE 802.21 standard system approach is by this paper authors identified as remarkably advantageous if compared with very generous “CALM” alternative definitely linked with enormous implementation complexity.

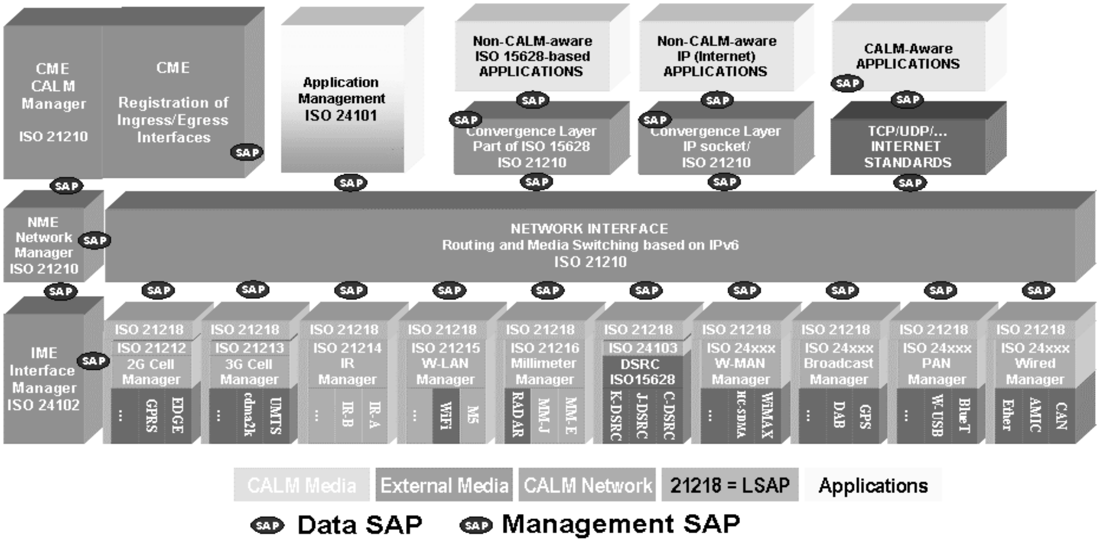


Figure 9. CALM Layer Architecture (Geneva review)

In this paper proposed solution based exclusively on the L3 can be categorized as the “intelligent routing”. Such approach offers advantage of the exclusively SW based implementation and minimal or no special HW requirements on system, like OBU (On Board Unit) installed in the vehicle.

VIII. MULTI-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.

IX. DOTEK

Decision processes representing basis for adaptability of communications wireless services have not been deeply enough resolved issue in CALM standards. We can identify recommendation 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.

Above mentioned 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 service selection from the set of available wireless services and it is based on system parameters benchmarking derived from the telematic application requirement

The main objective of the DOTEK project is motivated by the “CALM principles”. However, main difference if compared with CALM standards is implementation of routing principles on L3 layer replacing switching on L2 in case of CALM implementation. DOTEK project focuses mainly on the following areas:

- Analysis and selection of available wireless services applicable for different studied transport telematics services.
- Design of global and comprehensive management of these services 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.
- Realization of the decision in order to ensure proper operation of telematics applications.

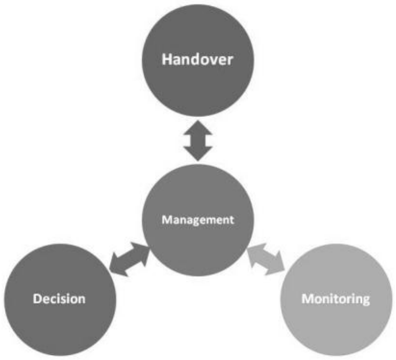


Fig. 10. General system architecture

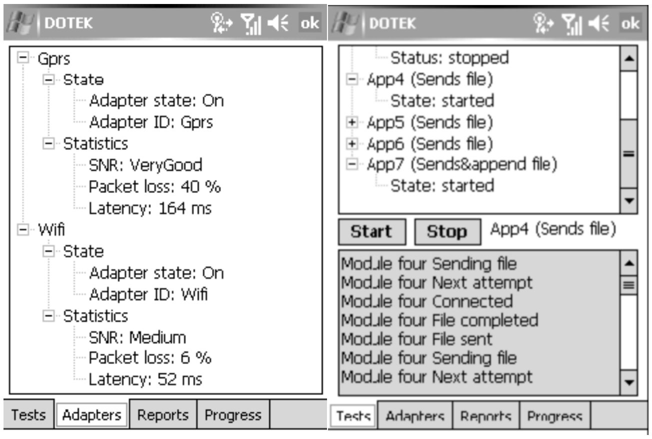
An important part of communication module is to monitor current system parameters and communication technologies in order to assess their current situation and decide about their suitability for use according to the specific requirements of telematic applications. Telecommunication technologies are described 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 final implementation in first working sample were chosen basic three monitored system parameters:

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

For further implementation is possible and appropriate to include other system parameters.



```
Gprs
  State
    Adapter state: On
    Adapter ID: Gprs
  Statistics
    SNR: VeryGood
    Packet loss: 40 %
    Latency: 164 ms
Wifi
  State
    Adapter state: On
    Adapter ID: Wifi
  Statistics
    SNR: Medium
    Packet loss: 6 %
    Latency: 52 ms
```

```
    Status: stopped
App4 (Sends file)
    State: started
App5 (Sends file)
App6 (Sends file)
App7 (Sends&append file)
    State: started
```

App4 (Sends file)

```
Module four Sending file
Module four Next attempt
Module four Connected
Module four File completed
Module four File sent
Module four Sending file
Module four Next attempt
```

Fig.11. Screenshots from testing application

Implemented decision algorithm supports appropriate access wireless service selection. It is based on specific application requirements of telecommunication service described by a set of parameters values ranges. Current status of available telecommunications technologies must be continuously available. Cost of each applied access wireless telecommunication service use to be taken in account, as well.

Decision to implement described simplified approach was done on based on evaluation of currently available research R&D man power resources. Full adaptive version described below was out of implementation capacity and allocated resources. With this implemented version was successfully tested this “extended PBM approach”. System successfully passed test scenarios for verification its basic functionalities. In one test scenario was measured time of the second generation handover. Results are available in the table 2.

TABLE 2.
RESULTS OF TEST SCENARIO FOCUSED ON THE TIME OF HANDOVER

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

Project DOTEK was successfully developed and integrated in universal vehicle OBU (On Board Unit) tested with four telematic applications – EFC (Electronic Fee (Tall) Collection), fleet management, e-Call and “intelligent” navigation. Solution represents the only SW package with no additional HW development required. This package has got modular structure and therefore it is practically technology independent and it can be integrated into existing systems to provide management of telecommunication technologies supported by these systems. Presented results prove that this system is functional and from presented handover times tests results it is clear that this approach can be applied in quite wide range of the telematics applications.

X. ADAPTIVE DECISION PROCESS

Below presented approach can be understood as the “conservative” approach based on Bayes statistics with 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 $\mathbf{x}\in\mathrm{R}^{\mathrm{D}}$to one of the C mutually exclusive classes knowing that the class of **x** takes the value in $\langle\Omega=\{\omega_1,........,\omega_C\}\rangle$ with probabilities $P(\omega_1),.....,P(\omega_C)$, and **x** is a realization of a random vector characterized by a conditional probability density function $p(\mathbf{x}\mid\omega),\ \ \omega\in\Omega$. This allocation means the selection of best fitted telecommunication technology based on knowledge of **x** vector.

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

$$\hat{\mathrm{f}}(\mathbf{x}\mid\omega)=\frac{1}{\mathrm{N}_\omega\cdot\mathrm{h}_\omega^{\mathrm{D}}}\cdot\sum_{\mathrm{i}=1}^{\mathrm{N}_\omega}\mathrm{K}\left(\frac{\mathbf{x}-x_{\mathrm{i}}^{\omega}}{\mathrm{h}_\omega}\right), \qquad (1)$$

where $K(\cdot\cdot)$ is a kernel function that integrates to one, h_ω 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 $K(\cdot\cdot)$.

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 $x\in R,\ \mu\in\mathrm{R},\ \sigma\in(0,\infty)$

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

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

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 $\mathbf{x} \in \mathrm{R}^{\mathrm{D}}$ takes value to one of C mutually exclusive classes $\Omega = \{\omega_1, \dots\dots, \omega_C\}$. The probabilistic measure of two classes separability for the feature d (d-th component of feature vector) $Q_{d,i,j}(d, \omega_i, \omega_j)$ is defined as

$$\mathrm{Q}_{\mathrm{d,i,j}}(\mathrm{d}, \omega_{\mathrm{i}}, \omega_{\mathrm{j}}) = \frac{\eta \cdot (\sigma_{\mathrm{i}} + \sigma_{\mathrm{j}})}{|\mu_{\mathrm{i}} - \mu_{\mathrm{j}}|}, \tag{4}$$

where ω_i and ω_j 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 $[\mu - 3.0 \cdot \sigma, \mu + 3.0 \cdot \sigma]$ is 0.998). The smaller is the value of the measure $\mathrm{Q}_{\mathrm{i,j,d}}$, the better is separation of the inspected classes made by the feature d. For $\mathrm{Q}_{\mathrm{i,j,d}} < 1$ 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:

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

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 $\mathrm{d}^{\text{-th}}$ 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.

XI. 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.

Public available GSM data services are designed to provide dominantly voice services. Selection of data services (2.5th generation) is provided with very limited or mostly no guaranteed performance parameters, i.e. as a complementary service in the best effort regime. Namely due to economical reason the 3rd generation (UMTS) mobile data services have not got potential to grow in appropriate way and service coverage is preferably concentrated on highly populated areas. Beyond 3rd generation solutions (namely LTE) are very promising future solutions, however, massive availability of these services cannot be expected sooner than in the next decade (2012 or later).

Strong potential is so recognized in combination of GSM data services with the alternative products provisioning namely if effective sharing of the GSM providers' infrastructure is reached. Alternative services are dedicated to fill the services gaps which cannot be provided by the core wireless network (continuously or in critical time periods, only). One of the most promising alternatives has been represented by technology based on standards IEEE 802.16d/e known as (Mobile) WiMax. Such access solution has been tested in areas, where served capacity and namely quality of GSM data services are recognized as not reasonable. WiFi services originally adopted as the low end of Internet access solutions dynamically grow in applicability in the "professional" solutions. Alternative services combination strategy with implementation of sophisticated decision processes (intelligent routing) can effectively extend potential of the widely spread GSM data services application substituted by the alternative solution where or when needed.

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). Implemented "Extended PBN based" decision processes were presented as well as principle parameters describing system behavior acceptable for wide range of transport telematics applications.

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 select the best possible alternative 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.

Solution represents SW product based with very limited or no requirements on available HW implementations. It is modularly structured with aim to be practically technology and operational system independent. It can be linked into existing systems structures with remarkable potential to provide effective management of the telecommunications alternatives being supported by the systems.

Described DOTEK simplified solution was successfully developed and integrated in the universal vehicle OBU (On Board Unit) system. Impelementation was tested with different telematic applications like EFC, fleet management, e-Call and “intelligent” navigation and reasonable parameters were reached. It was identified as applicable for wide range of telematic services. Additional improvement of the adaptive system behavior is expected in moment decision algorithms implementation based on described classification principles is completely finalized.

REFERENCES

[1] Svitek, M.: Architecture of ITS Systems and Services in the Czech Republic, International Conference Smart Moving 2005, Birmingham 2005, England.

[2] Svitek, M: Intelligent Transport Systems - Architecture, Design methodology and Practical Implementation, Key-note lesson, 5th WSEAS/IASME Int. Conf. on Systems Theory and Scientific Computation, Malta 2005.

[3] Svitek, M., Zelinka, T.: Communications Tools for Intelligent Transport Systems, Proceedings of 10th WSEAS International Conference on Communications, pp 519 – 522, Athens 2006, ISSN 1790-5117, ISBN 960-8457-47-5.

[4] Svitek, M., Zelinka, T.: Communications Solutions for ITS Telematic Subsystems, WSEAS Transactions on Business and Economics, Issue 4 (2006), Vol. 3, pp 361 – 367, Athens 2006, ISSN 1109-9526,

[5] Svitek, M., Zelinka, T.: Telecommunications solutions for ITS. Towards Common Engineering &Technology for Land, Maritime, air and Space Transportation – ITCT 2006, CNISF, Paris 2006.

[6] Svitek, M., Zelinka, T.: Communication solution for GPS based airport service vehicles navigation, EATIS’97 ACM-DL Proceedings, Faro (Portugal) 2007, ISBN #978-1-59593-598-4.

[7] Zelinka, T., Svitek, M.: Communication solution for Vehicles Navigation on the Airport territory, Proceedings of the 2007 IEEE Intelligent Vehicle Symposium, Istanbul, Turkey, pp 528–534, IEEE Catalogue number 07TH8947, ISBN 1-4244-1068-1.

[8] Svitek, M., Zelinka, T.: Communications Environment for Telematic Subsystems, Proceedings of 11-th World Multi-Conference on Systemic, Cybernetics and Informatics, Volume II, pp 362-367, IIIS/IFSR, Orlando, FL, USA, ISBN-10: 1-934272-16-7, ISBN-13: 978-1-934272-16-9

[9] Svitek, M., Zelinka, T.: Communications Challenges of the Airport Over-ground Traffic Management, Proceedings of the 11th WSEAS International Multi-conference CSCC, Volume – Advances in Communications, pp. 228 – 234, Agion Nikolaos, Crete Island, Greece, ISSN 1790-5117, ISBN 978-969-8457-91-1.

[10] Zelinka,T., Svitek, M.: Communications Scheme for Airport Service Vehicles Navigation, Proceedings of International Conference TRANSTEC Prague, Czech Technical University, Faculty of Transport Science and University of California, Santa Barbara, Praha 2007, pp. 160 – 166, ISBN 978-80-01-03782-9.

[11] Williams, B.: CALM handbook V1.0. Document ISO TC204 WG.16.1 CALM, 2004.

[12] Wall, N.: CALM - why ITS needs it, ITSS 6 (September), 2006 .

[13] Zelinka,T., Svitek, M.: CALM - Telecommunication Environment for Transport Telematics, Technology & Prosperity, 2006, Vol. XI, special edition (11/06), ISSN 1213-7162.

[14] Oliva, A. at al.: IEEE 802.21 enabled mobile terminals for optimized WLAN/3G handovers, ACM SIGMOBILE Mobile Computing and Communications, Volume 11, Issue 2 (April 2007), Pages: 29 – 40, ISSN:1559-1662.

[15] Yang, K., Wittgreffe, J., Azmoodeh, M.: Policy-Based Model-Driven Creation of Adaptive Services in Wireless Environments, IEEE Vehicular technology Magazine, September 2007, pp. 14-20.

[16] Svitek, M.: Dynamical Systems with Reduced Dimensionality, Neural Network World edition, II ASCR and CTU FTS, Praha 2006, ISBN:80-903298-6-1, EAN: 978-80-903298-6-7.

[17] Dempster, A., Laird, N., Rubin, D.: Maximum likelihood from incomplete data via EM algorithm. J. Royal Stat. Soc. 39, 1977, pp 1-38.

[18] Zelinka,T., Svitek, M.: Communication Scheme of Airport Over-ground Traffic Navigation System. Proceedings of the International Symposium on Communications and Information Technologies - ISCIT 2007. IEEE Sydney, 2007, pp 329 - 334. IEEE Catalogue No. 07EX1682(C), ISBN 1-4244-977-2, Library of Congress 2007920360.

[19] Svitek, M., Zelinka, T.: Monitoring of Transport Means on Airport Surface. Proceedings of 7-th International Conference on Transport Systems Telematics, Katovice-Ustron, 2007, pp. 285 – 292, ISBN 978-83-917156-7-3.

[20] Svitek, M., Zelinka, T.: Monitoring of Transport Means on Airport Surface. Advances in Transport Systems Telematics, Monograph edited by Jerzy Mikulski, Selesian University of Technology, Katowice, pp. 285 – 292, ISBN 978-83-917156-6-6.

[21] Zelinka,T., Svitek, M.: Decision processes in telematic multi-path communications access systems, International Journal of Communications, North Atlantic University Network NOUN, Issue 2, Volume 1, 2007, pp.11 – 16.

[22] Svitek, M., Zelinka, T.: Communications multi-path access decision scheme. Neural Network World, ICS AS CR and CTU, FTS, Praha, No. 6.,2008, pp 3 - 14, 2008, ISSN 1210 0552.

[23] Svitek, M., Zelinka, T.: Decision processes in Communications Multi-path Access Systems applied within ITS. Transactions on Transport Science, MTCR, Praha, No. 1, 2008, pp 3-12 , ISSN 1802-971X.

[24] Zelinka,T., Svitek, M.: Identification of Communication Solution designated for Transport Telematic Applications, WSEAS Transactions on Communications, Issue 2, Volume 7, Athens, 2008, pp 114 – 122, ISSN: 1109-2742.

[25] Zelinka,T., Svitek, M.: Multi-path communications access decision scheme, Proceedings of the 12-th World Multi-Conference on Systemics, Cybernetics and Informatics, Volume III, pp 3233-237, IIIS/IFSR, Orlando, FL, USA, ISBN-10: 1-934272-32-7, ISBN-13: 978-1-934272-33-6.

[26] Zelinka,T., Svitek, M.: Adaptive communications solutions in complex transport telematics systems, Proceedings of the 11th WSEAS IM CSCC 2008, New Aspects of Communication, pp. 206 – 212, Heraklion, Greece, ISBN 978-960-6766-84-1.

[27] Zelinka,T., Svítek, M.: Adaptive communications solutions in complex transport telematics systems. Monograph on Computers and Simulation in Modern Science-Volume II, WSEAS Press, Athens 2009, pp. 234 - 241, ISBN 978-960-474-032-1.

[28] Zelinka,T., Svítek, M.: Adaptive Wireless Access Environment in Transport Solutions “, Proceedings of, 13-th World Multi-Conference on Systemics, Cybernetics and Informatics, Volume IV, pp 310 - 315, IIIS/IFSR, Orlando, FL, ISBN 978-1-934272-62-6.

[29] Zelinka, T., Svitek, M., Srotyr, M., Vosatka, M.: Adaptive multi-path Telecommunications Solutions for ITS. Proceedings of the 14-th World Multi-Conference on Systemics, Cybernetics and Informatics, Volume I, pp 89 - 94, IIIS/IFSR, Orlando, FL, USA, ISBN 978-1-934272-98-5.

[30] Zelinka, T., Svítek, M. Vosátka, M.: Adaptive Approach to Management of the Multi-path Wirelesss Solutions. Plenary session invited paper, Proceedings of the Symposium Recent Advance in Data Network, Communications, Computers, WSEAS Press, Morgan State University, Baltimore/Athens, 2009, pp. 161 – 168, ISBN 978-960-474-134-2.

[31] Zelinka, T., Svítek, M., Lokaj, Z.: Adaptive Decision Processes the Multi-path Wireless Access Solutions Implementable on the IP Routing layer. EATIS’10 ACM-DL Proceedings, Panama City (Panama), 2010, ISBN 978-958-44-7280-9

[32] Zelinka, T., Svitek, M., Srotyr, M., Vosatka, M.: Adaptive Multi-path Telecommunications Solutions for ITS, Journal of Systemics, Cybernetics and Informatics Volume 9, No. 1, pp. 14 – 20, Orlando, 2011, ISSN: 1690-4524.