ITS Multi-path Communications Access Decision Scheme

Miroslav SVITEK
Faculty of Transport Sciences, Czech Technical University of Prague
110 00 Praha 1, Czech Republic

and

Tomas ZELINKA
Faculty of Transport Sciences, Czech Technical University of Prague
110 00 Praha 1, Czech Republic

ABSTRACT

Intelligent Transport Systems (ITS) require widely spread and guarantied quality communications services. Method of ITS decomposition to set of subsystems and quantification of communications subsystems parameters is introduced. Due to typical complexity of the IST solution and mobility as the typical system elements property idea of communications systems with multipath multivendor structures is adopted. Resolution of seamless switching within a set of available wireless access solutions is presented. CALM based system or specifically designed and configured L3/L2 switching can be relevant solution for multi-path access communication system. These systems meet requirements of the seamless secure communications functionality within even extensive cluster of moving objects. Competent decision processes based on precisely quantified system requirements and each performance indicator tolerance range must be implemented to keep service up and running with no influence of continuously changing conditions in time and served space.

Method of different paths service quality evaluation and selection of the best possible active communications access path is introduced. Proposed approach is based on Kalman filtering, which separates reasonable part of noise and also allows prediction of the individual parameters near future behavior. Presented classification algorithm applied on filtered measured data combined with deterministic parameters is trained using training data, i.e. combination of parameters vectors line and relevant decisions. Quality of classification is dependent on the size and quality of the training sets.

This method is studied within projects e-Ident[1], DOTEK[2] and SRATVU[3] which are elaborating results of project CAMNA[4].

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

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),
- 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 as well as design of structures and processes how these frequently extremely demanding requirements can be fulfilled.

2. INTELLIGENT TRANSPORT SYSTEMS

2.1 ITS PERFORMANCE INDICATORS DEFINITION

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 is being developed in frame of the ITS architecture (see [1] - [5]):

---

[1] e-Ident – Electronic identification systems within transport process – grant 2A-2TP1/108.of Ministry of Industry and Trade of the Czech Republic (MPO),

[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.

- 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 system parameters analysis is decomposition 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.

2.2 PROCESS ANALYSIS OF THE ITS SYSTEMS

The instrument for creating ITS architecture is the process analysis shown on Fig.1. The processes are defined by chaining system components through the information links. The system component carries e.g. the implicit system function (F1, F2, F3, G1, G2, G3, etc.). The terminator (e.g. driver, consignee, emergency vehicle) is often the initiator and also the terminator of the selected process.

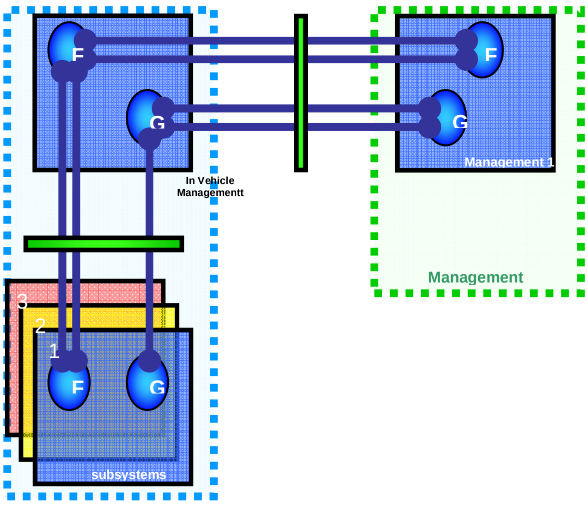

Fig. 1. Example of system decomposition

The chains of functions (processes) are mapped on physical subsystems or modules (first process is defined with help of functions F1, F2 and F3 on Fig.1, second process is defined by chaining the functions G1, G2 and G3) and the information flows between functions that specify the communication links between subsystems or modules. If the time, performance, etc. constrains are assigned to different functions and information links, the result of the presented analysis is the table of different, often contradictory, system requirements assigned to each physical subsystem (module) and physical

From the viewpoint of the construction of the selected subsystem it is possible to consider a single universal subsystem fulfilling the most exacting system parameters, the creation of several subsystem classes according to a set of system parameters, creation of a modular subsystem where the addition of another module entails the increase of system parameters, etc.

Following summary presents the basic strong ITS processes:

- Processes related to transport infrastructure: (i) Operation and maintenance control in transport infrastructure (transport roads and terminals), (ii) Planning and development of transport infrastructure (transport roads and terminals).
- Processes related to in-vehicle management like (i) traffic monitoring through vehicle, (ii) monitoring of driver's physical conditions during vehicle driving, (iii) monitoring of vehicle's technical conditions, (iv) information services inside the vehicle like navigation services inside the vehicle or automated cruise control of vehicles.
- Transport related processes like (i) control of traffic in transport infrastructure (transport terminals), (ii) traffic flow control, (iii) fleet management (freight and public transport management), (iv) interventions of emergency vehicles, (v) support for transport processes, (vi) monitoring and control of goods carriage.

In case all the processes are mapped by the physical subsystems or modules the following results of process analysis could be achieved:

- The functional specification assigned to each selected subsystem or module: (i) allocation of functions into subsystems or modules, (ii) performance parameters assigned to functions (reliability, safety, availability, etc.), (iii) sharing of data or functions within ITS databases or ITS subsystems.
- The interface specification includes: (i) definition of exchanged information between subsystems or modules (parameter synchronization), (ii) timing of exchanged information (time synchronization), (iii) performance parameters assigned to different information flows in selected interface - reliability, safety, availability, etc. (interface protocol optimization)
- The performance specifications of processes include (i) Optimization of telecommunication transmission within ITS system, (ii) omitting the process triggering by errors, (iii) avoiding the parallel processes within ITS system, (iv) Specification of information lifetime within each process (lifetime of data stored in databases, etc.)

This list of standard ITS identification processes and their results can help to understand variety of potentially applied communication solutions ITS solutions require from telecommunications services provider. ITS system decomposition principles are in direct relation to design the telecommunication environment between selected subsystems. In analogy with the telematic subsystem design communication environment is understood as system with modular architecture, as well.

Each communication solution module is, however, represented exclusively by set of telecommunications performance indicators combined in tolerance range of each performance indicators to so called Class of Service (CoS). CoS is not directly reliant to unique "physical" solution. Such performance modules are not technology dependent in a way that different technologies and/or their combination may be used in one performance module. This approach is understood as technology independence and the only "service" described by performance indicators is understood as relevant approach. Direct reflection of this fact can be identified in relevant regulatory framework we can see e.g. in European regulatory system, which identifies regulation as technology independent process. This fact does not imply absence of critical relations to the range of available technologies (namely the mobile ones) and their limits.

Core idea behind this approach is tendency of transport business to concentrate its afford on the core business and to delegate provisioning and responsibility of communications challenges to communications providers. However, detailed quantification of services parameters must be available to become basis for the SLA (Service Level agreement) signed between telematic and communication services providers. Provisioning of some specific telecommunications solutions with very specific requirements can anyhow remain in responsibility of the telematic service provider

Communications providers use to share their network available capacity including service/network management within more customers with aim to reduce provided services cost. Appropriate performance parameters requirement combined into services classes have been provided and guarantied, however, in the network critical periods on behalf of other services with "lower" CoS. In case of network sharing regime security integrity of each service, and specifically of the telematic ones) must be carefully managed and monitored.

First step in addressing the ITS applications is the analysis and establishment of performance requirements on telematics applications done in co-operation with the end-users and organizations like Railways Authority, Road and Motorways Directorates, Air Traffic Controls. Next step represents decomposition of the systems requirements to individual subsystems of the telematics chain.

List of representative telematic performance indicators was developed and accepted - see [1] - [3]:

- Safety - risk analysis, risk classification, risk tolerability matrix, etc.,
- Reliability - the ability to perform required function under given conditions for a given time interval, (iii) 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, (v) 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.

Substantial part of the performance parameters analysis regarding telematics application is represented by decomposition of these parameters to individual subsystems of the telematics chain, including a proposal for macro-functions of individual subsystems and information relations between macro-functions. Part of the analysis is the establishment of requirements on individual functions and information linkage so that the whole telematics chain should comply with the above defined performance parameters.

The completed decomposition of performance parameters enabled the development of a methodology for a follow-up analysis of telematics chains according to various criteria - optimization of the information transfer between a mobile unit and processing centre, maximum use of the existing information and telecommunication infrastructure, etc.

One of the criterions appropriate for transport-telematics applications with a Global Navigation Satellite System (GNSS) system is synthesis of the telematics system with minimized performance requirements on a locator, as well as communications solution resulting performance parameters of the telematics application to be maintained. This synthesis does not relate only to technical or technological part of the solution because the safeguarding of performance parameters of telematics applications is to be ensured by organizational and legislative instruments as well.

The transport telematics field is dealing not only with own technologies of ITS systems but particularly with organizational, economic, managerial and other implementing instruments of such systems, including the evaluation of the impact of ITS systems on the carriage of persons and goods like are the accepting of the approach by drivers, passengers, increase in the capacity of goods transport.

3. COMNUNICATIONS SOLUTION

3.1 Telematic sub-system requirements

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 –
  - Service Activation Time,
  - Mean Time to Restore (MTTR),
  - Mean Time Between Failure (MTBF) and
  - VC availability,
- Delay is an accumulative parameter effected by
  - interfaces rates,
  - frame size, and
  - 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 of communications performance indicators vector $\overrightarrow{tci}$ on the vector of telematic performance indicators $\Delta\overrightarrow{tmi}$ can be expressed by Eq. 1, 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]):

$$\Delta\overrightarrow{tmi} = TM \cdot \overrightarrow{tci}\,, \qquad (1)$$

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 are kept within given tolerance range.
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 "CALM" criteria, i.e. tolerance range of each performance indicator, to let decide which alternative access technology is in specific time and space evaluated as the best possible alternative.

3.2 Communications solution structure

Figure 2 presents typical telecommunications solution, originally developed for the pilot project Airport Praha (see cited research CAMNA project funded by the Czech Ministry of Transport): This structure was, however, generally accepted as typical architecture of majority of the ITS telematics solutions. Three units in different level of the grey color including On Board Units (OBU), GNSS Sensing System (SS) and set of Wireless Units (WL) all located in the oval border are intending to represent moving object within served area.

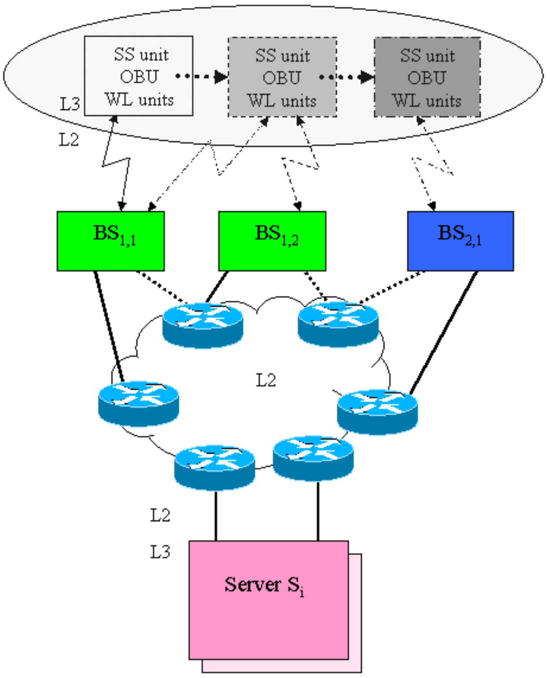

Figure 2. Telematic telecommunication scheme in chain diagram

Outdoor unit applies services of the GNSS (Global Navigation Satellite System) using one or more Sensing Systems (SS). Now localization service is provide only by GPS (Global Positioning System with not any SLA guaranteed) and in future there is expected to come also European Galileo GNSS, On-Board control and display Unit (OBU) and WireLess (WL) mobile communication units (WL_i – i-th cellular technology applied within solution). Terrestrial communication part consist of set of mobile cellular Base Stations (BS_{ij}) (i-th bases station of the j-th cellular system) as well as the terrestrial network based on L2 switches/nodes (TN_i) interconnected with Servers (S_i). E2E (End to End) service is provided based on IP protocol, L2 switching is Ethernet protocol based.

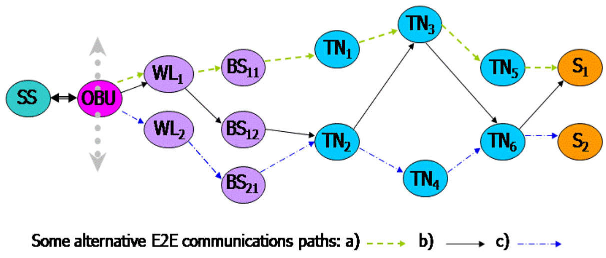

Figure 3. Telematic telecommunication scheme in chain diagram

Typical combination of different access telecommunications solutions applied within general transport telematic applications is demonstrated of Fig. 4 (see [11]).

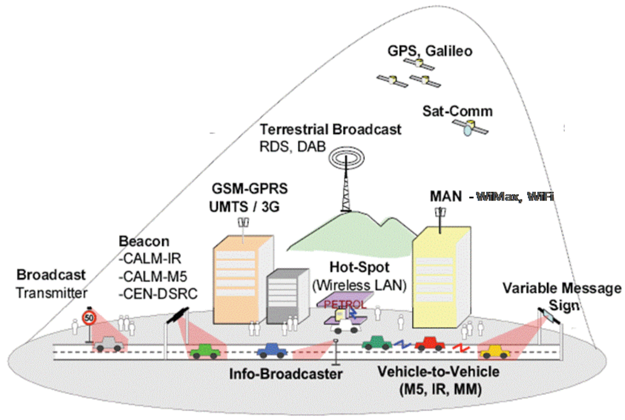

Figure 4. Transport telematics communications access solutions

One core technology can be typically selected as core solution (if possible), however, some areas need to be covered by alternative solutions. 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, as well. Technical implementation is described by standard CALM, even though there are available also alternative solutions e.g. based on L3/L2 switching principles.

3.3 CALM and L2/L3 switching

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, but also cost of provided service etc. 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 (MWB) 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 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.

4. 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 cannel 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 ZiBee (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.

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.

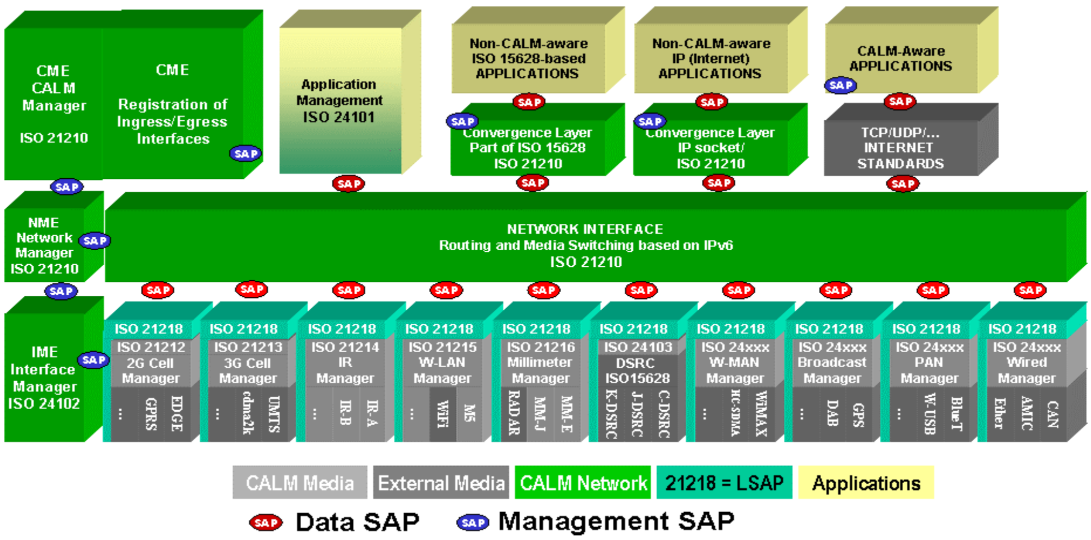

Figure 5. CALM Layer Architecture (Geneva review)

CALM standard resolves described issue by vertical system decomposition to the individual subsystems for each communications access path, however, management remains in the horizontal layers architecture see Fig. 5. 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 as correct 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 operated in specific configuration and settings see Fig. 6. This solution is understood as the only interim and in functionality limited substitution, however, with much less demanding and so faster implementation.

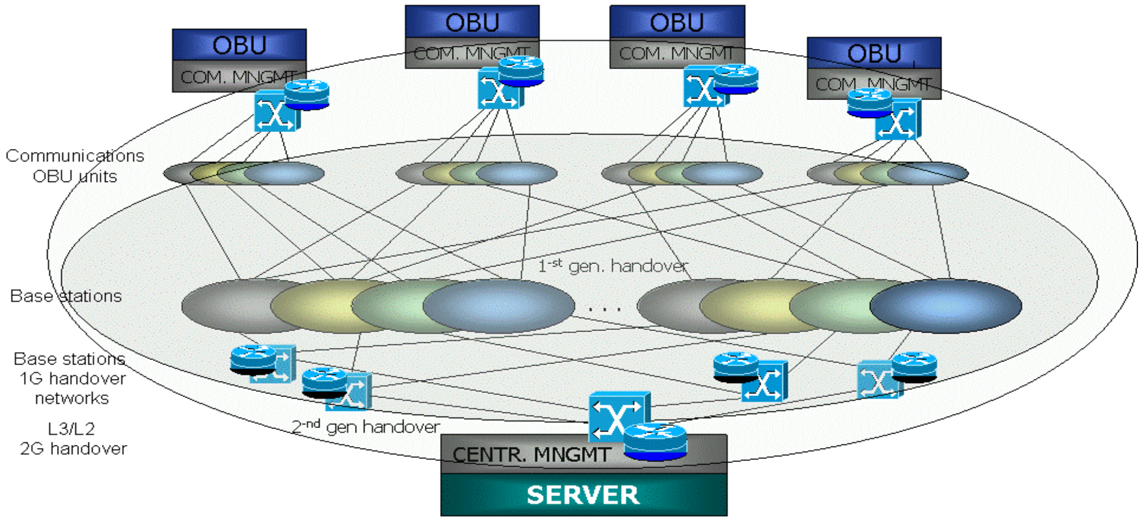

Fig. 6. Second generation handover within L3/L2 Switching Architecture.

Following paragraphs describe one of the potential approaches to the decision processes. Proposed methodology is based on following principles - see [13]:

- 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 or economical parameter together available as 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** and relevant selected paths.
- Success of classification is related to the size and quality of the training data lines.

This solution does not necessarily require 2HL communication with the other layers, nevertheless, it would be welcomed if such communication is at least partially possible in future implementations.

4.1. Estimation and prediction of measured performance data vector p(n)

Let us define parameter vector p(n) in the time interval n. We will suppose that the dynamic of parameter p(n) evolutes based on the following model (it is supposed that p(n-1) is known):

$$\boldsymbol{p}(n) = \boldsymbol{A}(n)\boldsymbol{p}(n-1) + \boldsymbol{b}(n) + \boldsymbol{q}(n) \qquad (2)$$

where A(n) is a transition matrix, b(n) is the deterministic vector of constant parameters and q(n) is the vector of Gaussian noise with the following property:´

$$\begin{aligned} &E[\boldsymbol{q}(n)] = 0, \\ &\operatorname{cov}[\boldsymbol{q}(n), \boldsymbol{q}(i)] = 0 \ \text{ for } \ n \neq i \\ &\operatorname{cov}[\boldsymbol{q}(n), \boldsymbol{q}(i)] = \boldsymbol{Q}(i) \text{ for } \ n = i \end{aligned} \qquad (3)$$

The equations (2) and (3) represent "evolution form of unknown parameters vector".

In many cases we cannot measure the vector of an unknown parameter p(n) directly, however, we can measure another vector z(n) that depends on unknown parameters as follows:

$$\boldsymbol{z}(n) = \boldsymbol{D}(n)\boldsymbol{p}(n) + \boldsymbol{r}(n) + \boldsymbol{w}(n) \qquad (4)$$

where ***D(n)*** is a transition matrix, ***r(n)*** is a deterministic vector of constant parameters and ***w(n)*** is the vector of Gaussian noise with the following property:

$$\begin{aligned} &E[\boldsymbol{w}(n)] = 0 \\ &\operatorname{cov}[\boldsymbol{w}(n), \boldsymbol{w}(i)] = 0 \ \text{ for } \ n \neq i \\ &\operatorname{cov}[\boldsymbol{w}(n), \boldsymbol{w}(i)] = \boldsymbol{W}(i) \text{ for } \ n = i \end{aligned} \qquad (5)$$

The equations (4) and (5) represent "evolution form of measurement vector".

The algorithm for estimation of a vector $\hat{\mathbf{p}}(n)$ of unknown parameters together with its covariance matrix **S**(n) can be summarized:

$$\begin{aligned} &\hat{\mathbf{p}}(n) = \hat{\mathbf{p}}_e(n) + \boldsymbol{H}(n)(\boldsymbol{z}(n) - \boldsymbol{r}(n) - \boldsymbol{D}(n)\hat{\mathbf{p}}_e(n)) \\ &\mathbf{S}(n) = \boldsymbol{S}_e(n) - \boldsymbol{H}(n)\boldsymbol{D}(n)\boldsymbol{S}_e(n) \end{aligned} \qquad (6)$$

Where $\hat{\mathbf{p}}_e(n)$ is an extrapolated estimate from the last step, $\mathbf{S}_e(n)$ is a covariance matrix of extrapolation and $\mathbf{H}(n)$ is Kalman gain. All the mentioned parameters are possible to be recursively computed from the last estimated parameters characterized by $\hat{\mathbf{p}}(n-1), \mathbf{S}(n-1)$ according to the form:

$$\begin{aligned}\hat{\boldsymbol{p}}_e(n) &= \boldsymbol{A}(n)\hat{\boldsymbol{p}}(n-1)+\boldsymbol{b}(n)\\ \boldsymbol{S}_e(n) &= \boldsymbol{A}(n)\boldsymbol{S}(n-1)\boldsymbol{A}(n)^T+\boldsymbol{Q}(n)\\ \boldsymbol{H}(n) &= \boldsymbol{S}_e(n)\boldsymbol{D}(n)^T\left(\boldsymbol{D}(n)\boldsymbol{S}_e(n)\boldsymbol{D}(n)^T+\boldsymbol{W}(n)\right)^{-1}\end{aligned} \tag{7}$$

Equations (6) and (7) are understood as "Kalman filtering algorithm".

Now, we suppose the non-linear evolution of an unknown parameter vector (2) and a measurement vector (4) through known non-linear functions f(.) and h(.):

$$\boldsymbol{p}(n) = f(\boldsymbol{p}(n-1)) + \boldsymbol{b}(n) + \boldsymbol{q}(n) \tag{8}$$

$$\boldsymbol{z}(n) = h(\boldsymbol{p}(n)) + \boldsymbol{r}(n) + \boldsymbol{w}(n) \tag{9}$$

The main idea is to linearize the equations (8) and (9) with the help of the first two components of Taylor series in extrapolated value $\hat{\mathbf{p}}_e(n)$ (extended Kalman filtering):

$$f(\boldsymbol{p}(n-1)) = f(\hat{\boldsymbol{p}}_e(n)) + \frac{1}{2}\cdot\left.\frac{\partial f(\mathbf{p})}{\partial \mathbf{p}}\right|_{\mathbf{p}=\hat{\mathbf{p}}_e(n)}\cdot(\boldsymbol{p}(n-1)-\hat{\boldsymbol{p}}_e(n)) \tag{10}$$

$$h(\boldsymbol{p}(n-1)) = h(\hat{\boldsymbol{p}}_e(n)) + \frac{1}{2}\cdot\left.\frac{\partial h(\mathbf{p})}{\partial \mathbf{p}}\right|_{\mathbf{p}=\hat{\mathbf{p}}_e(n)}\cdot(\boldsymbol{p}(n-1)-\hat{\boldsymbol{p}}_e(n)) \tag{11}$$

Based on the equations (10) and (11) non-linear equations (8) and (9) are transformed into a linear form and Kalman filtering could be used.

Kalman filtering can be started by the first measurement z(1). The initial parameters should be set up as:

$$\begin{aligned}\hat{\mathbf{p}}(1) &= \mathbf{H}(1)(\mathbf{z}(1)-\mathbf{r}(1))\\ \mathbf{H}(1) &= \left(\mathbf{D}(1)^T\mathbf{W}(1)^{-1}\mathbf{D}(1)\right)^{-1}\mathbf{D}(1)^T\mathbf{W}(1)^{-1}\\ \mathbf{S}(1) &= \left(\mathbf{D}(1)^T\mathbf{W}(1)^{-1}\mathbf{D}(1)\right)^{-1}\end{aligned} \tag{12}$$

4.2. Switching as classification process

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 of Kalman filtering described above.

Let us define the classification problem as an allocation of the feature vector $\mathbf{x}\in \mathrm{R}^D$ 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 $P(\omega_1),.....,P(\omega_C)$, respectively, 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:

$$\hat{\mathrm{f}}(\mathbf{x}\mid\omega) = \frac{1}{\mathrm{N}_\omega\cdot \mathrm{h}_\omega^{\mathrm{D}}}\cdot\sum_{\mathrm{i}=1}^{\mathrm{N}_\omega}\mathrm{K}\left(\frac{\mathbf{x}-x_{\mathrm{i}}^{\omega}}{\mathrm{h}_\omega}\right), \tag{13}$$

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 (13) is also called the Parzen window density estimate with the window function .

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:

$$f_L(x;\mu,\sigma) = \frac{1}{2\cdot\sigma}\cdot\exp\left(-\frac{|x-\mu|}{\sigma}\right), \tag{14}$$

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

$$\hat{f}(\mathbf{x}|\omega) = \frac{1}{N_\omega}\sum_{i=1}^{N_\omega}\prod_{j=1}^{D}\frac{1}{2\cdot h_{\omega,j}}\exp\left(-\frac{\left|x_j-x_{i,j}^{\omega}\right|}{h_{\omega,j}}\right). \tag{15}$$

Smoothing vectors $\boldsymbol{h}_\omega$ are optimized by a pseudo-likelihood cross-validation method using the Expectation-Maximisation (EM) algorithm (see [13] - [14]).

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

$$\mathrm{Q}_{\mathrm{d,i,j}}(\mathrm{d},\omega_\mathrm{i},\omega_\mathrm{j}) = \frac{\eta\cdot(\sigma_\mathrm{i}+\sigma_\mathrm{j})}{|\mu_\mathrm{i}-\mu_\mathrm{j}|}, \tag{16}$$

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 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:

$$\mathrm{Q}(\mathrm{d}) = \sum_{\mathrm{i}=1}^{\mathrm{C}}\sum_{\substack{\mathrm{j}=1\\ \mathrm{i}\neq\mathrm{j}}}^{\mathrm{C}}\mathrm{Q}_{\mathrm{d,i,j}}(\mathrm{d,i,j}). \tag{17}$$

All the features in the training data are then sorted according to their Q(d) measures. The function Q(d) is similar to 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 deliberated 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.

5. CONCLUSIONS

The main goal of our research is to introduce extension of existing telematic system improving safety, efficiency and comfort of transport services as well as technological transport processes like in past studied airport over-ground traffic management. This afford calls for new generation of real-time navigation service, which is continuously available (on defined probability level) for management system as well as for served vehicles e.g. under any weather condition.

Required communications delay limit (fix plus mobile) identified for the Top Class areas e.g. airport landing and take of areas within the pilot project CAMNA, has been outstandingly challenging and this requirement significantly determined selection and setup of the whole communications chain. Top Class services requirements, however, also represent general top reference level of the wide range of telematic services requirements.

Due to regular complexity of by telematic services covered areas (several classes of services with different system requirements) it is necessary to concentrate afford on the wireless access solution designed as seamless switched combination of more independent access solutions.

Process of access solution switching has been subject of intensive R&D and different approaches were already published. One of alternatives - family of standards CALM developed to transport applications - represents promising response on ITS requirements, even though due to complexity of proposed solution it is inevitable that a quite remarkble time to resolve all issues can be expected.

On the other hand proposed alternative approach based on L3/L2 TCP/IP switching operated in specific configuration and settings is understood only as the potential interim and in functionality limited substitution, however, with much less demanding and so faster implementation conditions comparing e.g. to the ones of CALM.

Method of different paths evaluation and decision process background has not been as widely discussed as were communicated the core switching approaches and that is why core principles of one of possible alternative is presented.

Measured parameters of all available alternative access paths are in presented solution processed by Kalman filter with aim to separate reasonable part of the data noise. Kalman filter also allows prediction of the individual parameters near future behaviour. Filtered flow of measured parameters vectors can be than extended by deterministic parameters like identification communicated with tall collection or economical parameters.

Resultant vector **x** time line allows to classify the best possible technology selection from those for which the relevant time line of vectors **x** is available. Classification algorithm is based on training procedure using relevant training data – i.e. line of training vectors **x** and relevant to data selected paths. Even though just linear separability is taken into account, the individual feature selection method based on the between-to within-class variance ratio represents very fast approach.

Presented classification approach is effectively applicable for relevant decision processes on the top layer of the communications system management to successfully select the best possible access alternative from the set of available paths. Decision is based on evaluation of both random as well as deterministic processes and introduced approach enables continuous decision processes training. Its sthrenth is namely in future information resources extension obtained namely from potentially available lower layers of the multilayer adaptive communications management system.

REFERENCES

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

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

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

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

[7] T. Zelinka, M. Svitek, **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] M. Svitek, T. Zelinka, **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] M. Svitek,, T. Zelinka, **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] T. Zelinka, M. Svitek, **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] B. Williams, **CALM handbook V1.0**. Document ISO TC204 WG.16.1 CALM, 2004.

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

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

[14] M. Svitek, **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.

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

[16] T. Zelinka, M. Svitek, **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.

[17] M. Svitek,, T. Zelinka**, 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.

[18] M. Svitek,, T. Zelinka, **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.

[19] T. Zelinka, M. Svitek, **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.

[20] M. Svitek,, T. Zelinka**, 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,

[21] M. Svitek,, T. Zelinka, **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,

[22] T. Zelinka, M. Svitek, **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.

[23] T. Zelinka, M. Svitek, **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.

[24] T. Zelinka, M. Svitek, **Adaptive communications solutions in complex transport telematics systems,** Proceedings of the 11th WSEAS International Multiconference CSCC 2008, Volume – New Aspects of Communication, pp. 206 – 212, Heraklion, Greece, ISSN 1790-5117, ISBN 978-960-6766-84-8.