Communication scheme for airport service vehicles navigation

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Abstract: Intelligent Transport systems (ITS) are essentially dependent on correct selection and operation of integrated communications solution. Requirements on the ITS communications environment are, however, regularly quantified indirectly by telematic sub-system performance indicators. Correct selection and configuration of the appropriate communication solution can be achieved if transformation matrix *TM* between vectors of communications and telematic performance indicators is correctly identified. This *TM* matrix identification process is core of introduced method developed within projects CaMNA[1] ("Car Movement maNagement on the Airport") and SRATVU[2]. Complexity of the airport area requires different values of telematic system performance indicators in various parts of the area. Specific airport conditions lead to combination of core wireless service with a set of the alternative access solutions. Second generation of cellular handover was adopted as a basic principle of the relevant dynamic communications access services selection. As a final point there are presented results of the communication solution parameters tests processed within CaMNA limited pilot installation as well as the relevant recommendation.

Key-Words: - Intelligent Transport Systems, Telecommunications Performance Indicators, Telematic Performance Indicators, Global Navigation Satellite System, handover, Quality of Service.

1. Introduction

The main goal of the project CaMNA1[1] (Car Movement maNagement on the Airport) is to improve efficiency and security of the airport over-ground traffic. This telematic application based on GNSS (Global Navigation Satellite System) has been developed with aim to be integrated with already operated management system A-SMGCS (Advanced Surface Movement Guidance and Control System) based on the non-GNSS based localization systems. CaMNA sub-system is designed in client – server structure. Powerful client is inevitable to be installed in every vehicle used at airport area. Client, i.e. OBU (On Board Unit) is designed as a modular system equipped with PC based unit. Right now there are available modules like GNSS unit, wireless communications units, display and audio unit. Both SW and HW modular architecture gives to CaMNA system remarkable potential to extend functionality of the system by means of optionally integrated modules.

Information about vehicle position is sent to the central server on periodical basis mutually with requirements generated by vehicle driver. Server collects and processes data received from all service vehicles. Obtained data are combined with data gained from A-SMGCS and they are delivered to the airport management unit. Simultaneously this positional information is sent to each vehicle equipped with active OBU. Each OBU receives also individual supervisory data generated by either airport control system or by dispatchers.

Described client-server application may resemble the widely spread publicly available car navigation systems. However, this application displays all identified objects in the area on both dispatcher and each user units. Moreover an extensive set of bidirectional interactivity tools is available, as well. There are also outstandingly higher requirements on telematic system performance indicators. This fact is caused by specific conditions of the airport area where this application is operated.

2. Communications solution

2.1 Telematic sub-system requirements

Airport is strictly, but precisely and transparently regulated area. CaMNA telematic sub-system

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[1] The pilot project is part of grant 802/210/112 "Joining of the Czech Republic into Galileo project" supported by Ministry of Transport of the Czech Republic

[2] SRATVU – "System Requirements and Architecture of the universal Telematic Vehicle Unit" is grant 2A-1TP1/138 of Ministry of Industry and Trade of the Czech Republic.

performance indicators (see e.g. [2] – [5]) are displayed in Table 1.

Perform. Indicator	limit value	probability level	time interval
Accuracy	7.5m	99%	-
Availability	30s	99%	after init.
Reliability	36s	99%	3,600s
Continuity	5s	99%	180s
Integrity	5s	99%	-

Tab.1 CaMNA Telematics Performance Indicators

Full mobility of the communication solution represents one of the crucial system properties specifically in context of particular demand on availability, quality and security of applied communication solution.

Required data transmission capacity represents another critical system parameter. Volume of the exchanged data set *pd* is set to 70 Bytes. If position each of *n* object is identified by GNSS method, *m* additional object are localized by A-SMGCS and measurement frequency is *f* than needed transfer capacity for localization data flow between server and clients is

$$tci = pd.n.f.(n+m).8 \text{ [b/s]}. \quad (1)$$

Required transferred capacity for localization data in opposite direction, i.e. from client to server is

$$tcc = pd.n.f.8 \text{ [b/s]}. \quad (2)$$

If broadcast regime instead of the individual communication between server and clients is applied than data transfer

$$tcb = pd.f.(n+m).8 \text{ [b/s]}. \quad (3)$$

It means that

$$tcb = tci / n \text{ [b/s]}. \quad (4)$$

Additional individual supervisory data flows between server and clients are not included in this calculation. Administration data volume is not, however, critical if compared with volume of the positional data.

Another alternative approach which leads to principal data flows reduction is based on control of positional data delivery in accordance to their evaluated importance. Distance between objects and their mutual speed represent effective criteria for such data flow control.

IP protocol offers general devices interoperability. This IP advantage is, however, paid by need of wide range of techniques and tools, which must be carefully installed and managed to obtain requested service quality, reliability and security.

Link layer (L2) BER can nowadays offer services with BER<10^{-9} (BER - Bit Error Rate) in case of carrier grade wireless systems and even BER< 10^{-12} for fiber networks namely due to physical layer (L1) continual quality parameters improvement. L1 has got so minor influence on the communication system BER. On the other hand due to packet/frame information structure L3 and L2 nodes (router/switch) functioning critically influence the whole communications performance. Following communications performance indicators quantify service quality:

- *Availability,*
  - *Service Activation Time* (SAT) - defined as time needed for activation/modification of the network archived on certain probability level,
  - *Mean Time to Restore* (MTTR) - defined as time service is restored from unexpected inoperable stage on certain probability level,
  - *Mean Time Between Failure* (MTBF) - defined as time between two unexpected inoperable stages on certain probability level and
  - *VC availability* - percentage of correctly provided service in appointed time interval on certain probability level.
- *Delay* - an accumulative parameter defined as time frames are delivered within a defined time period on a certain probability level. This parameter is effected by *(i) interfaces rates (ii) links capacity, (iii) frame size, and (iv) load/congestion* of all in line active nodes (switches).
- *Packet/Frames Loss* - percentage of undelivered packets/frames within defined time period on certain probability level.
- *Security* - Risk Analysis (RA) and classification must be done based on detailed knowledge of the system environment and potential risks. Risk of information integrity can be caused by attack on any part of the information transfer chain. Relevant solutions can be seen namely in additional security tools – like on L2 authentication, coding and on application layer - authentication, coding and tunneling.

2.2 Communications design methodology

Performance indicators described for communications applications must be transformed into telematic performance indicators structure and vice versa. Final additive impact of the vector of communications performance indicators $\overrightarrow{tci}$ on the vector of telematic performance indicators $\Delta\overrightarrow{tmi}$ can be expressed by Eq. 5, if probability levels of all indicators are unified on the same level and all indicators are expressed exclusively in time dimension.

$$\Delta\overrightarrow{tmi} = TM \cdot \overrightarrow{tci}, \quad (5)$$

where *TM* is transformation matrix. Identification of the *TM* represents iterative process and it is handled in four iterative steps. Identification process starts with matrix in as general as possible structure TM_0. Transformation matrix TM_0 takes in account all potential relations between communications and the telematic indicators. 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 strictly evaluated in period the TM_0 identification.

In case of CaMNA case vector $\overrightarrow{tmi}$ consists of

- *Accuracy* ,
- *Availability* $t_{ds,i}$,
- *Reliability* $t_{tna,i}$,
- *Continuity* t_i ,
- *Integrity* $t_{tsna,i}$

and vector $\overrightarrow{tci}$ consist of

- *time to upload* $d_{u,i}$,
- *time to download* $d_{d,i}$; ,
- *handover within the same access technology* $rc_{hs,m,i}$,
- *handover within different (CALM) media* $rc_{hd,m,i}$,
- *feedback parameters settings period* $rc_{rp,m,i}$,
- *MTTR of the terrestrial network service* $rc_{r,f,i}$,
- *MTTR of the access mobile service* $rc_{r,m,i}$,
- *time period fix service is not available (self-healing process not available or not successful)* $t_{na,f,i}$,
- *time period mobile service is not available (self-healing process not successful)* $t_{na,m,i}$,
- *time to accept OBU (On Board Unit) into relevant cell* $t_{oi,i}$.

General impact of listed set of communications performance indicators on above defined set of telematic performance indicators $\Delta\overrightarrow{tmi}$ is described by parameters

- *Accuracy* as distance vehicle maximally moves within whole communication cycle,
- *Availability* as time required to accept wireless unit into network plus time to deliver information about successful acceptance,
- *Reliability* as total time communications service is not available within defined period (final reliability is than expressed in %),
- *Continuity* as time period communications service is not available,
- *Integrity* as time to deliver information about system failure .

Transformation matrix structuture *TM* of Eq. 5 can be presented by Eq. 6.

$$TM=\begin{bmatrix} k_{p,u,i}\cdot v_i, & k_{p,d,i}\cdot v_i, & k_{p,hs,m,i}\cdot v_i, & k_{p,hd,m,i}\cdot v_i, & k_{p,rp,m,i}\cdot v_i, & k_{p,r,f,i}\cdot v_i, & k_{p,r,m,i}\cdot v_i, & k_{p,na,f,i}\cdot v_i & k_{p,na,m,i}\cdot v_i & 0 \\ k_{d,u,i}, & k_{d,d,i}, & k_{d,hs,m,i}, & k_{d,hd,m,i}, & k_{d,rp,m,i}, & k_{d,r,f,i}, & k_{d,r,m,i}, & k_{d,na,f,i}, & k_{d,na,m,i}, & k_{d,oi,i} \\ k_{s,u,i}, & k_{s,d,i}, & k_{s,hs,m,i}\cdot ns_{hs,m,i}, & k_{s,hd,m,i}\cdot ns_{hd,m,i}, & k_{s,rp,m,i}\cdot ns_{rp,m,i}, & k_{s,r,f,i}, & k_{s,r,m,i}, & k_{s,na,f,i}, & k_{s,na,m,i}, & 0 \\ 0 & 0 & k_{k,hs,m,i}, & k_{k,hd,m,i}, & k_{k,rp,m,i}, & k_{k,r,f,i}, & k_{k,r,m,i}, & k_{k,na,f,i}, & k_{k,na,m,i}, & 0 \\ k_{i,u,i}, & k_{i,d,i}, & k_{i,hs,m,i}, & k_{i,hd,m,i}, & k_{i,rp,m,i}, & k_{i,r,f,i}, & k_{i,r,m,i}, & k_{i,na,f,i}, & k_{i,na,m,i}, & 0 \end{bmatrix} \quad (6)$$

where v_i is vehicle velocity, $ns_{hs/hd/rp,m,i}$ represents number of phenomenon appearance (on agreed probability level) in time interval $\langle 0,T\rangle$. Value of $k_{xx,yy,m/f/-,i}$ is evaluated as either „0“ or „1“ in accordance to below described iterative process .

Each *TM* element is consequently in several steps evaluated based on the detailed analysis of the particular telematic and communications configuration and its appearance probability in 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. Four steps of the process leading to the final stage are:

[I] *primary elimination* of communication parameter based on implementation of relevant communication solution or setting (e.g. guaranteed homogenous radio signal coverage in defined area – e.g. airport runway),

[II] *primary disregarding* of communications indicator, if its weight can be justified as insignificant,

[III] *identification* and exclusion of indicators with significantly *lower* level of their *appearance probability* (e.g. in case of coincidence of processes with unified probability level of their individual occurrence - the dominant one is appointed),

[IV] *final iterative identification of dominant indicators* as the last step of the iterative process of the *TM* identification is based on the virtual communication solution parameters settings. Potential solution modification can, however, lead identification process back to step *[I]*.

Presented method principles are designed as general as possible with aim to cover the widest range of telematic solutions. Method is applicable for CALM media performance indicators limits identification, as well.

2.3 Communications solution for ITS

Most of ITS serve moving objects, so that appropriate wireless access solution is typicaly needed. GSM mobile providers preferably offer GPRS (General Packet Radio Service) – see [8] and EDGE (Enhanced Data rates for GSM Evolution) data services. UMTS (Universal Mobile Tele-communications System) data services have been more and more available, as well. It is possible to apply also DTMF (Dual-tone multi-Frequency), CSD (Circuit Switched Data), HSCSD (High Speed CSD), SMS (Short Message Service), USSD (Unstructured Supplementary Service Data), UUS (User to User Signaling) served via GSM (Global System for Mobile Communications networks) networks. However, GSM based data services performance indicators are noticeably limited to let apply GSM wireless access services particularly for specific “sensitive” ITS applications.

Carrier grade mobile wireless communications solutions Mobile WiMax, i.e. communications system based on IEEE Std. 802.16d and Amendment 802.16e is promising alternative, which will be able to meet most of ITS specific wireless access performance indicators requirements - see [10] and [11]. However, Mobile WiMax has will not be accessible in certified version before 4Q2007.

In a short term view we expect that Mobile WiMax will be mostly available only in dedicated installations. Reasonable value/cost ratio gives potential to Mobile WiMax to be successful in mid-term view in competition e.g. with UMTS. These expectations are strengthen by new much more visible activities of companies like Intel, Nokia (NSN), Samsung and Motorola in IEEE 802.16 WG.

IP communications have got for highly demanding solutions series of effective tools both on L2 an L3 of the TCP/IP model. Even though MPLS is understood as the L3 solution leader, L3/L2 switching (IEEE 802.3, 802.1d and 802.1q in the latest version) has been archiving remarkable position in ITS namely due to notably faster network convergence and reasonable value/cost ratio. ITS solution usually combines both mobile access and terrestrial backbone services and theirs simple transparent interoperability on L2 represents another crucial advantage.

2.4 CALM – family of standards

CALM (Communications Air-interface for Long and Medium range) family of standards (ISO TC204, WG16.1) (see [12] - [14]) offers for every particular application best available wireless access solution in given area and time. Process of the alternative wireless access solution substitution is usually referred as the second generation of the cellular handover principle known in its first generation from cellular mobile systems.

Handover process is controlled in accordance to set of in advance identified parameters limits. Criteria for the “best” solution include parameters like BER, level of received radio signal etc. Control system takes in account not only the absolute values of tracked parameters, but also theirs individual trends as well as trends of specific parameters combinations. Dynamics of the internal CALM media feedback control processes must be carefully taken in account to minimize contra-productive simultaneous processing on different levels of the hierarchical system.

Replacement by the alternative solution can be also caused by identification of more suitable alternative (evaluated by cost, life time etc.) to existing and still successfully used alternative.

Communications solutions, i.e. CALM media are:

- *Cellular systems* including 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 soon IEEE Std. 802.20,
- *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.

CALM represents Unified Modeling Language type of architecture. Details about this family of standards are available e.g. in [12] - [14]. Handover of CALM media is processed on L2 of the TCP(UDP)/IP model, i.e. it is not in TCP/IP competences. Handover competences given to this L2 is the only suitable alternative for wide range of the wireless solution. Alternative layer solutions are displayed on Fig. 1.

CALM family of standards does not represent strict implementations rules into a “physical body”. CALM will appear mostly as software package implemented into already existing vehicle computers dedicated e.g. for the telematics applications.

Goal of CALM implementations is the “only” optimization of the access wireless communications processes. Due to fact that CALM can directly touch vehicle control computers data busses, firewall protection must be implemented between vehicle control and communications system. It is absolutely crucial to keep privacy of the vehicle control system because of the final legal liability for the safety of the vehicle lies on the vehicle manufacturer.

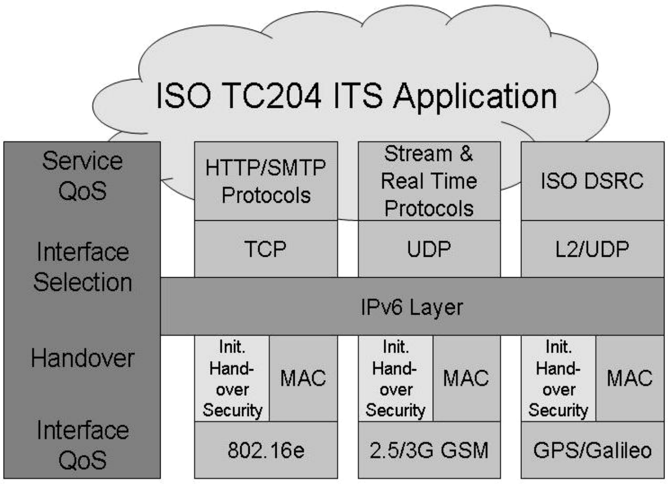

Figure 1. CALM Layer Architecture

2.5 CaMNA communications design

Applied transformation method identified telematic performance indicator “accuracy” as the dominant indicator. This dominance is caused by real-time character of the CAMNA application installed in the specific conditions of the airport area. Requested level of accuracy (see Table 1) must be reached for every object moveable with speed up to 120km/hour. GNSS sensor accuracy of 1m will be economically reachable by selection of the Galileo services. For present-days tests with the “public” GPS sensors such accuracy can be obtained in the differential configuration. Remaining approx 6.5m of the total required accuracy restricts maximal communications delivery delay on 200ms.

All the other limits defined in Table 1 are met if total reached delivery delay is below critical 200ms. Limit of 200ms so represent critical issue for the communications chain and it must be carefully kept namely in the airport critical areas - i.e. Class 1 areas like runways and their surroundings. This parameter considerably determines the communications chain performance indicators with consequences of elimination of most of available wireless communications solutions.

Mobile WiMax (IEEE Std. 802.16e) was identified as the only potential alternative of the wireless access solution for the critical airport areas. GPRS and EDGE and quickly penetrating UMTS data services served by public operators do not meet performance indicators requirements for the “sensitive” airport areas of Class 1 (200ms total max. delay of the whole communication system).

Even though Mobile WiMax is the only potential alternative for the core mobile access system unavoidable for the airport critical areas, whole airport area coverage with this core technology was not identified as an effective approach. Some of alternative access solutions identified as inappropriate for Class 1 like already mentioned EDGE/GPRS/UMTS or e.g. even in specific areas carefully individually installed WiFi can be applied, if alternative services performance indicators meet these areas specific performance requirements (Class 2 and lower). For solution to solution switching second generation of the cellular handover in CALM architecture was selected.

L3/L2 switching (IEEE 802.3, 802.1d and 802.1q on L2) in combination with HW based redundancy switching system “HYPER ring” (already available at Airport Prague proprietary solution produced by company Hirschman) was selected due to reachable values of the performance indicator MTTR (convergence procedure approx. 50ms per 1Gb/s Ethernet ring) as well as due to transparent possibility to effectively interconnect fix and mobile solutions.

Introduced mobile and fix communication chain offers relevant communications system parameters in context of by project required performance indicators.

3. Results of CaMNA pilot project tests

The main goal of the pilot project communications system tests was to identify parameters of the Wimax wireless access solution integrated into CaMNA system. Because of any certified Mobile WiMax systems was not commercially available, tests were processed with communication solution based on IEEE Std. 802.16d, which does not guarantee some performance indicators for communications with moving objects.

Figure 2. OBU and in-door antenna installed in vehicle (exclusively for pilot tests)

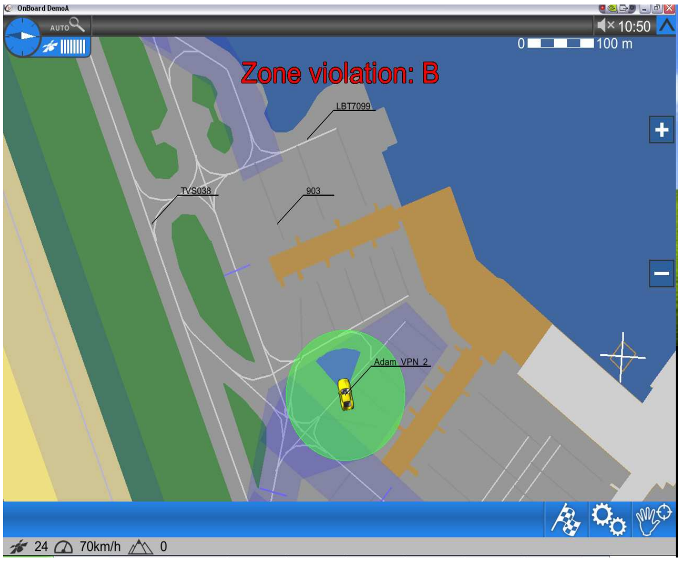

Figure 3. OBU screen in vehicle (pilot test)

The airport area with the heaviest over-ground traffic was selected to let provide representative results of the pilot installation. This area also included runways where was operated majority of this airport taking-off and landing. Limits of dynamic parameters given not only by standard IEEE 802.16d but also by parameters of the only that time available smart antenna were taken in account in the pilot tests design (see Fig. 2). Figure 3 introduce typical screen view, which also include information received from airport management.

Due to already discussed dynamic limits given by applied communications access wireless technology most of tests were processed exclusively in the static regime. Obtained results are summarized in Table 2.

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

Table 2. – Principle parameters of the WiMax access

where LOS means “Line Of Sight”, NLOS – “Non LOS”, ART “Average Round Trip” and ASNR “Average Signal to Noise Ratio”.

Spectra of Round Trip Delay (RTD) in ms are in static regime comparable for both LOS and NLOS configuration. Typical example of obtained RTD spectra is displayed on Fig. 4 for NLOS alternative.

Both measurements were processed in static regime. Sporadic packet re-transmission generated by applied TCP is most probably caused by occasional interaction between WiMax radio and airport radars systems. Probability of packet delivery delay longer than 100ms is, however, below requested 1% probability.

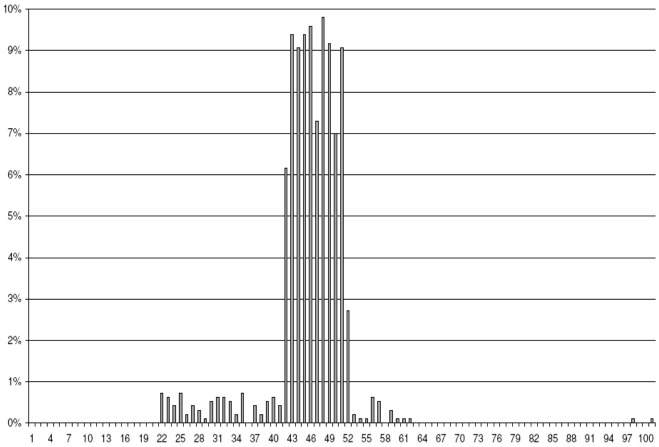

Figure 4. RTD spectra of NLOS Site 3

Test with moving vehicles were operated only in the “open area”, where switching between LOS and NLOS regime frequently accompanied with new setting of the antenna was not expectable. Motion tolerance up to required 120km/hour was identified in runways “open” area (Class 1) on mandatory probability level even with IEEE 802.16d based system. Handover dynamic parameters (system based on IEEE Std. 802.16e) will be tested immediately certified product is available.

Results confirmed, that critical dominant performance indicator, i.e. round trip delay, meets calculated requirements under accepted restrictions given by applied technology. Reached mobile part results give appropriate space (more than 100ms on probability level of 99.9%) to the terrestrial solution. It is reachable requirement on terrestrial backbone network based on Ethernet rings with HW switched redundancy like e.g. HYPER ring.

Final solution covering the whole airport area will evidently need cellular architecture, i.e. Mobile WiMax (IEEE Std. 802.16e based certified system) combined with alternative local access solutions in areas of Class 2 and lower, i.e. like parking and depot areas. Such solution leads to design of management system where are accepted the second generation of the cellular handover principles in CALM architecture.

4. Conclusion

CaMNA project represents typical Intelligent Transport System (ITS) where correct communication solution identification and its parameters settings play critical role. The main goal of the CaMNA project is to introduce telematic system, which based on positional identification of all moveable objects on the airport area, processing of gained data and relevant communication of obtained results to all involved users (dispatchers, drivers etc.) can improve safety and efficiency of the existing airport over-ground traffic management.

Most of available communications solution served via GSM and UMTS networks have got some significant performance indicators limits so that these services can be identified in specific ITS applications as insufficient.

Mobile WiMax (IEEE 802.16e) is wireless access solution with performance indicators meeting requirements even in the most critical parts of the airport area. Due to ability to provide its service quality efficient management as well as reasonable cost/value ratio Mobile WiMax is promising access solution for extensive range of ITS applications. We can expect that in mid-term view Mobile WiMax will reach position of important widely available competitor to UMTS and GSM data services.

Introduced method of selection and configuration of the communications solution for telematic application based on identification of transformation matrix *TM* between communications and telematic performance indicators vectors was presented. This method was applied for CaMNA project communications solution specification. Telematic performance indicator “accuracy” was recognized as the dominant one. Required accuracy must be unconditionally reached for every moving object in areas of Class 1. Communication delay was than identified as the key communications performance indicator. Telematic performance indicators limits are reached if the overall delay of the communications chain is kept below critical 200ms on probability level of 99.9%.

This limit represents the essential issue for the communications solution and it determines selection and setup of the communications sub-system. Delay limit must be, however, strictly respected primarily in the airport critical areas - i.e. Class 1 like runways and their surroundings. In these areas e.g. handover probability would be reduced to minimum by means of signal coverage topology.

Applied method disqualified for CaMNA application such communications leaders like MPLS backbone terrestrial network or GPRS/EDGE wireless access due to fact, that these communications systems cannot guarantee performance parameters limits valid for Class 1 areas. Arrangement of the Mobile WiMax as core access service and terrestrial L3/L2 switching solution combined with HW accelerated redundancy switching system was selected (HYPER ring). Core WiMax access solution can be combined with alternative access technologies, where it is quantified as a relevant approach (Class 2 and lower). Switching between access services is carefully controlled by management system with adopted CALM family of standards.

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