STATE OF THE ART SURVEY OF WIRELESS VEHICULAR COMMUNICATION PROJECTS

Lars Strandén
Electronics Department
SP Technical Research Institute of Sweden, SE-501 15 Borås, Sweden
+46 10 516 55 52, lars.stranden@sp.se

Elisabeth Uhlemann
Volvo Technology Corporation
Dept. 6600, M1:6, SE-405 08 Gothenburg, Sweden
+46 31 666 696, elisabeth.uhlemann@volvo.com

Erik G. Ström
Department of Signals and Systems
Chalmers University of Technology, SE-412 96 Gothenburg, Sweden
+46 31 772 5182, erik.strom@chalmers.se

ABSTRACT

In this paper the results of a state of the art survey, using publicly available information, are presented. The scope of the survey concerns projects that include wireless communication vehicle-to-vehicle and vehicle-to-infrastructure. Since there is a vast amount of information available, a specific methodology has to be developed and applied. This paper presents such a methodology which is based on a matrix representation that enables the definition of specific metrics. These metrics can then be used for further evaluation. The objectives of this work are threefold; to gather relevant project information, to define and apply a methodology for handling this information, and to compare and draw some general conclusions about the nature of projects carried out in Europe, USA and Japan.

KEYWORDS: wireless communication, vehicle, infrastructure, state of the art, survey, v2v, v2i

INTRODUCTION

Already today, wireless links are used in vehicular environments for, e.g., collecting tolls, telephony, traffic congestion management (TCM) and positioning (GPS). Wireless vehicular communication can further be used within the areas of safety, efficiency and infotainment. The purpose of this work is to make a survey of the state of the art in wireless vehicular communications based on available open information. The survey addresses projects that include wireless communication vehicle-to-vehicle (v2v) and vehicle-to-infrastructure (v2i). With infrastructure is here meant roadside equipment. The document can then be used, e.g., to

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identify aspects that are not previously covered or lack satisfactory solutions or as input to research proposals.

It is difficult to make an unambiguous definition of what should be included in this kind of survey. There are several reasons for this. Firstly, it is challenging to decide which issues to base the survey on to create a fair overview of the addressed area such that further analysis is possible and, secondly, the border between included and excluded items is not always clear. Thus a strictly defined set is not possible to achieve. For this survey the following prerequisites have been applied:

- A breadth first search is used. By not directly going into details there is a possibility of getting an overall view at the same level of generality.
- Only publicly available web-pages have been considered.
- Active (not passive) safety is addressed, i.e., active means for avoiding injuries and collisions.
- Traffic efficiency and infotainment are included.
- Future autonomous cars (sometimes denoted cybercars) are not considered.
- Only *projects* are considered, i.e., time-limited tasks. Thus continuous activities at universities, organizations and standardization bodies are not included. Also conferences and scientific papers are not included.
- Company-specific projects have been excluded since detailed information concerning these is generally not publicly available.
- Pure administrative projects are not considered, thus the included projects generate some kind of technical artifact(s).
- Focus is on Europe, USA and Japan since they are currently dominant in the vehicular communications area. Other countries could also be of interest, e.g., China, Canada and South-Korea; however, they are not included here.

Even with these limitations, 79 projects were found qualified for the survey. It should be noted that the survey cannot claim to be complete, even with the restrictions given above; however, it is believed to contain a representative set of projects covering the state of the art of the addressed area. The results presented in this paper are based on the full survey in (1).

METHODOLOGY

As mentioned above, only publicly available information on the Internet was used to compile the survey. The search for projects took place by starting with a set of known projects and using their respective links and then by Internet searches using keywords such as “wireless communication”, “v2v”, “v2i” etc. The searches as such were thus made country-independent and assessment, using the prerequisites defined above, took place afterwards. To get an overview of qualified projects a specific template matrix, Figure 1, was defined containing three overall fields: *Overview*, *Application type* and *Area of work,* where the latter two fields were used for project classification. The classification concerned the *major* impressions. For example, a project with 12 European partners and one partner from Japan would anyhow be characterized as European.

Overview				
"name/identifier"				
Duration:				
Financing:				
Size:				
Country interest:				
Link:				
Summary:				
Focus **Application type**	**Vehicle human**	**Infrastructure human**	**Technical**	
Safety application				
Efficiency application				
Infotainment application				
Application independent				
Artifact **Area of work**	**New algorithm / New technology**	**Specification**	**Realization**	**Evaluation**
Vehicle				
Communication				
Infrastructure				
Management				

Figure 1. Project overview template

The *Overview* consists of the following fields:

- The *name/identifier* of the project.
- *Duration* – calendar time.
- *Financing* – name/identifier of, e.g., research sponsor, partners etc.
- *Size* – the first hand choice is person-months but other measures could apply, e.g., money, number of partners etc. The purpose is to get an opinion of the impact of the project and understand its available resources.
- *Country interest* – countries of principal actors and one or more of the following: *Europe, USA, Japan, Other* where *Other* denotes a country outside Europe and not USA and not Japan.
- *Link* – web link to project home page or other relevant information.
- *Summary* – short description of the purpose and achievements of the project.

The *Application type* consists of the following fields:

- *Safety application* – an application for avoiding injuries, vehicle damage, etc.
- *Efficiency application* – an application for route planning, avoiding road work, etc. Also comfort-related applications are included here.
- *Infotainment application* – an application for weather forecast, video/music download, etc.
- *Application independent* – an application that cannot be directly mapped to the three types above.

Note that a project may contain both application dependent and application independent parts.
Each *Application type* has one or more foci:

- *Vehicle human* – focus on driver or passenger.

- *Infrastructure human* – focus on operator or management persons.
- *Technical* – focus on technical solutions.

The *Area of work* consists of the following fields:

- *Vehicle* – the part of the application local to the vehicle.
- *Communication* – the part of the application used for exchanging information vehicle-to-vehicle and vehicle-to-infrastructure.
- *Infrastructure* – the non-mobile part of the application external to a vehicle.
- *Management* – issues related to how people work, e.g., organization, roles, quality, etc.

Each *Area of work* generates one or more artifacts:

- *New algorithm / New technology* – new algorithms or technologies are generated.
- *Specification* – requirement specification or other types of specifications are generated.
- *Realization* – implementation in sw, hw or by other means.
- *Evaluation* – assessment is performed and documented.

For *Application type* and *Area of work* an 'x' denotes *relevant* and an empty cell denotes *not relevant* for the project. Note that a project can cover several aspects, i.e., several 'x' can exist.

For evaluation of projects *classification metrics* based on information in the cells *Duration, Size, Country interest*, *Application type* and *Area of work* can be defined. The following metrics were used in the survey:

- *Total scope* – this metric shows where efforts have been put and where they have not. This metric is available for all evaluated projects and values are given by summing the number of 'x' in each of the Application type and Area of work cells, respectively.
- *Total scope per country* – this metric shows (for Europe, USA and Japan, separately), where efforts have been put and where they have not. This metric is available for all evaluated projects (for Europe, USA and Japan, separately) and values are given by summing the number of 'x' in each of the Application type and Area of work cells respectively. The values are then normalized with respect to the number of projects for Europe, USA and Japan, respectively.
- *Application type generality* – this metric shows how specific the projects are with respect to Application type. The number of projects with only one Application type 'x' is counted (all foci are considered), then projects with two Application type 'x' are counted and so on.
- *Area of work generality* – this metric shows how specific the projects are with respect to Area of work. The number of projects with one Area of work 'x' is counted (all artifacts are considered), then projects with two Area of work 'x' are counted and so on.

RESULTS

A total of 79 projects were considered relevant for the survey. There was a significant country difference in number of projects; for Europe 60 projects, for USA 14 projects and for Japan 5 projects. As described above the approach for getting an overview of these projects was to combine project descriptions (i.e., project-explicit views) with project classification metrics (i.e., project-implicit views). An example of a filled-in template is given below in Figure 2.

Overview

COOPERS

Duration: 2006 – 2010

Financing: EU FP 6

Size: 40 partners, 16.8 M€

Country interest: Europe

Link: http://www.coopers-ip.eu/

Summary:
COOPERS stands for CO-OPerative SystEms for Intelligent Road Safety and focuses on the development of innovative telematics applications on the road infrastructure with the long term goal of a "Co-operative Traffic Management" between vehicle and infrastructure, to reduce the self opening gap of the development of telematics applications between car industry and infrastructure operators. COOPERS provides vehicles and drivers with real time local situation based, safety related status and infrastructure status information distributed via dedicated Infrastructure to Vehicle Communication link (I2V).

For drivers:

- traffic jam warning and guidance
- in-car display and alert of area-specific speed limits
- lane specific, selective ban of lorries
- estimated time of arrival, based on current traffic situation on the network
- car breakdown/emergency services

For network operators:

- enhanced traffic management based on floating car data
- safety related information for drivers, speed and distance proposal
- data exchange between operators for international seamless service handover
- monitoring of transport flows and information exchange for changing demands of transport

The purpose is to define, develop and test new safety related services, equipment and applications using two way communication between road infrastructure and vehicles from a traffic management perspective. COOPERS will build upon existing equipment and infrastructure as far as possible to incorporate bi-directional infrastructure-vehicle links as an open standardised wireless communication technology. The role of motorway operators in offering and retrieving safety relevant and traffic management information for specific road segments on European motorways based on infrastructure and in-vehicle data will be investigated.

Focus **Application type**	**Vehicle human**	**Infrastructure human**	**Technical**	
Safety application				
Efficiency application			x	
Infotainment application				
Application independent				
Artifact **Area of work**	**New algorithm / New technology**	**Specification**	**Realization**	**Evaluation**
Vehicle			x	x
Communication				
Infrastructure			x	x
Management			x	x

Figure 2. Filled-in template for project COOPERS

The metrics defined above were used for the classification. In order for the metrics to be representative the exploited information must exist for all 79 projects. This was true with a few

exceptions. The start time of the project DSSS was not found and *Size* was not available for all projects and, further, different size measures were specified. 13 projects had no size estimate at all, but since 66 projects had, *Size* was anyhow used (but with somewhat less credibility). For all projects having a size estimate, the number of partners was available. The results of the metrics calculations are given below.

All 79 projects are included in the table below for metric *Total scope*. The number of 'x' for each cell has been summed separately.

Europe, USA, Japan – A total of 79 projects				
Focus **Application type**	**Vehicle human**	**Infrastructure human**	**Technical**	
Safety application	6	1	34	
Efficiency application	2	1	23	
Infotainment application			3	
Application independent	1	1	28	
Artifact **Area of work**	**New algorithm / New technology**	**Specification**	**Realization**	**Evaluation**
Vehicle	9	12	42	37
Communication	6	25	37	35
Infrastructure	5	10	39	35
Management	1	8	3	12

Table 1. Total Scope Europe, USA, Japan

The results show that the following aspects are currently not in focus

- the role of humans
- infotainment
- management issues

Below is the result for Europe for the metric *Total scope per country*. Note the diversity of the projects. The counted number of 'x' in each cell has been divided by the number of projects (normalization) and multiplied by 100 (to give per cent).

Europe – A total of 60 projects				
Focus **Application type**	**Vehicle human**	**Infrastructure human**	**Technical**	
Safety application	10	2	40	
Efficiency application	3	2	32	
Infotainment application			3	
Application independent	2	2	35	
Artifact **Area of work**	**New algorithm / New technology**	**Specification**	**Realization**	**Evaluation**
Vehicle	15	20	57	50
Communication	10	28	37	35
Infrastructure	8	17	52	43
Management	2	13	5	20

Table 2. Total scope Europe

Below is the result for USA for the metric *Total scope per country*. Note that the projects are more focused than the ones in Europe but also that the number of projects is relatively small.

The counted number of 'x' in each cell has been divided by the number of projects (normalization) and multiplied by 100 (to give per cent).

USA – A total of 14 projects				
Focus **Application type**	**Vehicle human**	**Infrastructure human**	**Technical**	
Safety application			43	
Efficiency application			14	
Infotainment application			7	
Application independent			50	
Artifact **Area of work**	**New algorithm / New technology**	**Specification**	**Realization**	**Evaluation**
Vehicle			36	29
Communication		57	71	64
Infrastructure			21	29
Management				

Table 3. Total scope USA

Below is the result for Japan for the metric *Total scope per country*. Note that, like USA, the projects are more focused than the ones in Europe but also that the number of projects is small. The counted number of 'x' in each cell has been divided by the number of projects (normalization) and multiplied by 100 (to give per cent).

Japan – A total of 5 projects				
Focus **Application type**	**Vehicle human**	**Infrastructure human**	**Technical**	
Safety application			80	
Efficiency application			40	
Infotainment application				
Application independent				
Artifact **Area of work**	**New algorithm / New technology**	**Specification**	**Realization**	**Evaluation**
Vehicle			60	60
Communication			100	100
Infrastructure			100	100
Management				

Table 4. Total scope Japan

All 79 projects are included in the table below for the metric *Application type generality*. The table shows the number of projects having one 'x' in the *Application type*, the number of projects with two 'x' etc. As can be seen there is a strong focus on projects which address a single application type.

Number of 'x'	**Number of projects**
1	59
2	16
3	4

Table 5. Application type generality

All 79 projects are included in the table below for the metric *Area of work generality*. The table shows the number of projects having one 'x' in the *Area of work*, the number of projects

with two ‘x’ etc. The low value for 5 is not significant. The distribution is shown in the figure to the right. As can be seen, the outcome of a project is normally more than one artifact with an average of about 4.

Number of ‘x’	Number of projects
1	5
2	12
3	21
4	13
5	6
6	15
7	3
8	2
9	1
10	1

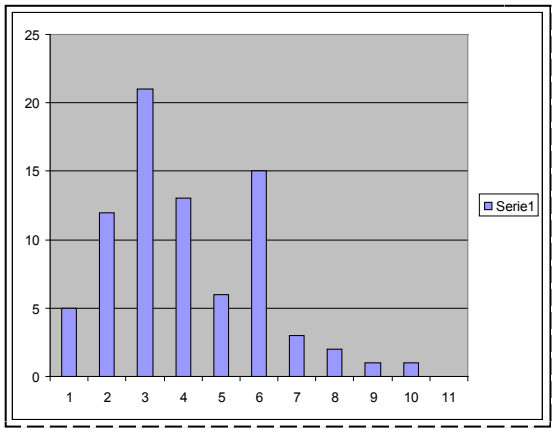

Table 6. Area of work generality

A reasonable assumption is that the more partners that are involved in a project, the higher the project’s impact and influence. The sorted list below shows the projects with the highest number of partners. Of the 79 projects, 66 were considered here since 13 projects had no size estimate at all. Note the significant gap between IVI and EAST-EAA.

Project	Number of partners	Country interest
CVIS	59	Europe
SAFESPOT	51	Europe
DAIDALOS	46	Europe
Ambient Networks	41	Europe
COOPERS	40	Europe
IVI	40	USA
EAST-EAA	24	Europe
HUMANIST	24	Europe
INVENT	24	Europe
MCP	20	Europe

Table 7. Impact

The projects could thus be divided into two groups:

- A medium-sized group having 4 – 24 partners, with an average of about 14 partners.
- A large-sized group having 40 – 59 partners. The existence of this group size might indicate the strive for consensus, especially since most projects in this group concern Europe with its many different countries.

The figure below shows the number of concurrent projects for each half year from 1989 – 2010 (however, since the start time of project DSSS is not known DSSS is not included here). One should be very careful when drawing conclusions from this figure but at least it indicates the number of initiatives (but both the extent and scope vary). The increase in the number of projects up to 2007 is significant. The peak around 2006-2007 could indicate a final maximum number of projects but it is not possible to decide for certain before the end of 2008 (or possibly even later). Thus, it is currently not possible to claim with certainty that the number of projects will decrease in the future.

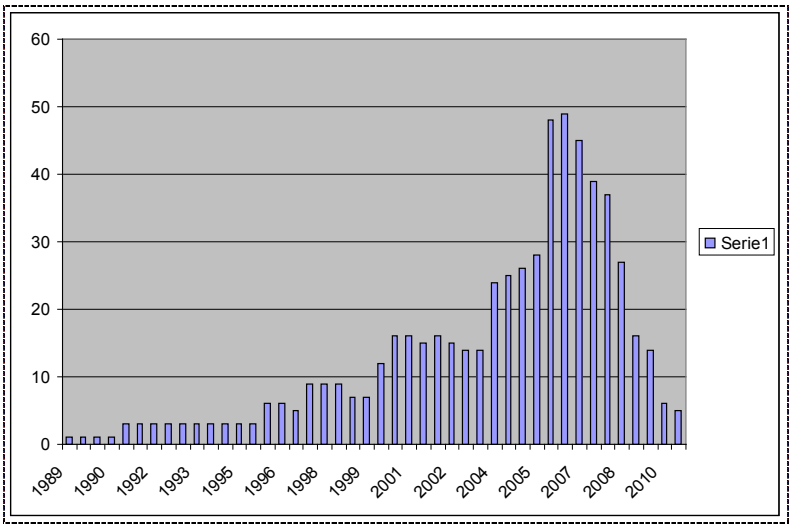

Table 8. Number of projects vs. time

COMPARISON BETWEEN EUROPE, USA AND JAPAN

A coarse comparison can be made between Europe, USA and Japan using the publicly available information on the Internet. There is a strong governmental support in USA and even more so in Japan. In Europe governmental support is indirect via the European Commission and the picture is more heterogeneous with many different countries involved. As it seems, this is reflected in

- The higher number of projects in Europe as compared to USA and Japan.
- More overlapping projects in Europe as compared to USA and Japan. Several projects seem to address the same issues.

A strong governmental support improves cost-effectiveness since the number of overlapping projects can then be minimized. In Europe, maybe the projects Coopers, Safespot and CVIS will become central projects (thus "replacing" governmental support) since all three are large projects with many important participants and addressing several complementing application areas. There is also a somewhat different prioritization:

- In Europe and USA strong focus is on safety.
- In Japan strong focus is on traffic congestion.

A generalization concerning project artifacts is:

- USA and European projects end with a demonstrator or theoretical results (e.g., a standard).
- Japan projects end with a product and deployment. Public full scale verification is common.

CONCLUSIONS

The results presented in this paper are based on the full survey in (1). The project information collected represents a state of the art survey of wireless communication, vehicle-to-vehicle and vehicle-to-infrastructure, based on publicly available information. Several prerequisites were needed in order to limit the scope of the survey while maintaining the breadth first approach. In spite of that, as many as 79 projects were still considered relevant although many more were initially considered. Despite the high number of projects, it is not possible to claim that the survey is exhaustive and care should be taken not to make too strong generalizations.

The approach of using project descriptions (i.e., project-explicit views) together with project classification metrics (i.e., project-implicit views) was found to be a suitable way of compiling a state of the art breadth-first overview, even if it was often difficult to classify a project unambiguously. For example, all projects involve specifications, in one way or another, but to judge if the specifications are the real artifacts of the project or not, is a more difficult task.

The survey is likely to cover European projects well. For USA and Japan project information is more difficult to obtain and public information is often not complete. In spite of that the much lower number of projects found for these two countries is still significant. Information about older, completed projects is sometimes difficult to find and in some cases the information was even contradictory. For future work, this survey could be extended, e.g., to include other countries and by sorting the projects with respect to influence and impact.

The full report (1) can be found at http://www.chalmers.se/safer/EN/projects/pre-crash-safety/wireless/, which also includes a list of most of the important and relevant organizations (about a hundred). The report is in pdf-format and can be used for searches, e.g., finding the projects that address the topic *platooning*.

REFERENCES

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