Performance Evaluation of Short-Range Communication Links for Road Transport & Traffic Telematics

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Abstract:

In this paper, the performance of short-range vehicle-roadside (beacon) communication systems, which support multiple RTTT (Road Traffic & Transport Telematics) services and applications, is analysed. After introducing general communication requirements of RTTT applications, a short overview about the current status of the Dedicated Short-Range Communications DSRC prENV draft standards developed within CEN TC 278 WG9 is given. Then, the concept of the performance analysis of vehicle-roadside systems based on integrated models of mobility, channel characteristics and communication protocols will be introduced. Simulation results based on an implementation of a high priority interactive service (Automatic Fee Collection) combined with an additional broadcast-oriented service (Dynamic Route Guidance) are analysed in detail (transaction failure rate, used length of the communication zone, interference between different applications, etc.) and optimal choices of system parameters such as antenna configurations are presented. The results show, that DSRC systems are able to provide multiple RTTT services using the same DSRC link to make best use of the available system capacity and to enhance the benefits for potential users.

Introduction

In order to increase the efficiency and safety of the traffic, new concepts and technologies for a future Integrated Road Transport Environment (IRTE) are currently developed and implemented in various national and international Research & Development Programmes (e.g. DRIVE II/Europe and IVHS/North America). National field trials aiming to assess the feasibility of Road Traffic & Transport Telematics (RTTT) systems are currently going on throughout Europe, e.g. in France, Italy, Germany, United Kingdom, Austria and Sweden. Both wide-range (e.g based on RDS/TMC and GSM) as well as short-range vehicle-roadside communications are investigated with regard to their capability to support various RTTT services [10].

Short-Range Vehicle-Roadside Communications

Vehicle-roadside communication systems as part of the IRTE [1] are very well suited to support a decentralized system approach, where data is distributed and collected in a local environment. They are able to provide a reliable, mobile communication link between vehicles and a roadside infrastructure in free traffic flow using low-cost on-board equipment (OBE). Due to the short communication zones, the exact position of the vehicles can be determined. Typical RTTT services, which require communication between vehicles and the roadside together with accurate localisation information, are: Automatic Fee Collection (AFC), Traveller & Traffic Information (TTI), Dynamic Route Guidance (DRG), Fleet Management (FM), Access Control (AC) and Parking Management (PM). Figure 1 shows a possible implementation scenario with installations on motorways as well as in urban environments.

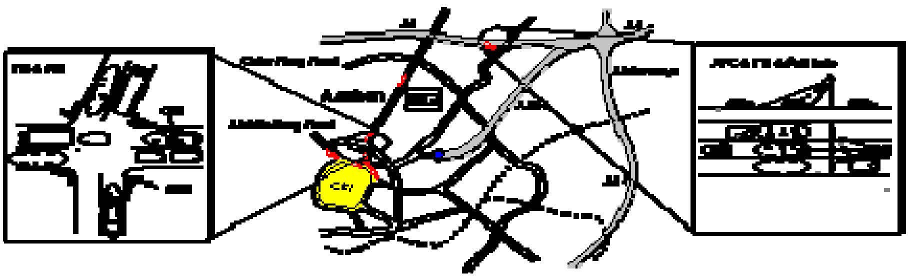


Figure 1: Possible implementation scenarios for DSRC systems

Standardisation of Dedicated Short-Range Communications (DSRC)

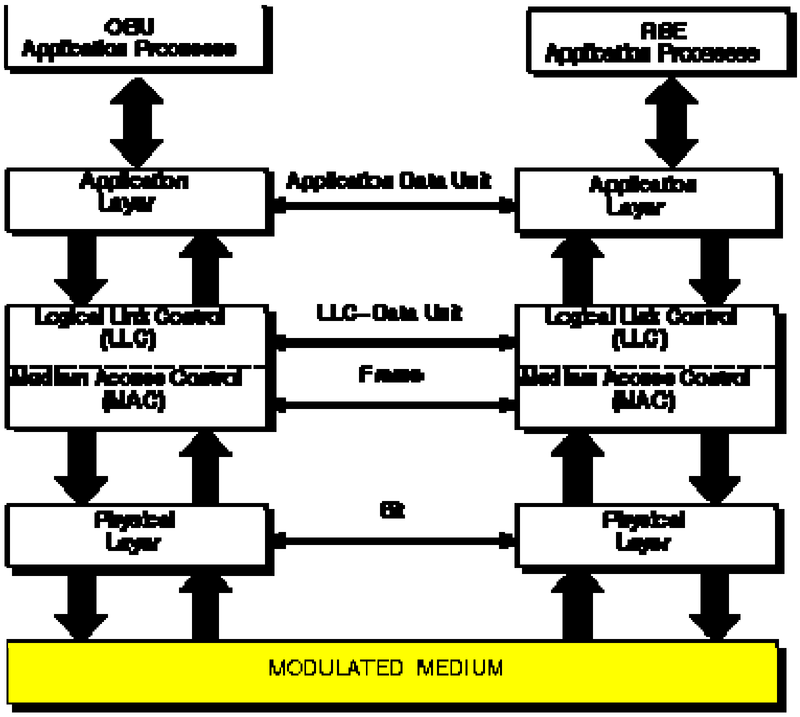


Figure 2: DSRC architecture

The standardization of application services and the corresponding communication architecture of vehicle-roadside communications (DSRC-Dedicated Short-Range Communications) is pursued in CEN TC 278 (Europe) and ISO TC 204 (International) and first draft standards are scheduled to be issued during 1995.
The DSRC architecture has been developed by CEN TC 278 WG 9 (see figure 2) according to the ISO-OSI philosophy. But due to the real-time constraints a three layer approach has been chosen. The **Physical Layer** standard proposals provide specifications for two media: 5.8 GHz and Infrared. The default downlink/uplink data rates are 500 kbit/s resp. 250 kbit/s. Lower and higher data rates can be chosen after a negotiation phase between OBE and RSE. The **Data Link Layer** [8] is built up by the Logical Link Control (LLC) and Medium Access Control (MAC) sub-layers. The LLC sub-layer has been adapted from the IEEE 8088.2 specifications for connection-less and connection-oriented services. The MAC sub-layer caters for efficient contention mechanisms to avoid and resolve data collisions in multi-lane environments. The **Application Layer** provides a service interface for the applications and specifies fragmentation, application multiplexing and a common initialisation mechanism for each communication process between OBE and the roadside equipment (RSE).
On top of this architecture, application standards are being developed by the application-oriented working groups within CEN TC 278, e.g for Automatic Fee Collection (AFC) and Traveller and Traffic Information (TTI).

Parallel support of different applications

To make the investment of an infrastructure built up by vehicle-roadside communication systems most beneficial, an optimal use of the system capacity can be achieved by offering several services at the same beacon site. Furthermore the user acceptance of newly introduced mandatory road pricing systems can be raised by combining them with additional services, which provide the driver with information about the current traffic situation and help him to find the optimal and safest route to his destination (such as Dynamic Route Guidance/Emergency Warning). An important requirement of road authorities and motorway operators is, that the reliability of a high-priority transaction should be not affected by the additional services. Therefore, in order to minimize the interference between services, appropriate priority strategies need to be introduced.

Need for performance evaluation tools

In order to determine the optimal system parameters and components of DSRC systems before the actual implementation, reliable performance evaluation methods are needed by system designers as well as system operators. Typical performance parameters are for example the transaction failure rate of the offered services, the interference between different services, the optimal control parameters for the communication protocols, the usage ratio of the communication zone and the influence of physical link characteristics (such as windscreen attenuation). During the standardization process, the comparison of the various proposed options under controlled conditions, e.g. different Medium Access Control schemes proposed in Europe and North America [11], has been enabled by the usage of appropriate performance evaluation tools. Furthermore the very low transaction failure rates specified by some applications (for example $10^{-6}$for AFC) cannot be proven by field tests only, since the number of vehicle passages will usually not be sufficient to guarantee a certain transaction failure rate. In the following, performance evaluation methods and tools will be introduced and results for typical implementation scenarios will be presented.

Performance evaluation of DSRC-systems using integrated models for mobility, channel behaviour and communication protocols

Due to the complex interdependencies, the performance evaluation of vehicle-roadside communication systems relies on the simulation of the complete systems in a realistically modelled environment. Analytical models are also used e.g. to determine optimal control parameters of the MAC protocols and to support the verification of simulation results and selection of suitable system parameters. Detailed descriptions of these analytical approaches can be found in [7, 13, 6].

Based on the object-oriented ComNets C++ Class Library (CNCL) the event-driven, stochastical simulation tool SImulation of Mobile COmmunications (SIMCO3++) for the evaluation of the DSRC (Dedicated Short-Range Communications) has been developed. The basic simulation concept integrates a microscopic traffic model, a realistic model of the communication channel and an implementation of the DSRC communication architecture (Physical, Data link and Application Layer) as well as several application processes (e.g. Automatic Fee Collection, Route Guidance) according to the developing standards.

Vehicle Generation Processes and Road Traffic Model

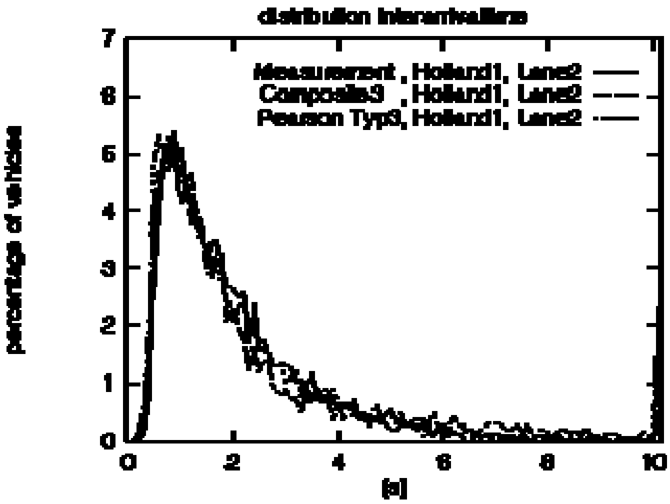


Figure 3: Headway distributions: vehicle generators vs. measurement

The traffic mobility model needs to provide realistic data about the intensity of the traffic, which determines the general traffic load for the communication protocols, as well as about the distribution of vehicle speeds (available communication time) and the distribution of inter-arrival times, which have an influence on the occurrence of multi-access interference. For vehicle-roadside communications due to the short communication zones only a short distance of a motorway is relevant for the performance evaluation. Therefore the vehicle generation process plays a key role for the traffic modelling. A number of different vehicle generation processes have been analysed and implemented (e.g. Pearson Type 3 generators). Especially for the detailed modelling of the distances of vehicles and the succession of vehicle types (which is relevant for the analysis of shadowing situations) only specific generation processes have been proven as suitable. Based on the composite model presented in [5] a generation process has been developed and implemented, which enables to generate vehicles according to given measurement data with the required accuracy.
The model distinguishes for cars and vans two types of generation processes:

- *Free-flow* mode: In this case the vehicles flow freely without restrictions due to vehicles in front of them. Therefore the headway distance between two vehicles is greater than a given threshold (usually 1.5 s). For free-flowing vehicles the head-ways are generated according to a negative exponential distribution.
- *Platoon* mode: vehicles driving in a platoon (headway below a threshold of e.g. 1.5 s) are generated according to a normal distribution.

The overall generation process switches between the different generators according to state transition probabilities determined from measurement data.

In order to validate the model, measurement data from various Dutch and German motorways have been analysed. The data produced during long-term simulations showed a very good correspondence with the measured data (see figure 3, which shows the results for the Composite generator and a Pearson Type 3 generator compared with measurement data).

Vehicle-Roadside Communications Channel Model

The channel model needs to take into account the antenna characteristics of both beacon and on-board unit, the dynamically changing influences of multi-path interference and shadowing as well as multi-access interference. The main function of the channel model is to provide data about the channel quality in terms of bit error rates. In order to keep the system simulations run-time efficient, a concept has been developed, which allows to perform the time-consuming detailed analysis of the channel characteristics (e.g. using ray-tracing techniques) to a large extent off-line before the actual system simulation.

Multi-path fading effects: In road traffic environments multi-path fading effects, which are caused by the interference of different propagation paths due to reflections from the road, the vehicle's own motor-hood or from overtaking vehicles, are encountered. Diversity techniques, such as space and polarisation diversity can reduce the effect of multi-path fading considerably, as shown e.g in [3]. To determine the signal-to-noise ratio (SNR) pattern in a given traffic situation in motorway as well as urban environments, ray-tracing techniques [9] have been adapted to 5.8 GHz. For the mobile station as well as for the neighbouring vehicles, different vehicle types are taken into account (limousine, city car, caravan, van, lorry, etc.), since characteristics such as the motor-hood length and angle as well as the windscreen angle influence the received signal strength. From the SNR patterns, the corresponding BER patterns, which will be used in the system simulation, are derived taking into account given modulation schemes. Apart from the calculated SNR/BER patterns, also data from measurements can be incorporated via specific interfaces.

Dynamic Bit Error Rates (BERs): During simulation, for each transmission of a data packet a BER depending on the current position of the vehicle can be determined. According to the type of vehicle and the specific traffic situations the SIMCO3++ channel model will chose the appropriate BER pattern. Therefore an accurate mobility modelling has to ensure, that the correct traffic situations are identified.

Shadowing effects: To calculate shadowing effects, a 3-dimensional geometrical model, taking into account the height and length of obstructing vehicles as well as the position of the vehicle's antenna, is applied.

Multi-Access Interference: Multi-access interference on the up-link is taken into account by assuming that two or more data packets, which are transmitted in the same up-link communication zone, lead to errors in both data packets (worst-case assumption).

Specification of Communication Protocols using Formal Description Techniques

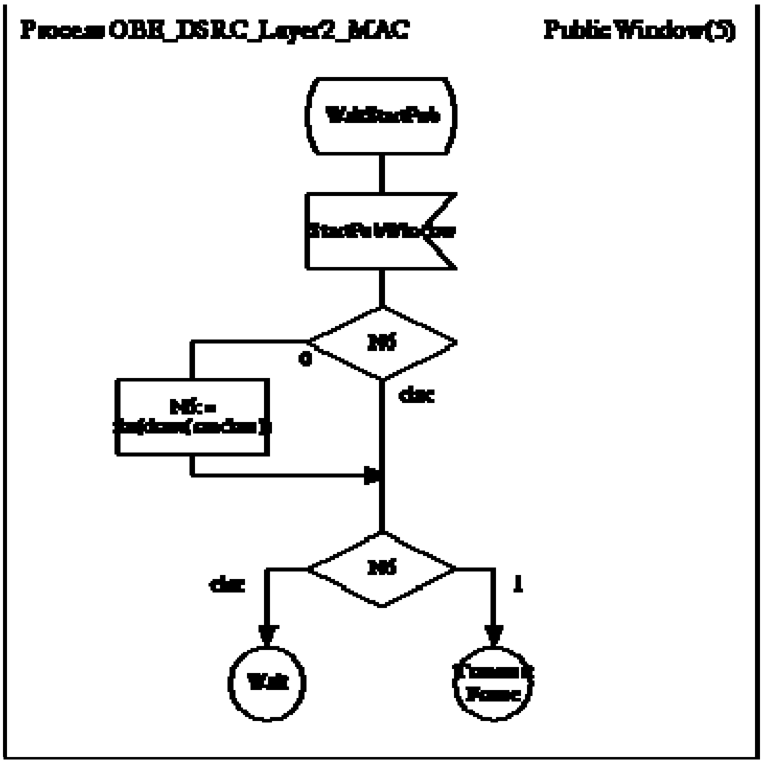


Figure 4: Excerpt from DSRC MAC Layer SDL-Specification

Standard communication protocols are often specified using formal description techniques, such as SDL (Specification and Description Language), which is recommended by the ITU/CCITT [2]. Furthermore the usage of SDL enables an hardware-independent transfer of specifications onto various platforms. The incorporation of communication protocols specified in SDL is supported by an automatic translation of SDL-specifications in CNCL-conformant C++-Code, which can be directly used for the simulations with SIMCO3++. Therefore an accurate mapping of specifications for the performance evaluation can be ensured. It is even possible to use the same SDL specifications for later implementations on the target hardware. Figure 4 shows an excerpt of the DSRC MAC Layer SDL specification, which describes a part of the contention mechanism using the Random Delay Counter (N6).

System Performance Parameters

During the simulation of a system, a number of parameters is collected and statistically evaluated, such as the beginning and end of the connection establishment and transaction phase, detailed statistics about failed transmissions due to bit errors, data collisions and shadowing. In this paper the following system performance parameters will be used. To compare the overall system performance of the different configurations, the successful completion of a transaction phase has been related to the used communication distance, which was needed for the connection and transaction phases (AFC and DRG) by using the following two parameters:

- the normalized communication distance *D* in %: ratio between the communication distance d_{used} in m, which was used by the vehicle to complete the transaction, and the available communication distance d_{avail} in m, which could have been used by the vehicle taking into account the position of the on-board equipment and the characteristics of the communication zone:

$$D = \frac{d_{used}}{d_{avail}}$$

- the non-completion rate *ncr*: ratio between the number of vehicles N_{ncompl}, which have not completed a transaction using *D*, and the number of vehicles N_{enter}, which entered the communication zone:

$$ncr = \frac{N_{ncompl}}{N_{enter}}$$

Reference System Scenarios

In the following, typical reference system scenarios for DSRC system implementations will be defined in order to demonstrate the usage of the presented performance evaluation methods.

System configurations In figure 6 the analysed system configurations are shown:

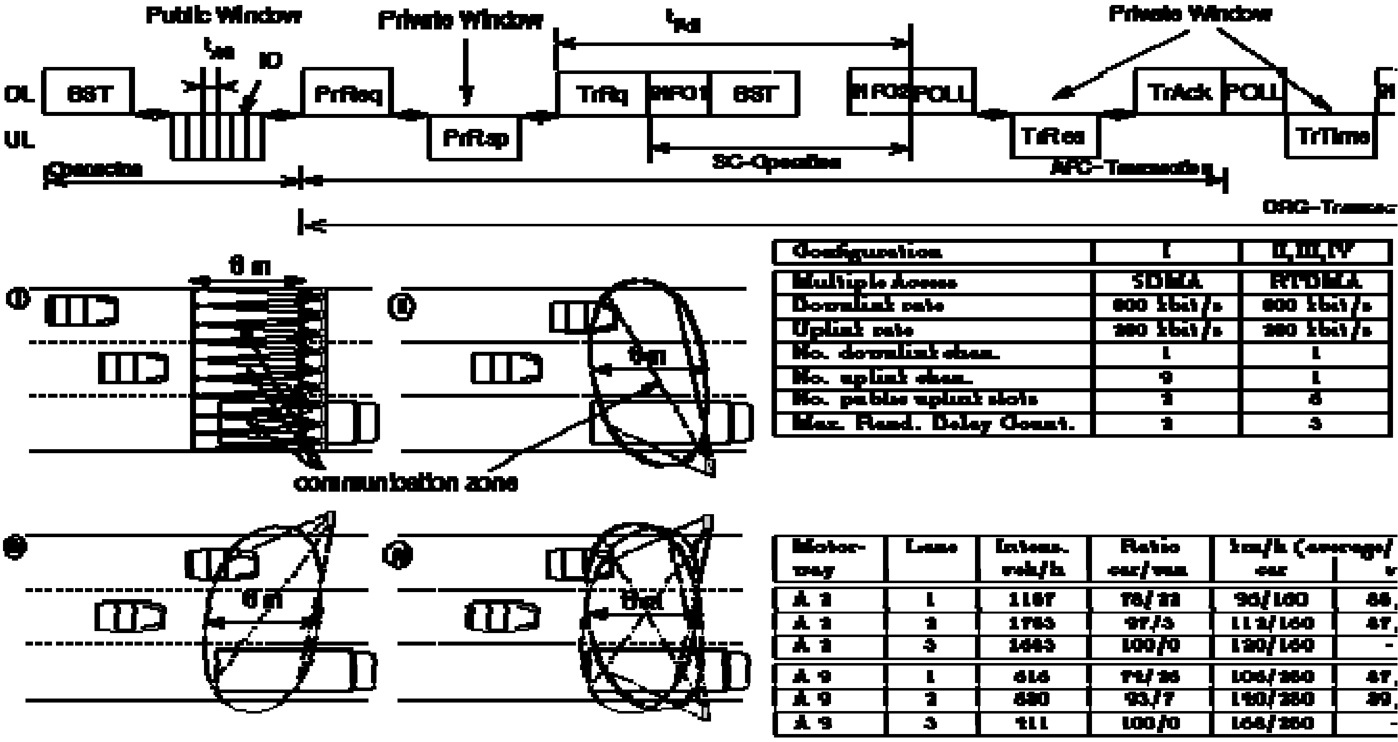
- SDMA gantry configuration with antennas providing communication zones, which practically exclude the possibility of data collisions. Furthermore parallel transmissions on the up-link are possible (see figure 6/I)
- RTDMA configurations with a single antenna positioned in 6 m height on the right and left of a motorway covering all three lanes (see figures 6/II and 6/III). A contention mechanism has to ensure, that data collisions are resolved.
- RTDMA diversity configuration with antennas positioned on both sides of the motorway (also each antenna covering all lanes) (see figure 6/IV).

Protocol Parameters: The parameters of the communication protocols have been chosen according to results from previous analysis, see for example [12, 13]. In figure 7, the parameter choices for the configurations (data rates, MAC parameters) are summarised. As an example for services with very different requirements, two services, which will be typically offered in a motorway environment, are introduced.

Interactive dialogue (AFC): In an interactive dialogue, which is initiated by the beacon, information is exchanged in two communication phases. After the information exchange in the first communication phase, there is a 'quiet' phase, during which the OBE processes information and prepares the data to be transmitted in the second communication phase. A typical service corresponding to such a communication process is Automatic Fee Collection, where electronic money is debited from a SmartCard. Figure 5 shows the implementation of an Automatic Fee Collection application process based on the medium access protocol according to CEN TC 278 WG 9 SG.L2. The time period, which is used for the debiting process (SC-Operation), depends on the used security algorithms and the SmartCard technology (a typical value is 40 ms).

Broadcast-oriented service-Dynamic Route Guidance: In a broadcast-oriented service, data is transmitted to all vehicles entering the communication zone. Sometimes it is combined with a short message sent from the OBE to the RSE. The Dynamic Route Guidance (DRG) application corresponds to this communication profile, since it needs to distribute information from regional traffic centres to the OBE in order to allow the driver to find the optimal route to his destination. To determine the traffic conditions, the regional traffic centres rely on information about the travel times of vehicles, which are therefore transmitted to the beacon (TravelTime report). In the communication process shown in figure 5 the broadcasted INFO messages and the TravelTime report from the vehicles can be identified.

Combination of different services: To analyse the interference between different services, the two services described above have been combined using a fixed priority strategy [4]. The higher priority was assigned to the interactive dialogue.



Configuration	I	II, III, IV
Multiple Access	SDMA	RTDMA
Downlink rate	500 kbit/s	500 kbit/s
Uplink rate	250 kbit/s	250 kbit/s
No. downlink chan.	1	1
No. uplink chan.	9	1
No. public uplink slots	2	6
Max. Rand. Delay Count.	2	3

Motor-way	Lane	Intens. veh/h	Ratio car/van	km/h (average/ car	v
A 1	1	1167	78/22	90/100	46,
A 1	2	1783	97/3	112/160	47,
A 1	3	1443	100/0	120/160	-
A 9	1	616	74/26	106/200	47,
A 9	2	680	93/7	140/200	39,
A 9	3	411	100/0	164/200	-

Figure 7: Scenario parameters
Figure 6: Reference system configurations
Figure 5: Typical communication process

Packet Lengths and Protocol Timers: The messages of the AFC protocol were set to the following lengths (incl. overhead): BST, PresentationRequest, TransactionRequest and TransactionResult 400 bit, PresentationResponse 500 bit, TransactionAcknowledge 240 bit, ID 80 bit. Link-Turn-Around (LTA) times and processing timers were set to 1 ms, which were added to the length of the data slots where appropriate. In order to continue the AFC-transaction after the SmartCard operation, a Poll message of 80 bit was sent after a poll time t_{poll} of 40 ms. The length of the DRG-INFO message was 12 kbit, fragmented in 10 packets, and the travel time report was 450 bit long.

Channel characteristics: In order to stress the differences of the performance with regard to the influence of shadowing effects, the length and characteristics of the communication zone differ only in the positions of the beacon antennas. The communication zone has a length of 6 m (on the ground), which is typical for 5.8 GHz transponder-based systems. The beacon antenna(s) are installed in 6 m height. The reference BER (Bit Error Rate) is set to 10^{-6} in the down-link and 10^{-6} in the up-link.

Traffic scenarios: As traffic scenario three lane motor-ways with validated traffic data were chosen (see also figure 7): from the afternoon rush hour on the A2 in the Netherlands (high intensity, medium speeds) and from a late evening period on the A9 in Germany (low intensity, high speeds). The influence of the quite different characteristics will be discussed in the next section.

Results of Performance Evaluations

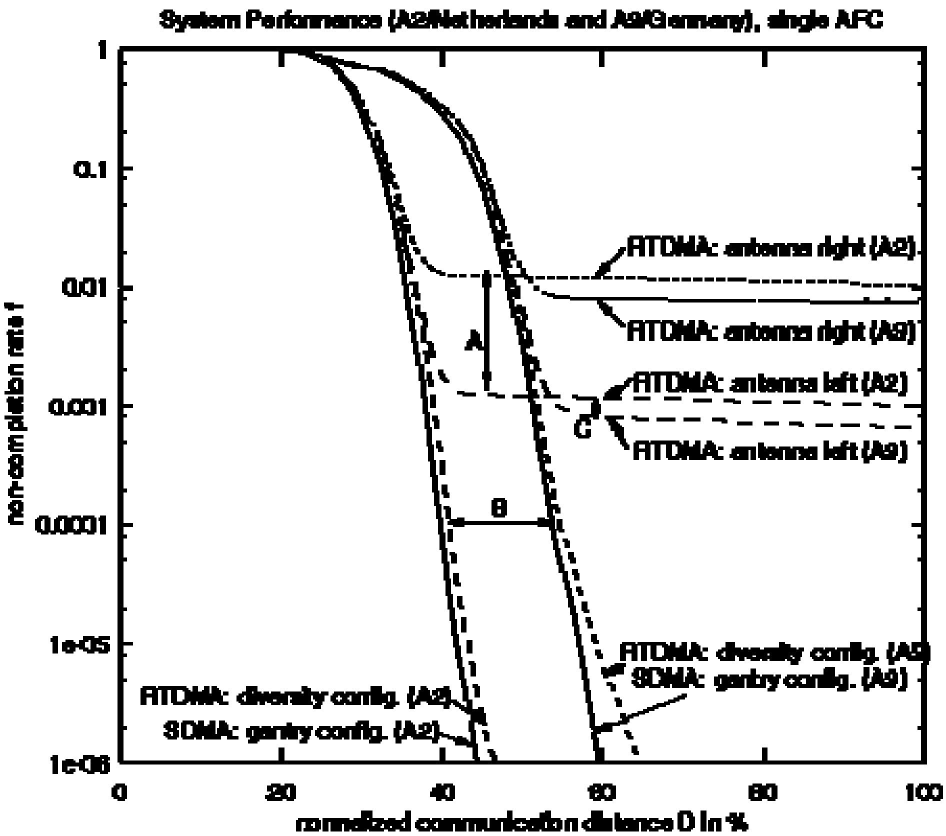


Figure 8: Interactive dialogue

Based on the scenario parameters as specified in the previous section, simulations using SIMCO3++/DSRC have been carried out to analyse the impact of antenna configurations, traffic characteristics and protocol parameters as well as the interference of different services, when combining them on the same link. In the following, the results will be discussed in detail.

In figure 8 the system performance results are shown for the single application scenario with the interactive dialogue (AFC). For the various antenna configurations the following conclusions can be drawn from the results:

Configuration I (SDMA): since there is no delay imposed by data collision resolution, this configuration achieves the best results, with 44 % max. used communication distance related to 1.000.000 vehicles. The antenna configuration furthermore ensures, that in normal traffic flow shadowing effects have practically no impact on the overall performance.

Configuration II and III (single sidepost): for both configurations a strong influence of shadowing effects can be observed, leading to transaction failure rates of 1 % (for the right sidepost) and 0.1 % (for the left sidepost). The better results for the left sidepost can be explained by the fact, that shadowing is mainly caused by high vans and lorries driving on the right lane. Therefore the impact of the shadowing is reduced, when positioning the antenna on the left lane (see label A in diagram). Nevertheless, the achieved transaction failure rates seem to be not acceptable for most RTTT applications.

Configuration IV (space diversity): By positioning sidepost antennas on both sides of the road, shadowing effects are practically excluded in normal traffic flow. But due to the need for collision avoidance (see choices for protocol parameters), more of the communication zone is needed than for the SDMA configuration (47 % instead of 44 %).

The impact of the traffic characteristics can be analysed, when comparing the results for the A2 motorway with the results for the A9 motorway.

Speeds: the influence of the higher speeds in the A9 scenario is clearly visible, leading to a max. used communication distance of 59 % (SDMA) instead of 44 % (SDMA) related to 1.000.000 vehicles (see label B in diagram 8).

Intensity: the results show also, that the lower traffic intensity in the A9 scenario leads to a reduced impact of shadowing effects for the single sidepost configurations (see label C).

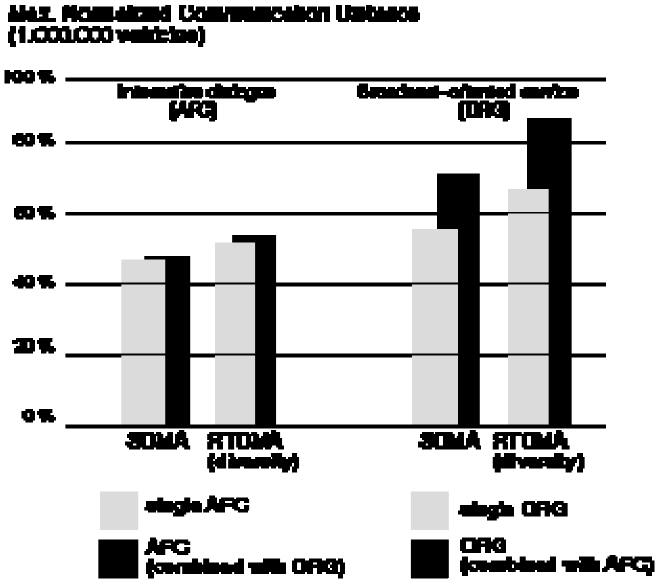


Figure 9: Interference between applications

In figure 9 the results for the single application scenarios (single AFC and single DRG) are compared with the results for the multi-application scenario (combined AFC/DRG) based on the A2 scenario:

Influence on high-priority service: the results for the interactive dialogue AFC show, that due to the applied priority strategy the impact of the additional application is kept to an amount, which should be acceptable for future system operators.

Influence on additional service: for the broadcast-oriented DRG service, the performance is reduced compared with the single application scenario. For the SDMA configuration 70 % instead of 55 % of the communication zone were used at maximum (related to 1.000.000 vehicles).

Capacity for additional services: The figure also shows, that using the RTDMA configuration less capacity is available for additional services, which require to transmit larger amounts of data. In the scenario considered here, together with each BST 6 consecutive public uplink slots were offered during the address acquisition phase to cope with data collisions efficiently, compared to only 2 public slots for the SDMA configuration. The time, which was saved in the SDMA configuration by using less public slots, is available for transaction data transmissions. Therefore the vehicles are able to complete the transaction earlier, which is demonstrated especially for the case of the broadcast-oriented service.

Conclusions

In this paper, an overview of the developing Dedicated Short-Range Communications (DSRC) standards for Road Transport & Traffic Telematics has been given. With SIMCO3++/DSRC a powerful tool for the performance evaluation of DSRC systems has been presented, which allows an integrated analysis of mobility, channel behaviour and the DSRC communication architecture. Based on typical implementation scenarios, simulation results

were presented, which showed, that on a three-lane motorway SDMA and diversity RTDMA configuration are able to provide the required system performance. Furthermore the results indicate, that a parallel usage of the same DSRC link by different services is feasible.
In future, a complete validation of the DSRC standards will be carried out in a European research project.

Acknowledgements

Prof. Dr.-Ing. B. Walke, Dr. C.-H. Rokitansky and the members of CEN TC 278 project teams (PT03 & PT07) have provided helpful discussions and important suggestions.

References

1
G. Brasche, C.-H. Rokitansky, C. Wietfeld. *Communication Architecture and Performance Analysis of Protocols for RTT Infrastructure Networks and Vehicle-Roadside Communications*. In *Vehicular Technology Conference*, Vol. 1, pp. 384-390, Stockholm, Sweden, IEEE-Vehicular Technology Society, June 1994.

2
CCITT. *Recommendation Z.100 and Z.110, Functional Specification and Description Language (SDL), Criteria for using formal description techniques (FDTs)*, blue book edition, 1988.

3
W. Detlefsen, W. Grabow, U. Kerksen, R. Schmedding. *Reliability of 5.8 GHz Short-Range Links in Vehicle-Roadside Communications*. In *Vehicle Navigation and Information Systems*, Ottawa, Canada, IEEE, October 1993.

4
L. Kleinrock. *Queuing Systems*, Vol. 2. John Wiley & Sons, 1976.

5
Adolf D. May. *Traffic Flow Fundamentals*. Prentice-Hall, Englewood Cliffs, New Jersey, 1990.

6
C.-H. Rokitansky. *Performance analysis and simulation of vehicle-beacon protocols*. In *Proc. Vehicular Technology Conference*, pp. 1056-1057, Denver, Colorado, USA, IEEE, 1992.

7
C.-H. Rokitansky, C. Wietfeld. *Markov Chain Analysis Methods and Simulation Tools for Performance Evaluation and Validation of Vehicle-Roadside Communications*. In *Personal,, Indoor and Mobile Radio Communications*, Toronto, Canada, IEEE, September 1995.

8

CEN TC 278 WG9 SG.L2. *Road Traffic and Transport Telematics - Dedicated Short-Range Communications - DSRC Data Link Layer: Medium Access and Logical Link Control*. Draft prENV 278/9/#64, CEN, European Committee for Standardisation, Central Secretariat, Brussels, March 1995.

9

B. von Ehren, H. Hussmann, C. Plenge. *Propagation channel modelling using raytracing techniques and stochastic modelling at 60 GHz*. In *Proc. RACE Mobile Telecommunications Workshop*, Amsterdam, May 1994.

10

B. Walke, C.-H. Rokitansky. *Short-Range Mobile Radio Networks for Road Transport Informatics*. In *MRC'91*, pp. 183-192, Nice, France, November 1991.

11

C. Wietfeld. *System Performance of Vehicle-Roadside Communications using Asynchronous and Synchronous MAC Protocols*. In R. Prasad, editor, *Personal, Indoor and Mobile Radio Communications PIMRC*, pp. 1399-1403, The Hague, Netherlands, IEEE, September 1994.

12

C. Wietfeld, C.-H. Rokitansky. *Performance of Vehicle-Roadside Communication Systems supporting Multiple Applications*. In *Vehicle Navigation and Informations Systems Conference*, pp.\ 133-138, Yokohama, Japan, IEEE, August 1994.

13

C. Wietfeld, C.-H. Rokitansky. *Markov Chain Analysis of Alternative Medium Access Control Protocols for Vehicle-Roadside Communications*. In *Vehicular Technology Conference*, Vol. 2, pp. 958-963, Chicago, U.S.A., IEEE, July 1995.

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Tue Apr 2 15:08:39 MET DST 1996