HISTOGRAM AND INTEGRAL BASED EVALUATION OF AN EXPERIMENTAL INTER VEHICLE COMMUNICATION TRIAL

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Abstract-We present a new approach to evaluate experimental communications system tests. Initial inter vehicle communications test trials have been performed. The equipment and the test scenarios will be presented. The common approach of a histogram based performance evaluation which considers the *message loss ratio* and the *link interrupt ratio* will be compared to a new integral based estimation method. Several test driving scenarios, including overtaking and oncoming traffic, are carried out and the results are presented in histogram form and in integral based form.

I. INTRODUCTION

Characteristics of inter vehicle communications have been described in detailed in [1,2,3,4]. Based on the theoretical work, we now perform the first experimental field trials to test technical performance of an inter vehicle communications system. Reference test scenarios have been set up [5] which enable comparisons to be made between different communications system candidates.

The major goal is to define suitable performance parameters and statistical evaluation methods which will enable a comparison to be made between different systems. We identify the weaknesses of the usual histogram based performance parameters and the motivation behind our new, integral based estimation approach.

We start with a short description of the communication system followed by the test scenarios. In the next chapter we present the performance parameters under consideration followed by first experimental test results.

II. COMMUNICATION SYSTEM

The test equipment consists of three components: The I/O device, the controller and the RF module. The I/O device is a standard 80386/25 Mhz PC which operates all test programs and stores the experimental test data.

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The controller operates the protocol. The controller board is a newly developed digital signal processor card with a DSP 56001 chip and connection to the RF module. On the controller the inter vehicle communication protocol CSAP [6,7] is implemented [8]. In CSAP the bandwidth is devided into time slots and frames, with a rate of 20 frames per second. Each frame consists of 120 slots with 520 bits per slot. The same slot in consecutive frames defines a channel.[2]

The RF-Module performs transmission and reception at 5.8 GHz, FSK modulated with a bitrate of 1.25 Mbit/s. A directional antenna with four patches is used. The main antenna directions point to the vehicles front and back while two direction point left and right hand of the vehicle. The maximum gain is 6 dB in the main directions. The antenna is mounted on the cars roof.

The CSAP protocol is TDMA based which requires a common slot synchronisation. For experimental tests a synchronisation sender is used operating at 460 MHz with FSK signals. Future systems will be based on the decentralized synchronisation scheme introduced in [9].

III. TEST SCENARIOS

Four test scenarions are selected for experiments. (a) Overtaking, (b) oncoming traffic, (c) car following and (d) car following with a shadowing car in between. Tests (a) and (b) are performed under low speed conditions (≈ 15-18 km/h) with no other traffic in the vicinity. In (c) and (d) normal

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[2]All tests have been performed with one transmitter and one receiver. Hence we tested the transmission characteristics and not the protocol performance. However CSAP behaves as expected. It holds the channel under good transmission conditions and tried to change under bad conditions.

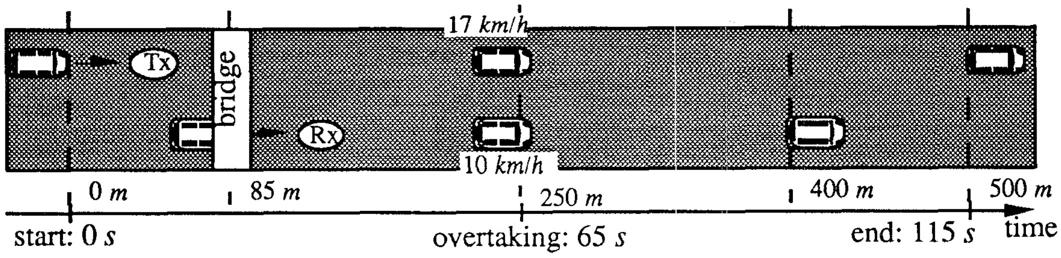

Fig. 1a: Scenario (a): overtaking with low speed and small Rx-Tx distance

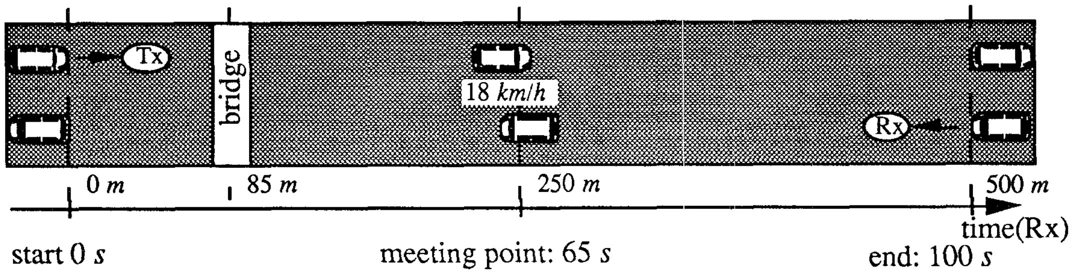

Fig. 1b: Scenario (b): oncoming traffic with low speed and large Rx-Tx distance

speed (≈ 50 km/h) and dense traffic conditions are selected. Fig. 1 shows the scenarios of the first two tests. Due to the restricted space, the results of scenarios (c) and (d) cannot be presented.

For each scenario several trials have been performed, 7 testdrives for the first and 10 for the second scenario. Based on the requirements for cooperative driving applications [1], the sender transmits one packet per frame. Packets contain a continuous numbering and a time stamp. Test durations are between 100 s and 120 s, so that statistics are based on 2000 up to 2400 transmitted packets per test.

IV Performance Parameter

A. *Histogram Based Estimation*

Cooperative driving applications performed by inter vehicle communications are based on the continuous distribution of vehicle status messages [1]-[5]. These status messages are transmitted 20 times per second. Following [5] two performance parameters can be identified, the Message Loss Ratio $MLR(\partial t)$ and the Link Interrupt Ratio $LIR(\partial t,N)$ which are defined as:

$$MLR(\partial t) := \frac{\#\ of\ incorrectly\ received\ messages\ in\ \partial t}{\#\ of\ transmitted\ messages\ in\ \partial t}$$

$$LIR(\partial t, N) := \frac{\#\ of\ link\ interrupts > N\ messages\ in\ \partial t}{\#\ of\ transmitted\ messages\ in\ \partial t}$$

After successful message reception, a link is defined as being interrupted if more than N consecutive messages are corrupted. We will concentrate on the *MLR*, although results of the *LIR* are not of minor importance.

Fig. 2 shows examples of the MLR. In the first line, the success or non success of a packet is a binary event, so ∂t coincides with the packet length. In the second line ∂t=250 ms is selected. The last line indicates ∂t-> infinity, leading to the mean value of one test drive. Selecting a suitable ∂t value to obtain sufficiently smooth estimators is a non trivial problem.

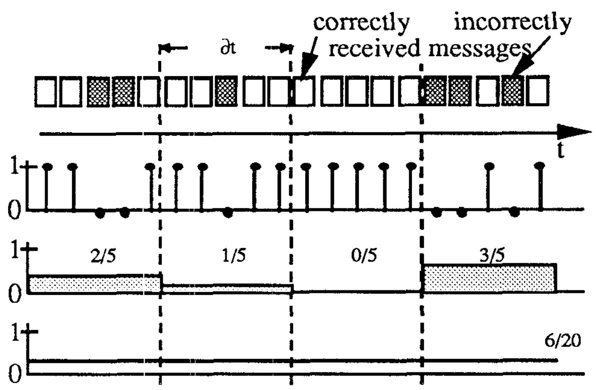

Fig. 2: Message Loss Ratio with different ∂t

If $S(t_p)$ defines the binary event "*packet correctly received*" at time t_p, and, $L(t_p)$ the event "*packet lost*" at time t_p, we may write:

$$S(\delta t_i) = \sum all\ S(t_p) \quad , \ t_p \in]\delta t_i]$$
$$L(\delta t_i) = \sum all\ L(t_p) \quad , \ t_p \in]\delta t_i]$$

for all time intervals ∂t_i. Now we can write:

$$MLR(\delta t_i) = \frac{L(\delta t_i)}{L(\delta t_i) + S(\delta t_i)} \qquad , \ i = 1,2, \dots ,n$$

where n is the number of time intervals per test. For statistical purposes each test scenario is performed several times. If m is the number of tests per scenario, the mean *MLR* becomes:

$$MLR(\delta t_i) = \frac{1}{m} \sum_{k=1}^{m} \frac{L(\delta t_i)_k}{L(\delta t_i)_k + S(\delta t_i)_k} \quad , i = 1,2, \ldots ,n$$

where $L(\partial t_i)_k$ is the number of lost packets of the *k-th* measurement in ∂t_i. The Link Interrupt Ratio can be defined similarly with

$$I(\delta t_i) = \sum all \; I(t_r) \, , \, t_r \in]\delta t_i]$$

where $I(t_r)$ defines the event "interrupted link". Hence the mean *LIR* becomes

$$LIR(\delta t_i) = \frac{1}{m} \sum_{k=1}^{m} \frac{I(\delta t_i)_k}{L(\delta t_i)_k + S(\delta t_i)_k} \quad , i = 1,2, \ldots ,n$$

B. Integral Based Estimation

The following procedure is motivated by the observation that it is difficult to give a smooth estimate of the Message Loss Ratio function $MLR(t)$ by a histogramm approach with predefined time intervalls ∂t. In general the packet arrival times at the receiving station will not be found at equidistant time points on a lattice, but will show up certain time delays depending on the individual technical equipment. Thus any fixed ∂t chosen as a basis for a histogramm based estimation will result in large variation of the corresponding relative frequencies.

In contrast, it is easy to estimate cumulated frequencies of successful packets at such instants where a successful packet is received.

We assume the following model. For each scenario there is a true -but unknown- packet success probability function $p(t)$, $0 \le t \le t_{max}$. $p(t)$ may equivalently be represented as a function of the distance d between transmitting and receiving vehicles. Since kinematic is predetermined by a certain scenario, t is easily transformed to the variable $d(t)$.

Our aim is to estimate $p(t)$ from the given data

$$\hat{f}(t_i) = \frac{S(t_i)}{L(t_i) + S(t_i)} \quad , i = 1, \ldots, n,$$

where $0 \le t_1 < t_2 < \ldots < t_{max}$ are arrival times of successful packets, $S(t_i)$ is the total number of successful packets up to time t_i, and $L(t_i)$ denotes the number of lost packets up to time t_i.

$S(t_i)$ is easily obtained by counting successful packets. $L(t_i)$ may be determined by providing transmitted packets with a consecutive numbering. If packet number m has been successfully received at time t_i, then $L(t_i)=m-S(t_i)$ is easily calculated as the total number of lost packets up to time t_i.

$\hat{f}(t_i)$ is a reasonable estimate of the cumulated packet success probability $f(t_i)$ up to time t_i, defined as:

$$f(t) = \frac{1}{t} \int_0^t p(x) dx \qquad , 0 \le t \le t_{max}.$$

$p(t)$ corresponds to $f(t)$ by $p(t)=f(t)+t \cdot f'(t)$, with $0 \le t \le t_{max}$, using the first derivative f' of f. In the following we assume that $p(t)$ belongs to the class

$$\mathcal{F} = \left\{ a_q t^q + \ldots + a_1 t + a_0 \mid a_0, \ldots, a_q \in \Re \right\} \quad , 0 \le t \le t_{max},$$

of polynomials of miximum degree $q \in N$. Then

$$f(t) = \frac{1}{t} \int_0^t p(x) dx = b_q t^q + \ldots + b_1 t + b_0,$$

say, is a member of $\mathcal{F}$ as well. We now estimate the coefficients $b_0, \ldots b_q$ from $\hat{f}(t_1), \ldots \hat{f}(t_n)$. This is done by the following least squares approach

$$\min_{b_0, \ldots, b_q \in \Re} \sum_{i=1}^{n} \left(\hat{f}(t_i) - (b_q t_i^q + \ldots + b_1 t_i + b_0) \right)^2 .$$

As is well known, the solution of this minimization problem is given by the Gauss-Markov estimator $(\hat{b}_0, \ldots, \hat{b}_q)$ in (1).

From $p(t)=f(t)+t \cdot f'(t)$ the polynomial $\hat{p}(t)$ is

$$\begin{pmatrix} \hat{b}_0 \\ \hat{b}_1 \\ \vdots \\ \hat{b}_q \end{pmatrix} = \begin{pmatrix} n & \sum t_i & \sum t_i^2 & \cdots & \sum t_i^q \\ \sum t_i & \sum t_i^2 & \sum t_i^3 & \cdots & \sum t_i^{q+1} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ \sum t_i^q & \sum t_i^{q+1} & \sum t_i^{q+2} & \cdots & \sum t_i^{2q} \end{pmatrix}^{-1} \begin{pmatrix} \sum \hat{f}(t_i) \\ \sum t_i \hat{f}(t_i) \\ \vdots \\ \sum t_i^q \hat{f}(t_i) \end{pmatrix} \quad \text{, sums ranging from } i = 1, \ldots, n \quad (1)$$

obtained as

$$\hat{p}(t) = (q+1)\hat{b}_q t^q + q\hat{b}_{q-1}t^{q-1} + \ldots + 2\hat{b}_1 t + \hat{b}_0$$
$$= \hat{a}_q t^q + \hat{a}_{q-1}t^{q-1} + \ldots + \hat{a}_1 t + \hat{a}_0$$

with $0 \le t \le t_{max}$, yielding a reasonable estimator of $p(t)$.

The above described procedure gives a smooth polynomial estimate $\hat{l}(t) = 1 - \hat{p}(t)$ of the message loss ratio. The class $\mathcal{F}$ is flexible enough to adjust models to a wide range of real scenarios. Nevertheless it is not essential to employ a polynomial class. Any class of functions

$$\Im = \left\{a_q g_q(t) + \ldots + a_0 g_0(t) \mid a_0, \ldots, a_q \in \Re\right\},\ 0 \le t \le t_{max},$$
$$g_i(t):\ [0, t_{max}] \rightarrow \Re\ ,\ i = 0, \ldots q,$$

may be used. Similar estimators are obtained following the above derivation. This gives the opportunity to incorporate cyclical or wave form behaviour of $p(t)$.

V. EXPERIMENTAL TEST RESULTS

We present test results of both scenarios, overtaking and oncoming traffic for the histogram based and the new integral based evaluation.

In Fig. 3 we show how the linearly interpolated *MLR* curves vary with different ∂t. The data is taken from the same single test drive. Obviously, it is a difficult problem to decide which ∂t is best suited for a global evaluation of the system behaviour. However, to compare results with the integral based method, $\partial t = 3s$ will be selected.

When we performed our test drives it was difficult to reproduce each drive exacty. Let us say the first test is the reference drive for the first scenario. Then each ∂t_i is related to a certain sender-receiver distance and angle. Now, the starting phase was the most critical part in each drive. This results in errors in the expected relation between sender-receiver distance and ∂t_i. To compensate for driving inaccuracies it was necessary to introduce starting time offsets between 3 s and 10 s.

Fig 4a shows the results (after offset compensation) of scenario one taken from $m=6$ test drives. We can see three maxima at 58s, 74s and 83s resulting from the antenna pattern which is not omnidirectional but directional. The maximum at the end of the test results originates from a slight curve of the test road so that antennas are not directed straightforward.

Fig 4b shows results of the second scenario with oncoming traffic. Again we see two maxima before and after 63 s which is exactly the time where the vehicles meet each other but maxima are smaller and shorter due to the higher relative speed of sender and receiver.

The thin curves in both figures indicates the highest and lowest measured values of all test drives. Deviations compared with the average value are always small.

Fig 5a and 5b shows results of the integral based evaluation compared with histogram based results taken from single tests. The advantage here is the smoothing of the strong variation in the original data, which are due to random irregularities during the test drives.

Nevertheless, the behaviour is not satisfactory. The maximum degree of the approximating polynomial should be high enough to follow the principle peaks of the data curve, which are explainable, e.g., from antenna characteristics and special scenario influences. But for degrees greater than four, numerical instabilities and the behaviour of the approximating polynomial become strange, especially at points near the boundary of the time interval. This is a well known effect of polynomial regression in design of experiments.

VI. CONCLUSION

For the historam estimators it seems to be nearly impossible to chose ∂t accordingly to a rational criteria. Integral based estimators enable this difficulty to be overcome, but they are not yet perfected.

In future work we will improve these estimators by choosing classes of orthogonal polynomials instead of monomes. This makes occuring matrices diagonal and resolves problems with bad conditioning. Other more sophisticated estimation and smoothing methode will be considered, such as kernel estimation in certain classes. Furthermore, cubic splines seem to be an appropriate method to estimate the underlying packet success probability function $p(t)$.

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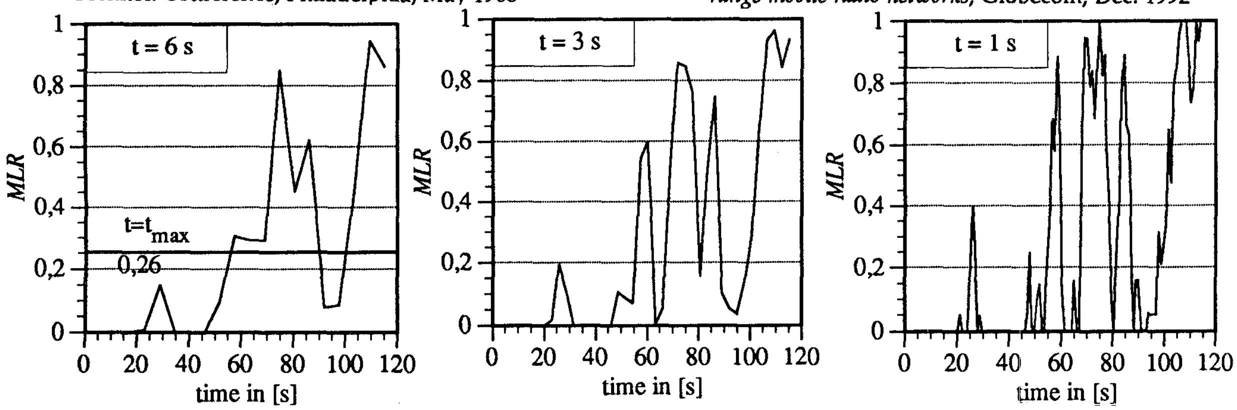

Fig. 3: MLR for different values of ∂t: 6s, 3s and 1s, taken from scenario 1, test drive #3

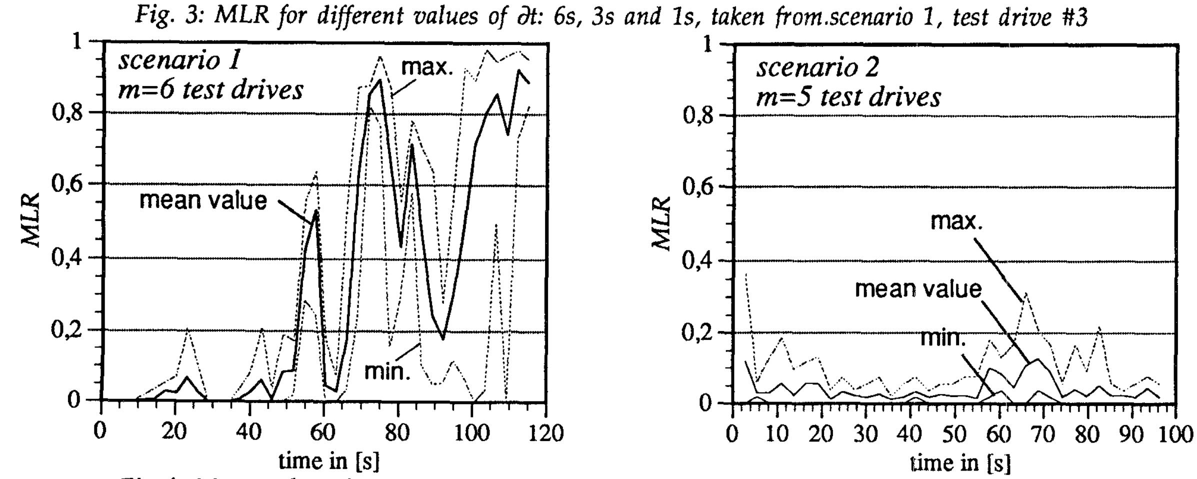

Fig 4: Mean value of MLR with maximum and minimum compensation offset considered.

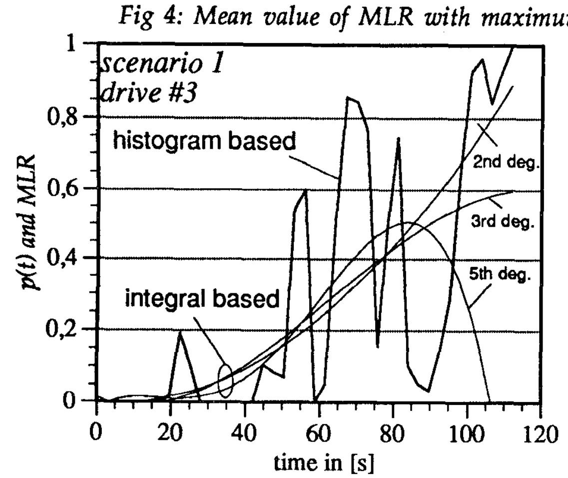

Fig 5a: Integral based results, scenario 1

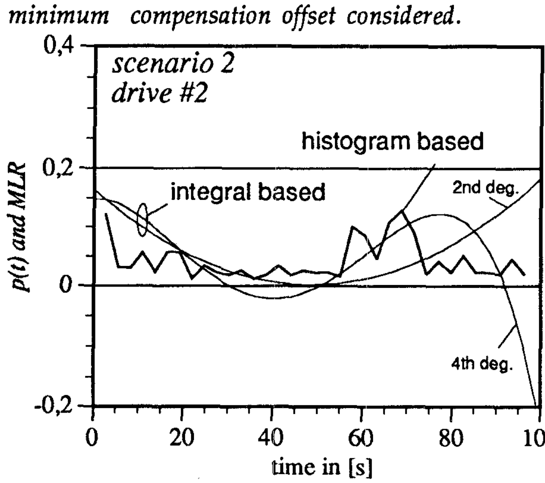

Fig 5b: Integral based results, scenario 2