Measuring and simulating an 802.3 CSM/CD LAN

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Measuring and Simulating an
802.3 CSMA/CD LAN

J. van Oorschot
A. Dekkers

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Jan van Oorschot*
Anton Dekkers**

*Delft University of Technology
P.O. Box 5031
2600 GA Delft
The Netherlands
email: JPMvOorschot@et.tudelft.nl

**Eindhoven University of Technology
P.O. Box 513
5600 MB Eindhoven
The Netherlands
email: wscoade@win.tue.nl

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Abstract

A single 802.3 CSMA/CD segment is measured resulting in throughput response times for several workloads and workstation parameters. During the measurements, the network carried an artificial workload with the characteristics of a real-life workload. A simulation of the laboratory test is developed using the artificial workload parameters and the 802.3 CSMA/CD standard of the CCITT.

The measurements showed that it is possible to determine the workstation parameters with a great accuracy using simple throughput measurements on an empty network. It is then possible to isolate exact ethernet parameters during throughput measurements on a network with a known workload. The behaviour measured is reproduced in a simple simulation. The results of the simulation conform to the measured values.

Some conclusions are that a 802.3 CSMA/CD segment can be measured and simulated with accurate results. This test environment is used to model a real-life ethernet network in circumstances that can not be measured in a real-life situation. Parameters that can be used to fine-tune the simulation are the interframe gap time, and the workstation distance on a network.

Introduction

In our research we concentrate on the performance evaluation of Local Area Networks (LANs). Our aim is to develop a set of tools in which domain our knowledge on LANs is included and which enables the troubleshooting and capacity planning of LANs. These tools will be based on analytical models, simulation models and experience based rules. The class of LANs considered here uses the well known and widely spread ethernet protocol for control over the transmission medium. On top of the ethernet protocol will be a layered architecture such as the Open System Interconnection (OSI) model from the International Organization for Standardization (ISO) [8] or Transmission Control Protocol/Internet Protocol (TCP/IP) [2].

In the literature there are many practical as well as theoretical articles on ethernet. But in most practical papers no modelling and analysis is provided and in most theoretical papers no verification of assumptions takes place. In this paper we try to fill this gap between models and measurements.

We have developed models for ethernet which describe its performance accurately. One of the performance characteristics derived from these models will be the response time of a frame. In this paper we are merely interested in developing and validating an accurate model, based on a realistic situation, than in covering the effects of variations occurring in real-life. The effect of variations in network load will be studied with aid of the simulation model and presented in a forth-coming paper.

This article deals with the broadcasting of a frame from the moment it is presented to the Medium Access Layer, the layer of the protocol stack in which the access to the medium is controlled, and followed until that frame is broadcasted successfully over the ethernet segment. The results derived for one segment will be the basis for an extension to higher protocol layers and larger networks.

The research on ethernet consists of three phases. In the first place we will measure its performance in a laboratory environment. In order to analyse the response time for one frame, throughput measurements are done on an ethernet segment with varying load and for frames of varying length. This yields for one frame of a certain length the response time as a function of the utilization of the network. The load is generated artificially, but the distributions used are obtained from measurements in a real-life ethernet network.

In the second phase the response time for one frame is also obtained by using a simulation model for ethernet based on an accurate imitation of the CCITT standard CSMA/CD 803.2 protocol implementation [1]. This representation requires a thorough understanding of the functioning of an ethernet segment. For the simulation program the workload parameters of the machines in the configuration are derived from measurements on a net with only one of these machines. The differences between the results of measurements and the results of simulations are very small, enabling the use of the simulation results as representative for the real-life situation. The reason for the use of simulation is the flexibility of simulation compared to measurements. Simulations are less time consuming, less equipment is involved and it is much easier to vary the load on the cable, for example by increasing the number of connected machines. Furthermore in a simulation everything can be "measured" whereas in reality this can only be done for a restricted class of events and with a restricted accuracy.

In this way an accurate tool is developed which can be used in the performance evaluation of ethernet based LANs. The third and most important phase, planned in the near future, will be to analyse the model used for the simulation. This should yield analytical expressions for the response time as a function of the load and frame length. An advantage of an analytical expression is that the insight in the performance of an ethernet will increase. Another advantage of an analysis over a simulation is that it yields instantaneous results and that there is no influence of a random mechanism.

In the remainder of this paper we will first give an overview of ethernet in Section "The 802.3 CSMA/CD LAN (ethernet)". In Section "Measurements" the configuration which is used for the measurements of the response times on an ethernet segment and the results derived with this configuration are described. The framework and results of the simulation of an ethernet segment are discussed in Section "Simulation". Section "Conclusions" contains some concluding remarks and suggestions for further research.

The 802.3 CSMA/CD LAN (ethernet)

The ethernet used in the measurements is a local area network conforming to the IEEE 802.3 CSMA/CD standard. This type of network is widely used as transport medium for connecting computer equipment.

The computer equipment is connected to the ethernet as symbolic depicted in Figure 1.
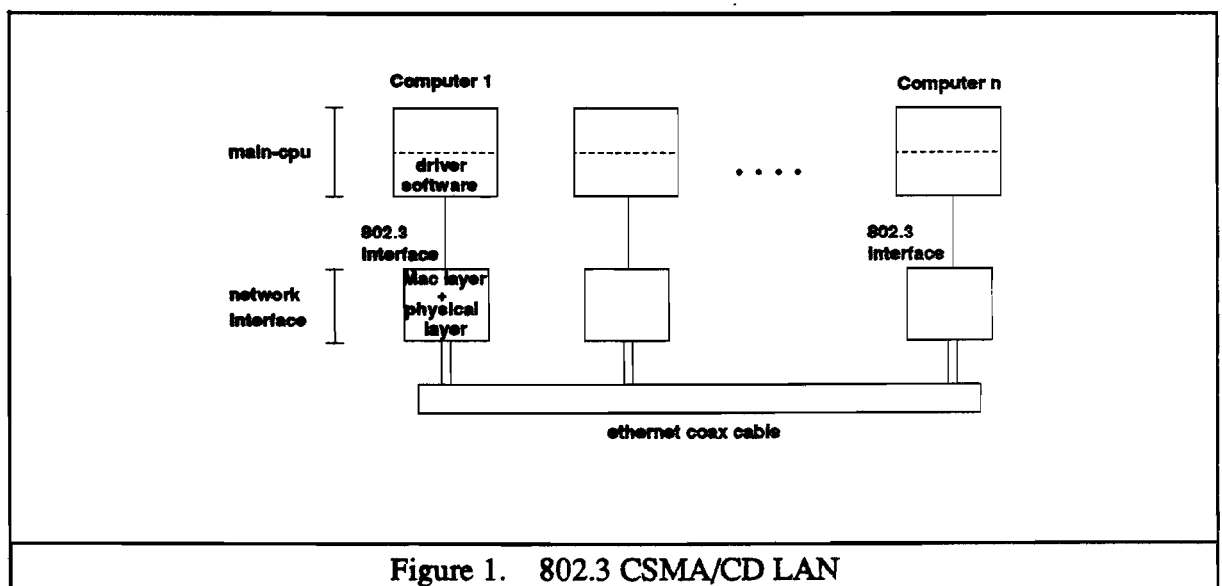

Figure 1.   802.3 CSMA/CD LAN

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The exact operation is described in the IEEE standard [1]. In the following paragraphs an incomplete description of the operation is given, that is sufficient to comprehend the principles involved and to be able to reproduce the measurements and simulations. Each computer formats the data to be sent in frames, see Figure 2.

Figure 2.   802.3 CSMA/CD frame layout
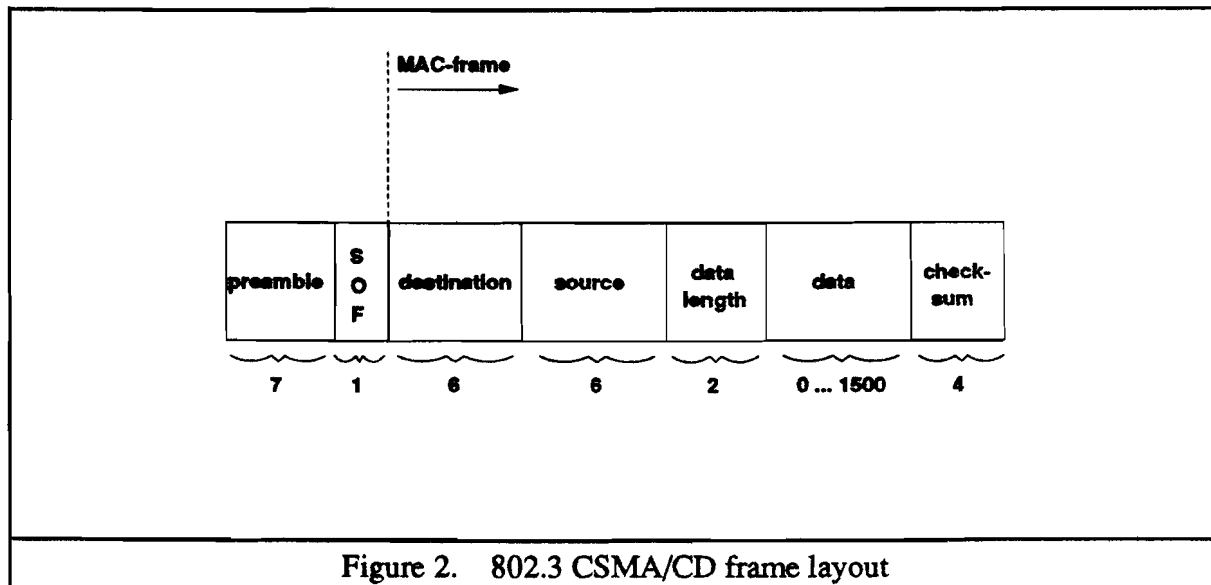
This frame is send to the 802.3 CSMA/CD interface. The interface will wait until the medium is free and then it will try to send the frame over the ethernet broadcast cable. If a collision occurs with another sending workstation, the interfaces of both computers back off for a random time before retrying. After sending a frame, the interface will defer from sending for a fixed period of time to avoid dominating the medium.

The exact parameters used for the protocol are given in [1]. Main parameters are the random back-off method, and the minimum interframe gap time. These are well defined for ethernet.

A characteristic of ethernet is that the time needed to deliver a frame is random only if waiting is included and that no upper limit to this time can be given. During periods of heavy load on the network, frames can suffer of multiple collisions and long waiting times.

Notice that the total time needed to send a frame is not only dependent on the characteristics of the 802.3 CSMA/CD network, but also on the speed of the computer generating and copying the frame. The latter aspects are not considered in this paper.

Measurements

The goal of the measurements was to determine the behaviour of the ethernet as a function of the network workload.
The behaviour is measured by letting a workstation generate a fixed number of fixed length frames. The total time to send these frames is taken as performance indicator.
This performance indicator is measured for a range of frame-lengths and different workstations.

The measuring process is described by the following algorithm.

Main-cpu	For	(a fixed number of frames of length <n>)
	{	
	(1)*	wait unit network-card is ready to transmit
	(2)*	activate network-card
	(3)*	create frame and copy to the network card
	}	

Network-card	for	(infinite)
	{	
	(a)*	wait for a frame to be send
	(b)*	wait until network is free
	(c)*	send frame
	(d)*	notify main-cpu
	}	

The main performance parameter is:

$T(n) =$ "*time needed to send one of N frames of length <n>*"

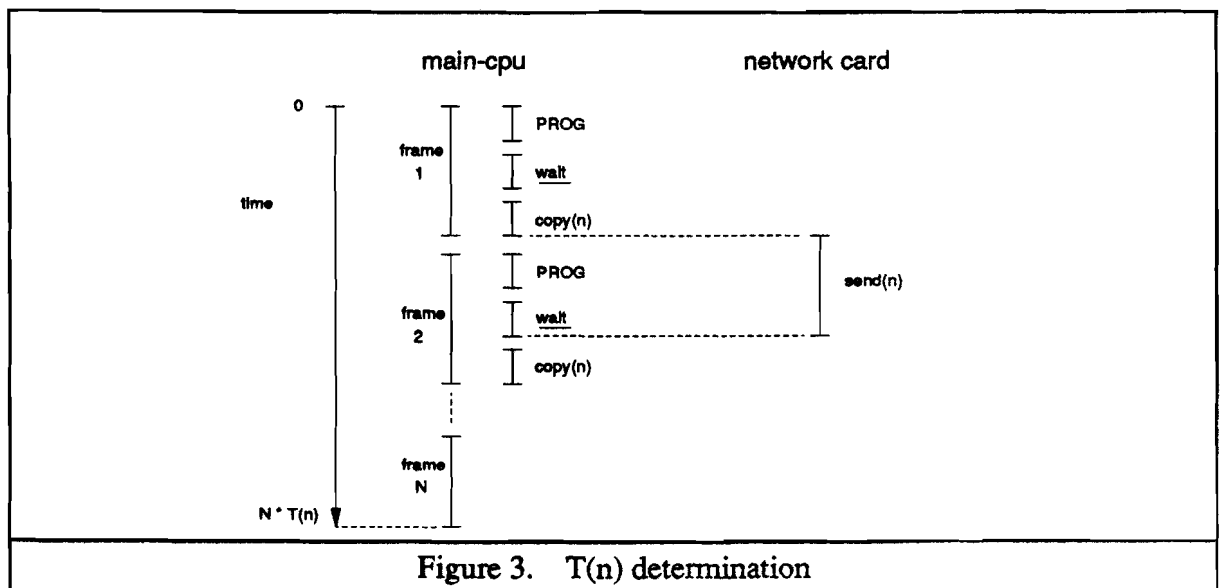This parameter can be split up in components as depicted in Figure 3.

Figure 3.   T(n) determination

The following assumptions are made:

(i)   send(n)   =   *time needed by the network card to send an <n> bytes frame*

$$S_a * n + S_b \tag{1}$$

(ii)   copy(n)   =   *time needed to send an <n> byte frame to the network card*

$$C_a * n \tag{2}$$

(iii)   wait   = *random variable describing the time between the moment a frame is ready to be send by the network-card and the moment it is actually sent*

(iv)   PROG   = *time needed by the measurement program to create a new frame*

On an empty network where wait = 0, T(n) is described by the following two formulas (discarding startup effects):

PROG > send(n) : T(n) = N * [copy(n) + PROG]
PROG < send(n) : T(n) = N * [copy(n) + send(n)]

Table 1 and Figure 4 give the results of measuring T(n) for 5 different workstations on an empty ethernet segment. The workstations used are different types of microcomputers. The "m80" is an IBM PS/2 model 80. The "m70-1" and "m70-2" are two slightly different IBM PS/2 model 70. The "m290" is an Olivetti model 90 microcomputer. The "m30" is an IBM PS/2 model 30 computer. All microcomputers were equipped with an Western Digital ethernet adapter. Table 2 gives the calculated workstation parameters.

The results show clearly the stage where the main-cpu is the bottle-neck (PROG > send(n)) and where the network interface is the bottle-neck (PROG < send(n)). Furthermore, the results show that T(n) is linear in n on both areas.
The constants in formula's (1) and (2) are calculated using the measurements results (Table 2).
The constants used in the simulation are the workstation characteristics as derived here.

Table 1. T(n) (msecs) for computer parameter determination					
n (bytes)	m80	m70-1	m70-2	m290	m30
100	0.3322	0.4939	0.4940	0.8929	1.1121
200	0.3687	0.5367	0.5388	0.9936	1.1970
300	0.4061	0.5783	0.5818	1.0957	1.2784
400	0.4995	0.6214	0.6255	1.1959	1.3636
500	0.6070	0.6703	0.6754	1.2987	1.4477
600	0.7250	0.7656	0.7719	1.4002	1.5335
700	0.8415	0.8890	0.8964	1.5014	1.6153
800	0.9601	1.0137	1.0216	1.6027	1.6983
900	1.0766	1.1371	1.1463	1.7103	1.7829
1000	1.1944	1.2616	1.2719	1.8828	1.8705
1100	1.3114	1.3849	1.3963	2.0686	1.9495
1200	1.4291	1.5094	1.5218	2.2522	2.0544
1300	1.5454	1.6326	1.6462	2.4381	2.2198
1400	1.6638	1.7571	1.7714	2.6242	2.3874
1500	1.7800	1.8802	1.8958	2.8073	2.5544

The assumption made about the linearity of the workstation activities (copy (n) and send (n)) are confirmed by the measurements (Table 1)
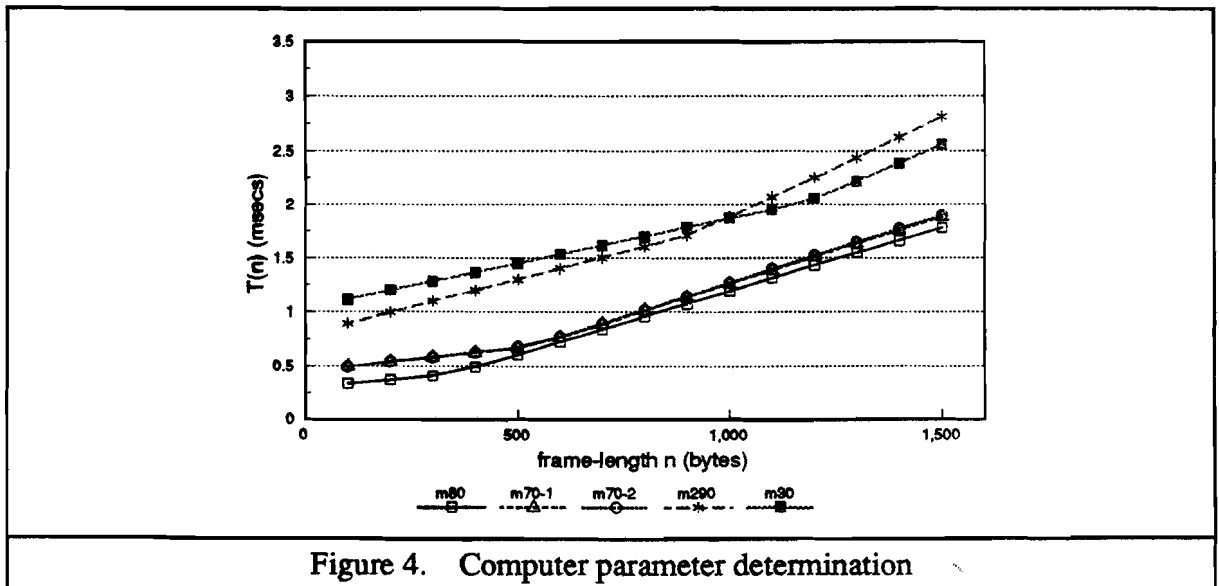
Figure 4.   Computer parameter determination

The next set of measurements involves the measurement of T(n) on a network with an artificial workload. The workload is generated with one to four load generators (workstations with special software) that generate frames with frame-lengths and interframe-times distributed as measured on the Delft University Campus network.

Table 2.   Computer parameters

	m80	m70-1	m70-2	m290	m30
PROG	0.29510	0.45155	0.45065	0.78966	1.02817
Ca	0.00037	0.00042	0.00044	0.00102	0.00084
Sa	0.00080	0.00081	0.00081	0.00083	0.00083
Sb	0.02059	0.02221	0.02216	0.03386	0.05274

Each load generator uses the same software as the measuring workstation, only with random time between frames and varying the frame length. The interframe gap time and frame lengths are drawn from bucket distributions given in Figure 6. These distributions are derived from the campus ethernet of the Delft University of Technology.

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Figure 5. Measurement configuration

Figure 6. Frame-length and gaptime distributions
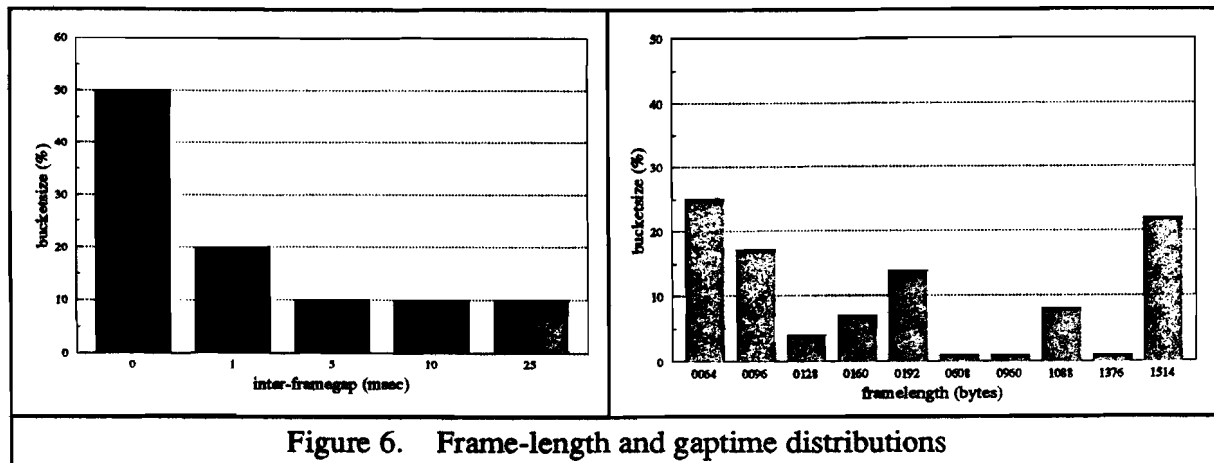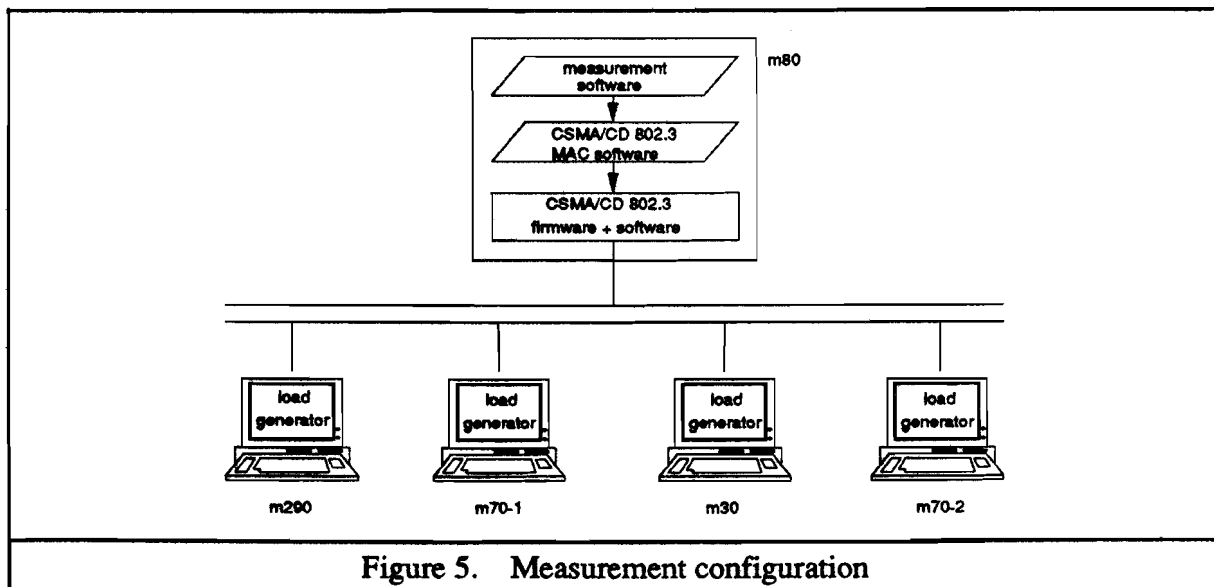
This results in each load generator generating an average of 125 Kbytes/s (average gap 4.2 msec., average length 525 bytes).

The results of the measurements are given in Table 3 and Figure 7.

It should be noted that the generation of a realistic workload can not be done with one or two load generators, because of the lack of collisions.

n (bytes)	0 gen's	1 gen	2 gen's	3 gen's	4 gen's
100	0.3321	0.3530	0.3764	0.4322	0.5857
200	0.3685	0.3940	0.4247	0.4903	0.6591
300	0.4095	0.4388	0.4861	0.5749	0.7170
400	0.4895	0.5289	0.6011	0.6782	0.8321
500	0.6067	0.6547	0.7325	0.8582	1.0985
600	0.7246	0.7827	0.8708	1.0184	1.2097
700	0.8413	0.9076	0.9940	1.1473	1.3695
800	0.9506	1.0390	1.1294	1.2907	1.5400
900	1.0762	1.1537	1.2598	1.4248	1.7611
1000	1.1939	1.2870	1.3834	1.5862	1.9050
1100	1.3109	1.3927	1.5195	1.7386	2.0061
1200	1.4286	1.5196	1.6603	1.8873	2.0761
1300	1.5449	1.6521	1.7855	1.9711	2.2482
1400	1.6632	1.7866	1.9227	2.1185	2.4396
1500	1.7794	1.8722	2.0314	2.2106	2.6869

Table 3. T(n) measurements (msecs)

Figure 7.   T(n) measurements
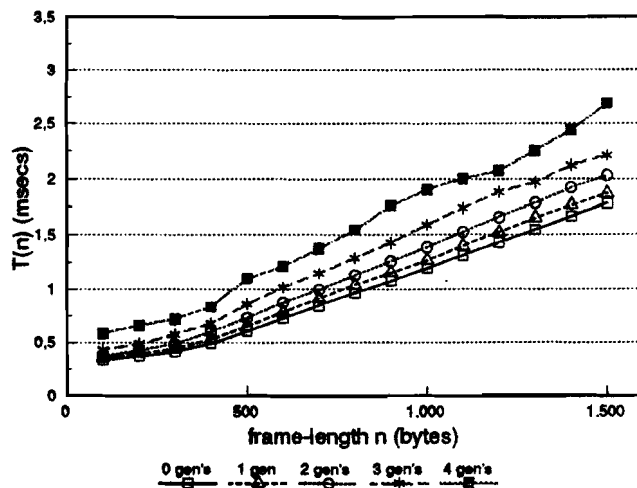
Simulation

In this section we will describe the simulation of an ethernet segment with several hosts using this segment as its broadcast medium. Aim of the simulation is to provide a tool in which it is possible to extend the configuration in a lab to a larger scale. The advantage of the simulation tool is that less equipment is involved and that the results are still very accurate.

The simulation program is developed in a UNIX-environment and is written in standard C. It consists of a small set of functions, all especially written for this application. The design of the simulation is event-driven, i.e. after each event the configuration and administration are updated, followed by the determination of the next event that will happen in the system.

In the simulation the reality is imitated as close as possible. The IEEE Standard on CSMA/CD [1] is used as a guide-line. The collision handling is implemented exactly as given in the standard [1], including the interframe gap (9.6 microsec), jam size (32 bits) and slot time (512 bit times). The backoff mechanism in the simulation is the truncated binary exponential backoff algorithm with a backoff limit of 10 and an attempt limit of 16, i.e. the backoff time after a collision is a random integer multiple of the slot time, where the integer is chosen uniformly from the interval $[0, 2^k]$. In this expression k is the minimum of 10 and the number of previous attempts. A station cannot send a second frame until the first one is broadcasted successfully or failed 16 times to gain control over the medium. A frame that failed 16 times is discarded and the protocol layer above will be notified of this failure to broadcast.

The distribution for frame lengths and interarrival times between frames on one machine are defined by the same bucket mechanism as in the measurements.

In our simulation we will consider the same stages of the broadcasting process for a frame as are considered in the measurements. Thus our observations start at the moment a frame is presented to the MAC-layer and end when a frame is broadcasted successfully or discarded.

The workstation parameters used in the simulation are those already presented in Table 2. The functions describing Main-CPU and Network-card are implemented as independently.

The simulation of a network without other load is a reference point for the parameter setting. Once these parameters are known we can simulate the same configuration as measured. The results can be found in Table 4 and Figure 8.

| Table 4. T(n) simulation (msecs)					
n (bytes)	0 gen's	1 gen	2 gen's	3 gen's	4 gen's
100	0.3320	0.3506	0.3805	0.4193	0.5018
200	0.3689	0.3940	0.4355	0.4900	0.5654
300	0.4057	0.4370	0.4768	0.5475	0.6466
400	0.4881	0.5273	0.5850	0.6554	0.7622
500	0.6050	0.6546	0.7204	0.8089	0.9622
600	0.7218	0.7797	0.8566	0.9604	1.1189
700	0.8388	0.9022	0.9684	1.1282	1.3250
800	0.9557	1.0275	1.1202	1.2582	1.4827
900	1.0725	1.1452	1.2473	1.3998	1.6820
1000	1.1894	1.2636	1.3791	1.5349	1.8424
1100	1.3063	1.3924	1.5095	1.6799	1.9714
1200	1.4230	1.5107	1.6300	1.8338	2.1527
1300	1.5400	1.6288	1.7695	1.9839	2.2874
1400	1.6571	1.7536	1.8811	2.1007	2.4556
1500	1.7741	1.8676	2.0061	2.2397	2.6353

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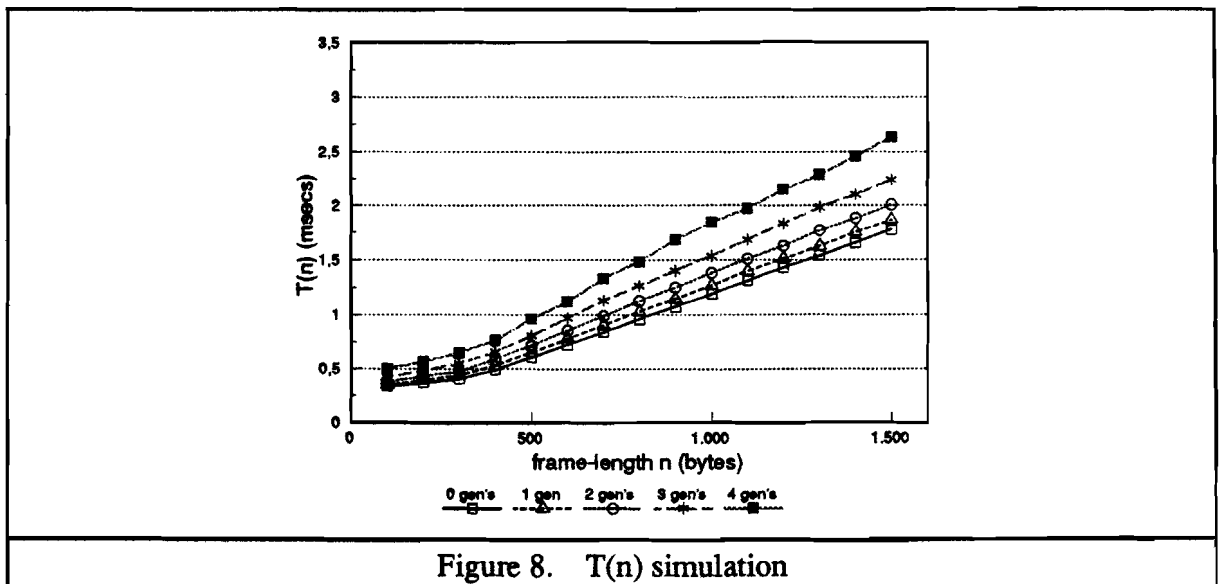
Figure 8.   T(n) simulation

From Figure 9 one can see that the simulations yield almost the same results as the measurements. The differences can almost totally be explained by the random behaviour of the load generators.

An important question is the validity of these results for other configurations and distributions with the same overall load on the ethernet segment. Several cases with more machines or different distributions for the frame length and/or for the inter arrival times (e.g. batch arrivals, Poisson gaps) were simulated. In all these cases the differences with the original configuration with an equal load were at most a few percent. Therefore we may conclude that the ethernet protocol is rather insensitive for the distribution of the input data given a certain utilization of the net. The response times on an ethernet can be represented as a function of the load. In a forthcoming paper we will discuss these variations in more detail.

Another interesting result of a simulation study is the maximum fraction of the time a segment can be used efficiently. This is more than 95% of the time with a large number of machines, the rest of the time is lost due to interframe gaps and collisions occupying the net.

The simulation will be very helpful in the modeling and analysis phase. For modeling it is important that assumptions do not violate the reality of an ethernet segment. With a simulation it is easy to check whether an assumption will yield acceptable results or not, by implementing this assumption and executing the adapted program.

A further advantage of a simulation is that it is possible to administrate every detail required. In a real system only a restricted small set measurements of a certain type can be done, while in a simulation no (such) restrictions exist.
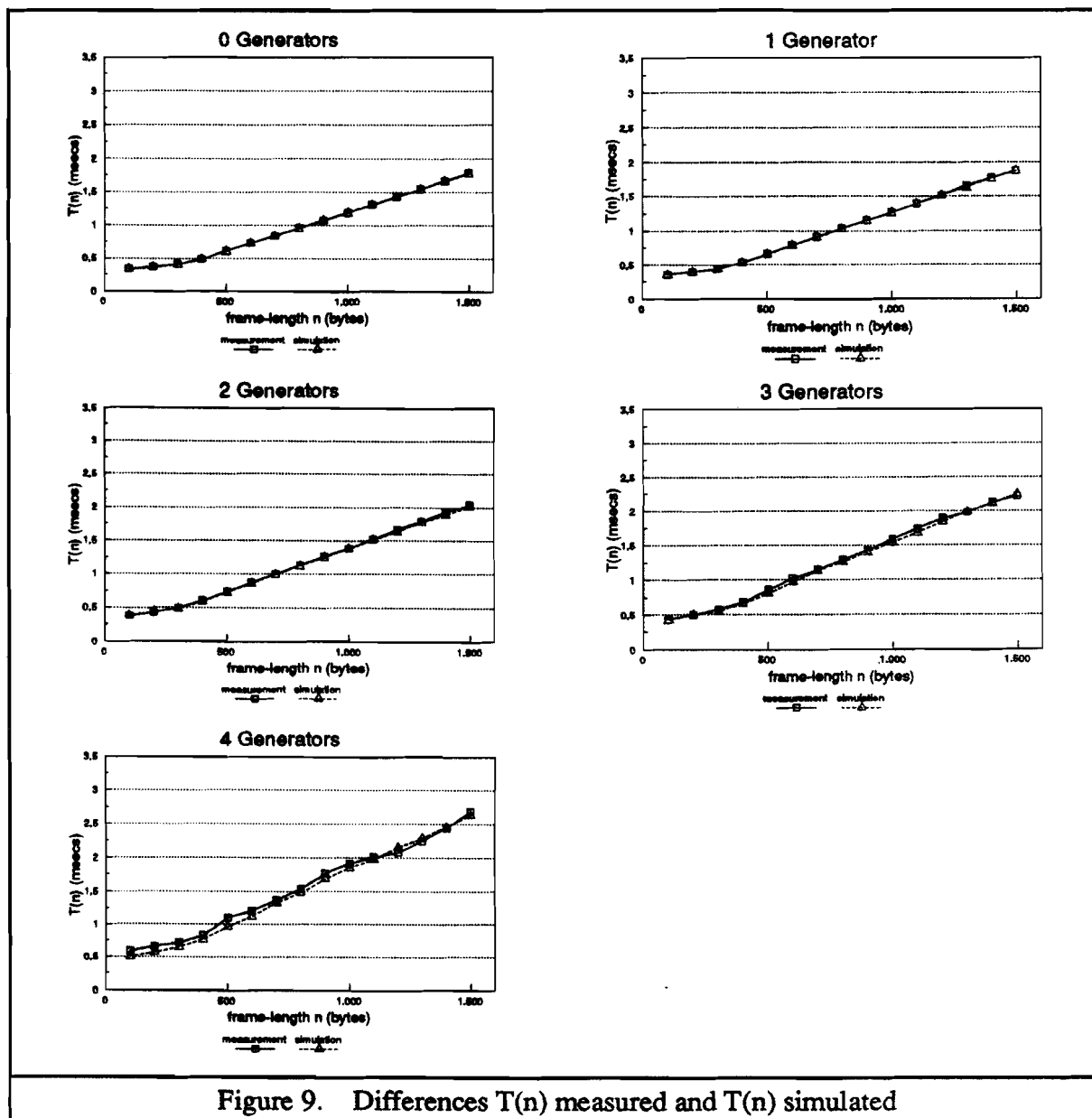
Figure 9.   Differences T(n) measured and T(n) simulated

Conclusions

In this paper we have discussed the performance of an ethernet segment with the IEEE 802.3 CSMA/CD protocol. We have used two techniques in our study: measurements on a real ethernet in a laboratory environment and a detailed simulation of the standard protocol for it. We have concentrated on throughput measurements, i.e. we observed a system in which one station tried to transmit a large number of frames as quickly as possible. This was done for various workloads, generated by a different number of machines.

The results for the simulation of the standard protocol are very close to the measurements in a real ethernet. The small differences are due to the randomness of measurements and simulations.

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A second observation might be that the load in the net is a factor of importance to the response time of a message, for the waiting time is a substantial part of the transmission time. The distribution of inter-arrival time of frames is of little influence on the throughput times.

We assume that a realistic ethernet workload can be generated using four workstations as workload generators. This is one of the items which will also be studied in our forthcoming research.

The research presented here is a basis for new research in two directions. One direction is using these results for a mathematical analysis of the performance model of an ethernet segment. The other direction is to use these results as a start for equivalent research on higher protocol layers and/or an extension from one segment to more than one by using bridges or gateways.

Acknowledgements

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EINDHOVEN UNIVERSITY OF TECHNOLOGY
Department of Mathematics and Computing Science
PROBABILITY THEORY, STATISTICS, OPERATIONS RESEARCH AND SYSTEMS THEORY
P.O. Box 513
5600 MB Eindhoven - The Netherlands

Secretariate: Dommelbuilding 0.03

Telephone: 040 - 47 3130

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M 90-02	January	D.A. Overdijk	Meetkundige aspecten van de productie van kroonwielen
M 90-03	February	I.J.B.F. Adan J. Wessels W.H.M. Zijm	Analysis of the assymmetric shortest queue problem Part II: Numerical analysis
M 90-04	March	P. van der Laan L.R. Verdooren	Statistical selection procedures for selecting the best variety
M 90-05	March	W.H.M. Zijm E.H.L.B. Nelissen	Scheduling a flexible machining centre
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M 90-19	July	I.J.B.F. Adan J. Wessels W.H.M. Zijm	Analysis of the symmetric shortest queue problem
M 90-20	July	I.J.B.F. Adan J. Wessels W.H.M. Zijm	Analysis of the asymmetric shortest queue problem with threshold jockeying
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M 90-26	July	J. van Oorschot A. Dekkers	Measuring and Simulating an 802.3 CSMA/CD LAN