IEEE 802.11
Wireless Access Method and Physical Layer Specifications

Title: Wireless Network Performance Modeling Approach

Presented by:

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Abstract: This paper discusses the Network Performance Simulation and modeling effort that is being used to evaluate MAC protocol alternatives for a Wireless Network. The simulation methodology and the modeling of several physical effects are described in detail.

Summary:

Simulation will become very important to analyze performance aspects for access protocols in a complex environment like Radio Lan's. It is important that the relevant Radio medium characteristics are modeled such that their major impact on the performance and operational robustness are factored in.

This document describes a simulator that has been designed to analyze the CSMA/CA protocol used by the WAVELAN product, and is being used to evaluate MAC protocol alternatives. In particular the mutual network interference and reuse characteristics of the medium are important effects that need realistic modeling of the Physical environment. In addition different traffic models can have a large effect on the performance, as was already explained in Doc. IEEE P802.11-91/125. The simulator uses as input the actual locations of stations in two networks. The relative location of both networks can be varied. The model uses individual signal path attenuation values between all stations, to evaluate interference conditions and capture effects at the receiver locations.

Introduction

Media Access protocols can be analytically analyzed for key network characteristics like throughput and response times as function of the offered load, and efficiency of the access protocol as function of the number of stations. The problem becomes more complex when multiple networks possibly of different types are interconnected using different kind of resources. To analyze such networks for possible performance bottlenecks network simulation is usually needed.
Wireless networks especially Radio Lan's are also more complex because there are a lot more parameters that influence the performance of such a network, due to the nature of the medium. There are such things like network topology, station location, capture effect, mutual network interference, medium sharing and interference by other sources like for instance microwave ovens, that together with the particular access protocol will determine the performance.
To analyze and parameterize Wireless MAC Protocol alternatives, network performance simulations are essential.

Which characteristics need to be modeled

The basic need for simulations are caused by the diverse characteristics of the PHY. Not only the fact that there is only one medium which need to be shared by multiple networks, especially when there is only one band available. Also the extreme dynamic range of both wanted and interference signals and effects like fading, will effect the performance of individual stations.

The relevant PHY characteristics that are candidates for modeling are:

- Signal path attenuation as function of distance
- Effect of attenuation boundaries like walls and ceilings
- Fading / Shadowing
- Capture effect
- Co-channel interference
- Adjacent channel interference
- Microwave oven interference (jammer)

In addition there are also other factors that determine the behavior of a network like:

- Network Topology (location of the Server)
- Network Operating System
- Type of traffic (R, W, RW)
- Peer-to-peer versus Client-Server traffic
- Traffic load
- Media Access Protocol

A third class of effects are especially related to mobile environments:

- Station velocity
- Roaming / handoff protocol effects

It has become clear that a Wireless MAC protocol must be very robust for lost packets which are caused mainly by interference and possible Medium Access Collisions. Therefore it will be very essential to use performance simulations which include the different PHY effects, to make the necessary trade-offs during the Wireless MAC protocol development.
Experience shows that simulations are essential, especially for the analyses of mutual network interference effects.
A simulation model has been constructed that models the above mentioned PHY characteristics, while different traffic types are modeled for both peer-to-peer and Client-Server traffic in a Novell environment.

The approach

The CSMA/CA protocol of WAVELAN was modeled in an absolute model with traffic generation according to the high load Perform3 test environment of Novell.
The objective was that mutual interference effects between co-located networks were simulated as realisticly as possible.
The first thing needed was a concurrent processing environment, to allow a large number of more or less independent stations and associated server stations, in multiple networks to run in parallel. For this purpose an event driven multiprocessing kernel was developed. On top of that several processes are running which are related according to fig-1. The model allows two networks consisting of a number of stations and a server to run in parallel. The handshaking between the station and server processes are according to the Novell Network Core Protocol (NCP).

The following different processes are modeled:

- Workstation transmitter and traffic generator using CSMA/CA
- Server transmitter using CSMA/CA
- Server process with an input and output packet Queue
- Microwave interference generator
- Medium manager which is part of the event driven simulation engine
- Event scheduler to allow concurrent operation

Model Characteristics

The following is a general description of the features and characteristics of the model.

- Single Network mode: 1 Server and up to 15 WS's (workstations)
  Dual Network mode: 2 Networks with 1 Server and up to 7 WS's each.
  Larger populations are possible but less practicle especially for high load environments.

- Allows entry of Workstation and Server location coordinates for one Network.

- Second network has the same topology but the distance between the two networks can be varied in any direction.

- In addition to the attenuation as function of the distance, an extra attenuation offset can be specified between the two networks. This means that the effect of a wall or operation of the two networks on a different floor can be included in the simulation.

- Currently two Traffic Model versions are supported:

  . "Peer to peer" traffic heavy load performance: "IPXLoad".
    Note: Server is not active, and destination is random.
  . Client - Server traffic heavy load performance: "Perform3".

- Three different traffic modes are supported for the Client - Server model:
  . Continuous Read
  . Continuous Write
  . Random Read / Write

- Carrier Sensing (Good Signal detection) based on Path attenuation between any station, and depends on selected attenuation coefficient.

- Capturing effect Included. Access collisions can cause:

    - Both packets lost when separation between the two signals at the receiver < SIR (Signal Interference Ratio).
    - One packet lost when separation > SIR, while the other packet separation < SIR.
    - No packets lost when destination addresses are different and both meet separation > SIR condition.

- Co-channel Interference calculated based on Path attenuation and SIR separation requirement.

- A Normal Distribution "Fading Margin" uncertainty can be specified and will be applied for all Path attenuations calculations. This means that path attenuation is different for every packet.

- Apart from the errors occuring on the PHY, a uniform distribution error probability can be specified for packet transmissions, and is applied independent of path attenuation.

- A Micro Wave oven interferer (jammer) can be specified, which uses a programmable on-off duty cycle at a programmable level.

- A Adjacent Channel environment can be selected that allows both networks to use different frequency bands with the isolation between the channels controlled by a parameter. Note that stations do not defer when in-band signal level caused by the other band is above the carrier detect threshold.

- Server and Workstation processing delay can be specified separately, so that traffic load can be controlled. The packet generation delay is the sum of a given fixed delay and a random delay. All packets are generated independently. The packet arrival process on the medium will therefore constitute a Poisson distribution.

- All CSMA/CA parameters and PHY parameters like transmit level and Carrier Sense level can be controlled.

- "Novell retry timeout" currently limited up to 320 msec, to allow event scheduler to work in fixed point.

- All kind of tallies are maintained that monitor the packet transmission conditions and reason of packet loss. This is done separately for the link to and from the Server.

- The average MSDU delay is calculated for the individual station.

- Performance measured in KBytes/sec actual data throughput excluding Novell overhead in the Perform3 test.

- Peer to peer performance measured including overhead, and without NCP handshaking. Traffic destinations are random.

- Very high performance Simulator is "Event driven" and runs about 10 sec per one second simulation on a PC486/33 MHz for 2 fully loaded networks. Event resolution used is 10 µsec.

- Produces two different output files:

  - Detailed report showing performance and lost packet statistics of individual Stations separated in "To the Server" and "From the Server" directions in each network.
  - Summary report showing throughput and Collision probability per network as a function of an iteration parameter like "Distance between Networks".

The Simulation Engine

The Simulation Engine is an event driven machine, which will fire off different processes based on events on an event calendar, which are scheduled by the different processes defined in the machine as illustrated in the blockdiagram of fig-1.
Two Networks can be specified with each consisting of N workstations and one Server (only active in Perform3 test). Packets generated by the Workstations Tx processes are put into a Server Rx-Queue per network. A separate Server process per network will fetch the packet from the Rx-Queue, process it for a specified fixed + random Server Processing time and puts a response packet in the Server Tx-Queue.
The Server Tx process per network will fetch its Packets from the Tx-Queue and transmits it on the Medium.
When a process is activated by the process scheduler, it performs the operation relevant for that

state of the process. It will schedule the next state of the process, after a delay time that is put on the event calendar for that process.
The Scheduler decrements all events on the event calendar and activates the three different processes when appropriate. This is done on a sampling time interval of 10 μsec. So all events are scheduled in units of 10 μsec each. A higher resolution can be selected by changing one parameter, at the expense of lower simulator performance. But in the 2 Mbps system under test, 10 μsec seems a good tradeoff between accuracy and simulation speed.

A separate Medium Manager updates the medium busy status per network on a sample interval bases, and maintains a Medium Busy length counter.
Separate handshake signals (SRFlag) are used to notify the scheduler that new packets are put into the Server Rx-Queue, so that it can activate Server processes when needed. In turn the Server processes can activate a handshake signal (STFlag) to start of a Server Tx process when not already active.
When Workstations have transmitted their packet they set up a Timer. This event timer will be reset by the Server Tx process only when it has successfully transmitted a response packet to that workstation. The Queues do only contain workstation addresses, and packet length information.
Not shown in Fig-1 but in Fig-2 and Fig-3 are handshaking signals between the processes and the Medium Manager.
As can be seen only Tx processes are modelled. For those protocols that only require receiver activity when they are specifically addressed, no receiver process modeling is needed. All evaluation whether the packet was successfully received at the receiver location, is done within the transmit process. Tallies are maintained that monitor the successful and lost packet status, and the reason for packet loss.

Workstation Tx-N Processes

The Workstation processes consist of a CSMA/CA State Machine as shown in fig-2.
In total 7 states are shown. A short description per state follows:

-Idle: In this state a packet is scheduled for transmission after a fixed plus random Workstation processing time. For Perform3 (Read mode) only short 64 Byte (Novell request) packets are sent to the Server. For IPXLoad a random mixture of 60% Long and 40% Short packets are scheduled to be sent to a random destination.

-Sense Carrier: Calculates signal levels of all other transmitters on either of the two networks. When above the CRS Threshold then control is given to the Defer+Backoff state after the Medium busy length as maintained by the

Medium Manager.

-Send PHY preamble: In this state the transmitter is actually turned-on after the carrier sense delay time of one slot interval. In this state it is also registered whether a Collision has occurred, and whether capture takes place. In addition it is determined whether there is mutual interference of this packet with possible traffic on the other network.

-Send Data: Only schedules the length of the Data part. (Could be combined with other state.

-IFS + Gap: At this point the packet is actually transmitted. When the transmision is successful (No collision or jam), then the packet is put in the RX-Queue and the SRFlag is set. The transmitter is turned off and the appropriate tallies are updated. The next event is scheduled after the IFS + Gap wait time.
Note that the Rx-Queue is not filled during an IPXLoad test.

-Wait Time-out: This state schedules the next event after the Novell Time-out timer. It takes this time before the next packet is generated. In case no response was received from the server. This state is not used during an IPXLoad test (no timeout).

-Defer+Backoff: This state calculates the Backoff period and maintains the backoff counters. When the maximum retry limit is exceeded, then the packet is dropped and counted as lost and the next activity is scheduled after the Novell Time-out period.

A lot of tallies are maintained by the transmit processes, which are used to update a detailed report on the screen during the simulation. When the test is completed (usually 5 sec real time is simulated), the final result together with the parameter settings of the test, are also stored in a detailed report file. Several flags are used to communicate error conditions between the different transmitters.

The actual Medium Busy status is maintained by the Medium manager, which assures that this all happens on the same time, so that it is not related to the order of sequential processing of those events that are scheduled at the same time interval. Also the source and destination addresses of the pending packets are maintained.

Server Tx-Process

The Server Tx-Process works according to the Server CSMA/CA State Machine as shown in fig-3. The states are roughly the same as for the workstation. The differences are in the "Idle" and "IFS + Gap" states. The Idle state fetches the destination address for the next packet to transmit from the Rx-Queue and generates Long response packets that includes the specified data length and the Novell and MAC overhead. The main difference in the IFS + Gap state is that there is no time-out after a packet is transmitted. Also to signal the proper transmission of the packet to the destination workstation its event counter (which was preset to the Novell time-out) is reset so that the appropriate workstation process is activated again (via the Scheduler).
Note that the Server Tx-Process is not active during the IPXLoad test.

Server Process

The Server Process is not shown but it is a very simple State machine with 2 states; Idle and Active. It fetches a packet from the Rx-Queue and puts it in the Tx-Queue after a fixed + random Server processing time.
The momentary status of both the Queues are monitored and reported in the detailed test report.
Note that the Server Process is never active during an IPXLoad test.

Fading effect modeling discussion

The signal path attenuation between any station to each other station is calculated from the distance between the individual stations, and results in an average signal strength at that location determined by the attenuation coefficient parameter of the environment. However, due to fading the actual level can be different from the average level with a probability function according to the Raleigh fading model. When antenna diversity is used as in the WAVELAN product, the probability function shape is becoming close to a normal distribution function. In addition the shadowing effect will be a normal distribution function.
To simulate fading effects, a normal distribution fading component is added to every signal path calculation as done in the model. So signal path attenuation between stations for one packet is uncorrelated to the path attenuation of the next packet. This corresponds to a situation where the receive antenna is continuously in motion around the average distance.
For the modeled CSMA/CA protocol the independent signal paths as shown in Fig-4 are evaluated to determine the access and packet transfer success.
Before Network Access, the medium activity is checked. When another transmitter (TxB) is active then it is checked whether the receive level at TxA1 is above or below the Carrier Sense

threshold. When it is below the threshold then the transmitter will be turned on. Then to determine the transmission success, the wanted signal level at RxA is determined, as well as the interference level at that point generated by the other active transmitter TxB. The difference between both levels must be larger than the SIR parameter for a successful transmission.
When at the same time interval a collision occurs with for instance TxA2, then it is determined which of the two signals will be captured by the RxA receiver. Then it is determined which of the packets will be successfully received by RxA, if any (assuming that both TxA1 and TxA2 have the same destination, for instance RxA).
Also when TxA1 is turned on, then the effect of the already on-going transmission between for instance TxB and RxB is determined, by again calculating the signal to interference ratio at location RxB. Again every signal path calculation is the average level at that distance plus a uncorrelated normal distribution "fading component".
This covers for instance the situation, that the TxA1 to TxB signal is weak while the TxB to RxA signal can be strong, introducing a high probability of failure at location RxA.
The current model evaluates the conditions as shown in figure-4. It does not take into account the second order effects, like the effect of multiple interferers. For instance, the interference level at location RxA, is in the described case with also TxA2 and TxB active, the sum of both interference levels, but the model will first evaluate the Capturing, and then evaluate the interference level experienced from TxB. It is not expected that this simplification of the model has any measurable influence.

Adjacent Channel model

A similar approach is followed for the Adjacent Channel mode. However in this mode, the Carrier Sense function does not "see" the other network, while the interference level is decreased by a "network isolation" parameter. This should account for the side lobe attenuation of the transmit spectrum, and the effect of the receive filter at the other channel.

Another effect which is not included in the current model, but which is planned, is the non linear distortion that is generated in the receiver when a strong nearby channel signal causes signal clamping in the receiver.

Modeling simplifications

Currently the model uses an abrupt boundary to determine the effect of interference and capturing. There is a sharp performance edge at the SIR boundary. In reality there will be a error probability to SIR that follows a curve from 0 to 100% over a couple of dB variation of the SIR. Also the success rate in this area of the curve will depend on the length of the packet. For simplicity reasons this is not included in the model. Instead the normal distribution functions added to both the signal and the interference will more or less serve a similar purpose, and will partly compensate for this.

In addition the success rate per packet can be controlled by a "noise" parameter, that allows you to control the percentage of lost packets. This effect will be independent for the actual level of the signal and the packet length. However because the wireless network is expected to be interference bounded instead of noise bounded, this is not considered critical.
The same would apply for other effects like channel coherence changes during the transmission of a packet.
Although it would not be difficult to more accurately model the described relations, they are considered to have a minor influence on the global accuracy of the results.

Model sizing

The model allows only up to 2 networks to work in parallel with a limited number of stations per network. Simulation of more than 2 networks is not felt needed, because the 2 network case gives a good feeling for the interference issues involved, and it allows us to determine the boundary between sharing and reuse. Also increasing the number of stations per network, although it could be simply implemented, is not felt relevant. Simulation of network behavior with a large number of stations each contributing a relative low load, is impractical. It is difficult to get meaningful results out of such simulations. It would require very long test time, and it would be difficult to analyze the peak load behavior, because it will only occur temporarily.
The proposed method for these large networks is the following:

- Characterize the high load behavior as function of the number of simultaneous active workstations, similar to the tests shown in Doc. IEEE P802.11-91/125.
- Analyze the traffic pattern of a station needed per transaction/session.
- Use a Markov chain analyses approach based on this traffic pattern and the total number of stations to determine the probability figures for the concurrent activity of 2 to n stations, and its effect on the performance.

Example Test reports

As already discussed two reports are generated:

- An overview showing multiple test iteration results
- A detailed report showing results of individual stations, and the counted packet failures by type, and by direction (to or from the server).

he appendix shows a sample test report of two networks situated side by side with a large wall or floor in between. The stations 0 and 8 are the Server stations of network 1 and 2 respectively. In addition both networks each have 7 workstations, all generating a high load on the network. Note that in reality this kind of load would typically only occur in probably a few percent of the time in a moderately loaded network with 50-100 users.

- The overview report shows the parameters, the topology (only one network is shown), and the throughput (excluding Novell and MAC overhead) of individual networks, as well as the percentage of times that either the packet to the server or the response from the server are in error.
- The first detailed report shows a sample with both networks 45 meters apart, behind a wall or on another floor. The columns shown are as follows:

WS:	The station number
TxTot:	Total number of packets transmitted by this node
Retry:	Total number of times, that the station is forced into backoff
Rlim:	Number of times that max. retry limit is exceeded.
Ccnt:	Collision count from workstation to server
JamC:	Jam count from workstation to server
Lost:	Total number of packets lost from station to server
PcK:	Total number of successful packets from this station arrived at the server
SPck:	Total number of responses from the server arrived at this station
SLst:	Total number of lost packets from server to this station
SJmc:	Jam count from server to station
SCcnt:	Collision count from server to station
TxL:	Transmit level at 1 meter from antenna
Del:	Average delay from station to server
%Busy	Percentage that medium was busy
%Good	Percentage of used bandwidth that was used successfully
SRx-Q	Receive Queue contents (Instantaneous)
STx-Q	Transmit Queue contents (Instantaneous)
StS-Level	Average Server to server attenuation
Plost	Percentage of packets lost
Mlost	Percentage of either packet to server or packet from server being lost.

A second detailed report shows asimilar report, but now with the Ack protocol enabled. Experience shows that the detailed report is very important,because overall network throughput can still be very good, despite of the fact that individual stations can have low throughputs compared to others. It is also crucial in determining the root cause of the stations behavior, which could be resolved by protocol improvements and changes in parameterization.

Protocol enhancements

One of the protocol enhancements which is included in the model is a MAC level Acknowledge protocol. This can be included by extending the state machine with a few states. Still it is not needed that a separate receiver is modeled. Of course the model also evaluates the possible interference generated by the Ack signal, and the correct reception of the Ack is evaluated in a similar way as done with the packet itself. In addition the detailed report file also gives the number of Ack's that get lost due to interference as is shown in the second detailed report. Note that this means that the actual packet is received successfully, but due to the failure of the Ack, it is still counted as an error, and the packet will be retransmitted.

Other protocols

Implementation of other protocols requires the implementation of other transmitter state machines. In addition it is possible that more facilities are needed to communicate different conditions between the processes. It is also possible that also receiver processes need to be implemented to allow simulation of all possible effects. For instance the 4 way LBT MSDU format as described in the Ken Biba proposal, needs implementation of receiver functionality. This is because not only the situation at the addressed receiver of the packet must be evaluated as described in this paper. In that protocol at least the RTS and CTS packets cause actions in the other receivers in the network, which is important to control the network access function. This means that for every transmitted packet all receivers need to be activated, and the individual interference conditions need to be evaluated separately. This will make things much more complex and will effect the performance of the simulator.

Implementation

The simulation program is implemented using the structural Power Basic language. The basic simulation engine uses fixed point computations as much as possible to optimize for speed. Consequently there is not much performance difference when running without a co-processor. The first operational version was for the CSMA/CA protocol as used within the WAVELAN product. The simulation results were verified against the actual field measurements. Since then more functionality is added regularly. Implementation of other protocols like the 4-way LBT protocol is planned.

Conclusion:

A powerfull simulation tool for MAC protocol evaluation in a Radio environment has been constructed. The main characteristics of the PHY have been successfully modeled:

- Signal path attenuation as function of distance
- Effect of attenuation boundaries like walls and ceilings
- Fading / Shadowing
- Capture effect
- Co-channel interference
- Adjacent channel interference
- Microwave oven interference (jammer)

These characteristics are considered crucial for analyses of the impact of co-channel and adjacent channel mutual network interference.
The objective is to evaluate performance aspects of different MAC protocol approaches, and their robustness against interference. The simulator has been designed to analyze the WAVELAN CSMA/CA protocol and is being used to evaluate several protocol alternatives.
The model provides simulations at a high traffic load in a realistic Client-Server, and in a Peer-toPeer environment. The model allows efficient Analyses of the causes of packet loss at individual stations, by the detailed result report.
The model provides the possibility to evaluate the medium reuse aspects, and the relevant protocol characteristics to support it.

Wireless Network Performance Modeling Approach

* **Objectives**

    - **Develop a performance simulator suitable to evaluate MAC protocol alternatives in an indoor Radio environment.**

    - **The simulator should allow us to make the necessary tradeoffs in the development of a efficient and robust wireless protocol.**

    - **The relevant PHY characteristics should be modeled to provide a "realistic" environment for performance analyses and parameter tuning.**

Wireless Network Performance Modeling Approach

* PHY effects modeled:
  - Signal path attenuation as function of distance
  - Effect of attenuation boundaries like walls and ceilings
  - Fading / Shadowing
  - Capture effect
  - Co-channel interference
  - Adjacent channel interference
  - Microwave oven interference (jammer)

* Other modeling aspects:
  - Network Topology (location of the Server)
  - Network Operating System
  - Type of traffic (R, W, RW)
  - Peer-to-peer versus Client-Server traffic
  - Traffic load
  - Media Access Protocol (CSMA/CA)

Wireless Network Performance Modeling Approach

* **Model Characteristics:**

- **Single Network mode: 1 Server and up to 15 WS's (workstations)**
  Dual Network mode: 2 Networks with 1 Server and up to 7 WS's

- **Allows entry of station location coordinates for one Network.**

- **Second network has the same topology but the distance between the two networks can be varied in any direction.**

- **Extra attenuation offset between the two networks to simulate effect of a wall or operation on a different floor.**

- **Two Traffic Model versions are supported:**
  - **"Peer to peer" traffic heavy load performance**
  - **Client - Server traffic heavy load performance**

- **Three different traffic modes for the Client - Server model:**
  - **Continuous Read**
  - **Continuous Write**
  - **Random Read / Write**

- **Carrier Sensing based on Path attenuation between any station.**

Wireless Network Performance Modeling Approach

- **Capturing effect Included.**
  - **Both packets lost when separation receiver < SIR**
  - **One packet lost when separation > SIR, while the other packet separation < SIR.**
  - **No packets lost when destination addresses are different and both meet separation > SIR condition.**

- **Co-channel Interference model based on Path attenuation and SIR separation requirement.**

- **A Normal Distribution "Fading Margin" uncertainty applied for all Path attenuations calculations.**

- **Provide means to induce lost packets.**

- **A Micro Wave oven interferer (jammer) with programmable on-off duty cycle at a programmable level.**

- **An Adjacent Channel environment isolation between the channels controlled by a parameter. (No carrier sensing)**

- **Traffic load controlled by fixed + random delay per station.**

- **All CSMA/CA parameters and PHY parameters like transmit level and Carrier Sense level can be controlled.**

- **"Novell retry timeout" applied.**

Wireless Network Performance Modeling Approach

- **Monitors packet lost tallies per link.**
- **Average MSDU delay calculated per individual station.**
- **Performance measured in KBytes/sec actual data throughput excluding Novell overhead in the Perform3 test.**
- **Peer to peer performance measured including overhead, and without NCP handshaking. Traffic destinations are random.**
- **High performance "Event driven" Simulator.**
- **Produces two different output files:**
  - **Detailed report showing performance and lost packet statistics of individual Stations separated in "To the Server" and "From the Server" directions in each network.**
  - **Summary report showing throughput and Collision probability per network as a function of an iteration parameter like "Distance between Networks".**

Appendix-A

```
                PERForm3 Test  (Client Server)
 Date: 02-26-1992          Time:10:41:46    File: Perfr63 .dat
*******************************************************************
************    Two networks separated by wall/floor
*******************************************************************
Performance test  2  Networks with  7  Workstations each
Traffic Mode                 = R
Attenuation Coefficient      =  3.5
Fading Margin                =  5 dB Normal Distributed
Extra noise outage           =  0  %
SIR                          =  10 dB
Carrier Sense level          = -82 dBm
Server delay                 =  .5  msec  + random  .5  msec
Workstation delay            =  1  msec  + random  .5  msec
Packet Data length           =  512  Bytes
Lost Packet Timeout          =  300  msec
Test time                    =  5  sec
Attenuation offset between Networks =  20  dB
*******************************************************************
      . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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      . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . . 3 . . . 6 . . . . . . . . . . .
      . . . . . . . . . . 1 . . . . . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . 7 0 . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . . . . 4 . . . . . . . . . . . . .
      . . . . . . . . . . . . 2 . . . . 5 . . . . . . . . . . . .
      . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
Scale = 10 meters per dot.
*******************************************************************
```

Network-1			Network-2			
Separation	Throughput	%Lost	Throughput	%Lost	Total	
5.0	77.3	10.2	85.5	9.2	162.8	R
25.0	126.1	3.0	124.6	3.3	250.7	R
45.0	128.4	4.8	135.4	3.6	263.8	R
65.0	141.0	2.3	137.0	3.3	278.0	R
85.0	138.1	2.8	138.0	2.6	276.2	R

PERForm3 Test (Client Server)

Date: 02-26-1992 Time:10:39:51 File: Perf63.dat

****

************ Two networks separated by wall/floor

****

Performance test 2 Networks with 7 Workstations each

Traffic Mode	=	R
Attenuation Coefficient	=	3.5
Fading Margin	=	5 dB Normal distributed
Extra noise outage	=	0 %
SIR	=	10 dB
Carrier Sense level	=	-82 dBm
Server delay	=	.5 msec + random .5 msec
Workstation delay	=	1 msec + random .5 msec
Packet Data length	=	512 Bytes
Lost Packet Timeout	=	300 msec
Distance between Networks	=	45 0 meter
Attenuation offset between Networks	=	20 dB

****

WS	TxTot	Retry	Rlim	Ccnt	JamC	Lost	Pck	SPck	SLst	SJmc	SCcnt	TxL	Del	R
0	1278	468	0	0	0	0	0	0	0	0	0	-6		
1	254	210	0	4	1	5	249	246	3	0	3	-6	2.56	
2	182	170	0	9	0	9	173	172	0	0	0	-6	2.86	
3	198	183	0	7	0	7	191	188	2	0	2	-6	2.81	
4	233	342	0	3	0	3	229	225	4	0	4	-6	4.64	
5	104	202	0	5	0	5	99	93	6	5	1	-6	5.63	
6	86	196	3	4	0	7	79	73	6	5	1	-6	4.90	
7	265	262	0	5	0	5	259	257	2	0	2	-6	3.03	
Totals			3	37	1	41	1279	1254	23	10	13	0		2.63

TimeStamp	%Busy	%Good	SRx-Q	STx-Q	StS-Level	Throughput		128.4 KByte
500000	73.4	99.5	0	1	-88	PLost	2.5 %	MLost 4.8 %

WS	TxTot	Retry	Rlim	Ccnt	JamC	Lost	Pck	SPck	SLst	SJmc	SCcnt	TxL	Del	R
8	1338	473	0	0	0	0	0	0	0	0	0	-6		
9	86	295	5	2	0	7	78	74	4	4	0	-6	8.64	
10	170	234	0	4	0	4	166	162	4	0	4	-6	4.18	
11	238	208	0	4	0	4	234	231	2	0	2	-6	2.56	
12	213	239	0	6	0	6	207	206	0	0	0	-6	3.40	
13	171	199	1	7	0	8	163	162	1	0	1	-6	3.02	
14	195	208	0	3	0	3	191	187	4	0	4	-6	3.22	
15	304	321	0	3	0	3	300	300	0	0	0	-6	3.07	
Totals			6	29	0	35	1339	1322	15	4	11	0		2.63

TimeStamp	%Busy	%Good	SRx-Q	STx-Q	StS-Level	Throughput		135.4 KByte
500000	76.8	99.6	0	0	-88	PLost	1.8 %	MLost 3.6 %

PERForm3 Test (Client Server)

Date: 02-26-1992 Time:10:54:48 File: Perf63.dat

****

************ Two networks separated by wall/floor

************ With Ack Protocol Enabled and max retry limit= 20

****

Traffic Mode = R
Attenuation Coefficient = 3.5
Fading Margin = 5 dB Normal distributed
Extra noise outage = 0 %
SIR = 10 dB
Carrier Sense level = -82 dBm
Server delay = .5 msec + random .5 msec
Workstation delay = 1 msec + random .5 msec
Packet Data length = 512 Bytes
Lost Packet Timeout = 300 msec
Distance between Networks = 45 0 meter
Attenuation offset between Networks = 20 dB

****

WS	TxTot	Retry	Rlim	Ccnt	JamC	Lost	Pck	SPck	SLst	SJmc	SCcnt	AckL	TxL	Del	R
0	1332	576	0	0	0	0	0	0	0	0	0	0	-6		
1	200	291	1	6	0	7	199	198	4	0	4	0	-6	3.89	
2	186	310	1	9	0	10	185	184	2	0	2	0	-6	4.72	
3	212	316	0	10	0	10	212	211	5	0	5	0	-6	4.33	
4	183	369	1	5	0	6	182	181	3	0	3	0	-6	5.76	
5	194	396	0	10	0	10	194	193	8	2	6	0	-6	6.50	
6	153	381	3	6	0	9	149	149	7	6	1	0	-6	6.73	
7	216	290	0	1	0	1	216	215	1	0	1	0	-6	4.03	
Totals			6	47	0	53	1337	1331	30	8	22	0		2.80	

TimeStamp %Busy %Good SRx-Q STx-Q StS-Level Throughput 136.3 KByte
500000 83.9 99.4 0 5 -93 PLost 3.0 % MLost 6.0 %

WS	TxTot	Retry	Rlim	Ccnt	JamC	Lost	Pck	SPck	SLst	SJmc	SCcnt	AckL	TxL	Del	R
8	1346	559	0	0	0	0	0	0	0	0	0	0	-6		
9	54	470	8	1	0	9	45	45	1	0	1	0	-6	23.89	
10	198	337	1	5	0	6	196	196	3	2	1	0	-6	4.88	
11	231	312	0	7	0	7	230	230	2	0	2	0	-6	3.84	
12	224	314	0	5	0	5	224	223	3	0	3	0	-6	4.16	
13	220	328	0	3	0	3	220	219	4	0	4	0	-6	4.49	
14	210	298	1	5	0	6	208	208	3	0	3	0	-6	3.94	
15	226	300	0	4	0	4	226	225	1	0	1	0	-6	4.00	
Totals			10	30	0	40	1349	1346	17	2	15	0		2.77	

TimeStamp %Busy %Good SRx-Q STx-Q StS-Level Throughput 137.8 KByte
500000 84.1 99.6 0 3 -93 PLost 2.1 % MLost 4.1 %