# Modeling and Simulations of Biomedical Data Networks

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**KEYWORDS**

Modeling, simulation, transactions, adaptive modem, waveforms.

**ABSTRACT**

This paper presents a simulation research of a data network and data transmission for biomedical and telemedicine purposes. The information exchange, adaptive data waveforms for wireless channels and traffic simulations of data flow is the substance of this investigation. Simulations have been made with a Comnet 3 network traffic simulator package.
First section is a motivation section showing examples of innovative use of data networks and emerging new terminologies. Biomedical information technologies combined with data network, collaboration, grid, adhoc and virtual organization are discussed.
Second section is the basis of the study. It deals with customer data communication needs. The communication channels can be radio channels or wired lines (analog or digital). In the latter case digitized analog voice (voice coding) is transmitted by Voice over IP (VoIP). The channel bandwidth of the network is usually a bottleneck of performance. Thus the transmission capacity of the network is an important target of the simulation investigation. We investigate the need of the channel bandwidth in bits per second by simulating data transmission delays in connectionless data networks. Delay simulation results of some standard wireless data communications systems are compared with adaptive data waveform results.
In third section modeling and simulation results of the network design are investigated. Data transmissions are evaluated by simulations of biomedical or telemedicine traffic using modeled data transmission networks. The quality of service (QOS) in digital data networks is measured with bit error rate (BER) or time delay. BER of a communication channel describes QOS of the modulation method used. It depends on the signal-to-noise (S/N) ratio of the channel.
In last sections we propose and discuss the adaptive data communication design principles of the networks. We evaluate the proposal modulation selection system and the use of secure adaptive waveforms. We design end-to-end security on the physical OSI reference model level 1 and at the same time we improve throughput of data traffic of our network. The investigation of the sensitivity of a network structure, the message flow fluctuations and the growth process are important. We present principles for network design and channel capacity planning. The channel bandwidth and the S/N are well known parameters in network design by Shannon's formula. With this metric we get different limits for wireless channel traffic (bit rates), transactions in the system and data network performance.

**INTRODUCTION**

New emerging technologies combined with innovative use of data networks are studied in many countries. Three motivating examples for military use from USA present information technology areas (USA DoD 2000):

- Advance distributed learning (ADL).
- Smart Sensor Web (SSW).
- The biomedical technology area.

New information technologies present the opportunity to make significant improvements in training and education effectiveness. The DoD enterprise of education and training offers a key opportunity to reduce costs in these domains.
Smart Sensor Web (SSW) is a recent focus inspired by extraordinary technological advances in sensors and microelectronics and by the emergence of the Internet as a real-time communication tool. The near future will see a proliferation of sensors and associated processors available for battlefield use. The overall vision for SSW is an intelligent, secure, web-centric distribution and fusion of sensor information that provides greatly enhanced situational awareness, on demand, to Warfighters at lower echelons.
The biomedical technology area is focused to yield essential technology in support of the DoD mission to provide health support and services to U.S. Armed Forces. Most national and international medical investment is focused on public health problems of the general population. Military medical study is concerned with developing technologies in order to preserve combatant health and optimal mission capabilities despite extraordinary battle and non-battle threats to their wellbeing. Preservation of individual health sustains warfighting capabilities.
The Ohio State University had started a prototype implementation and presented a paper of grid support for collaborative clinical and biomedical research studies (Hastings et al. 2002). Throughout many areas in science and commerce, there is an increasing recognition of the need to support the information service needs posed by overlapping, often ad-hoc collections of work groups and organizations. They used the name "virtual organization" (Foster et al. 2002) to refer to an ad-hoc collection of work groups and organizations. Most work groups and organizations already make use of their own information systems. The term Grid (Chervenak et al. 1999, Foster et al. 1999) refers to hardware and software infrastructures and frameworks that provide access to heterogeneous collections of computational resources across multiple institutions and multiple domains. The underlying premise of Grid computing is to harness this wide-area network of resources into a distributed computation and data management system.

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A lot of information technologies are available for telemedicine (xDSL, OFDM, GPRS, 3G) but not discussed here. Our research is focused on

- Biomedical information transactions as the source of the telemedicine data traffic,
- Quality of the service of present data networks (delays, BER, S/N) achieved with standard data transmission methods,
- Security design of mobile wireless communication channels and
- Adaptive modulation methods (waveforms) as a new approach.

The results of this study may be applied to the military sensor communication (data fusion) and other secure ad-hoc communication needs. Our research method is modeling and simulations with a data traffic simulation package Comnet 3 (Caci 1995).

## INFORMATION EXCHANGE

In this section we present simulation results and discuss old and present information exchange possibilities, nature of data traffic, mathematical distributions used in our modeling and our adaptive communication system for use in telemedicine data channels.

### Need for Information Exchange

The basis of this study is in the customer data communication needs. The need, nature and benefits of the biomedical information exchange is described in references (Hasting et al. 2002, Lees et al. 2002, Andrade et al. 2001-2002):

- Analysis of medical images requires the ability to query, retrieve, and process large amounts of image data. In a collaborative environment these studies could be aggregated from multiple participating institutions.
- In collaborative environments, data replication across storage systems and caching of data hot spots close to groups of clients can significantly increase throughput and decrease response times seen by clients (Andrade et al. 2001-2002). Data replication and caching would alleviate the bottleneck that will be created by a single data source.
- Application dependent processing of large volumes of data is a critical component in many fields of medicine.
- The regional health-telematics-network, interconnects healthcare facilities in the region, supporting the development of the regional healthcare information infrastructure.
- Internet technology provides secure multilingual access to medical records in a cardiology department.
- The scalable and modular architecture can support interconnectivity between medical records of cardiology patients in departments within the same and different institutions.

### Modeling and Simulation

We have modeled and simulated message transmissions of source instruments and data transmission of a biomedical or

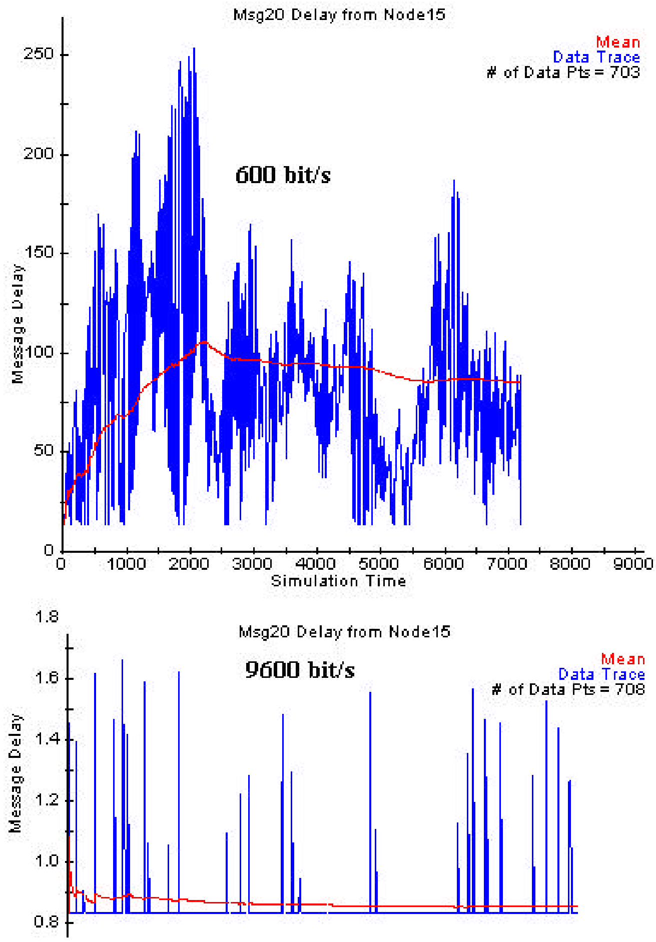


Figure 1: Message Delays in Seconds

telemedicine network model. The network model is based on Comnet 3 (Caci 1995), Figures 1-4. The simulation model, traffic parameters and results are discussed in more detail in the next sections.

### Nature of Data Traffic

The nature of data traffic was seen in Figure 1. The main difference between data and voice communication is traffic bursts in data transmission. Figure 1 shows burst data traffic simulation results in a backbone network structure of Figure 4. Wireless band-limited data rates of the channels are evaluated based on the present day realism in military and commercial equipments. Delays depend heavily on the data transmission lines used in simulations as the results of mean delays indicate:

- <0.5 s delay with 9600 bit/s and
- <100 s delay with 600 bit/s.

Many heavy unpredictable variations in traffic and delay times are seen in the low bit rate case. The modeling of the data traffic has been found difficult in many references. We used the well-known exponential distribution for traffic generation with 10 sec arrival times, Figure 3. In Figure 2 we had a fixed 1000 byte mean message size. Delay times with the 600 bit/s lines are not acceptable but 9600 bit/s might be acceptable in many real world applications. This example demonstrates with 600 bit/s rate the radio channels of a common analog military message system and with 9.6 kbit/s rate cellular data channels widely used in GSM technology.

## Bit Rates

In Figure 2 we have simulated data transmission over the standard telecommunication channels in an example network using different wireless or wired technologies and standard bit rates in band-limited channels:

- Radio channels 600, 2400 and 9600 bit/s.
- Adaptive radio channels 22500 bit/s.
- Wired ISDN channels 64 kbit/s.

The lowest bit rate 600 bit/s is used in a conventional analogue military tactical vhf radio messaging system. The low bit rate channels 2400 bit/s are common in all new digital military hf-vhf radios. This data bit rate is also available with newest frequency hopping waveforms, which can secure our data transmission. Cellular data transmission (GSM) has been used since the beginning of mobile Internet connections with 9600 bit/s data channels. Adaptive radio channel is made with our prototype modem added to a conventional tactical radio. The system was field-tested in 2000 (Lallo 2001). Wired ISDN technology has a fixed 64 kbit/s bit rate. The simulated message delays with these channels are presented in Figure 2. Interesting is the standard deviation of delay as an indicator of QOS.

We are not discussing here the present ADSL or other wideband technologies, which can offer 512 kbit/s or 2 Mbit/s. Although ADSL-technology has rapidly developed in the wired telecommunication networks as the basic access system to the Internet but we concentrate on the mobile wireless communication and mobile band-limited Internet access in this study. Next we will show how critical is the channel bandwidth measured as bit/s.

## Message Delay

The quality of data transmission in our modeled network is evaluated with message delay simulations. Figure 2 shows simulated message delays versus bit rate. Table 1 gives also the maximum delays. We can found that 64 kbit/s data rate is good enough in burst data transmission case with the zero delay deviation. Message delay (average and its deviation) is a good measure for quality of service (QOS). In some instrumentation cases a low bit rate may be practical because it saves channel capacity and maybe channel costs. If our instrumentation references are biomedical instruments of a hospital or military sensors in the field there may be a specific QOS limit for a real time system delays. In Figure 2 an important result is that QOS decreases rapidly when the bit rate of the transmission channel is under a certain limit. The limit in this simulation is 2.4 kbit/s or 9.6 kbit/s depending on the particular message delay requirements of the application in concern.

Table 1: Delay Simulation Results (ms)

| Bit rate | Average | Std dev | Maximum |
|---|---|---|---|
| 600 | 24797.64 | 15677.19 | 92547.3 |
| 1200 | 7911.91 | 2472.74 | 18013.3 |
| 2400 | 3552.63 | 650.25 | 6479.4 |
| 9600 | 846.24 | 78.73 | 1479.4 |
| 22500 | 358.27 | 17.30 | 523.9 |
| 64000 | 125.84 | 0 | 125.8 |

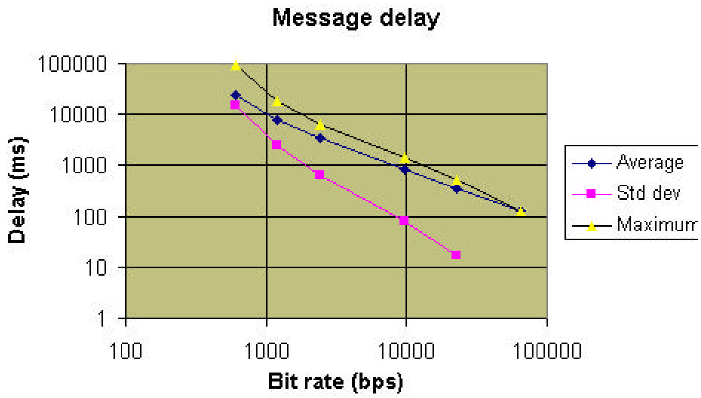


Figure 2: Message Delay vs Channel Bit Rate

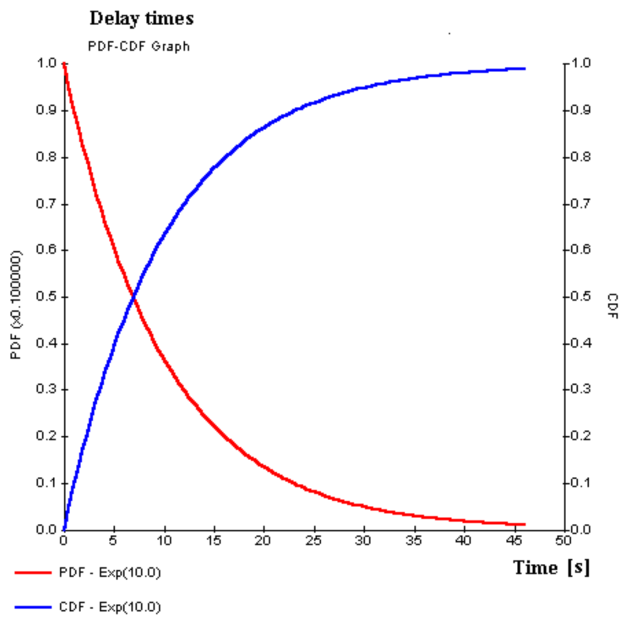


Figure 3: Message Arrival Times (Caci 1995)

2.4 kbit/s value is the maximum value of most tactical radio channels. In cellular world the value is higher 9.6 kbit/s or 14.4. kbit/s with GSM based data transmission or with GPRS technology about 50 kbit/s in practice. With these options we have now good possibilities to use wireless communication for instrumentation. A software modem with adaptive modulation, waveform and bit rate selection is a perfect and secure communication tool for different band-limited channels, noise and multi-path conditions (Lallo 2002).
A practical measure for the traffic quality is the deviation of the message delay found in simulation, Figure 2. We found that 64 kbit/s data channels offer zero delay time deviation, which means that no bursts were found in the data traffic, Table 1.

### Security

The indoor instrumentation might be based on new standards like Bluetooth or wireless LANs. Although the security on OSI reference model upper levels in data communications over Internet is solved with tunneling methods there is a lack of the OSI level 1 security in LANs. However, we can have a secure IP-based virtual private network (VPN) between biomedical LANs. There is a VPN standard for tunnel management (RFC 1701/1702). Tunnels can originate and terminate in the enterprise server or in the service provider's access switch. Security problems are in LANs themselves, where we do not have OSI level 1 security. Thus we propose the use of adaptive end-to-end (PC-to-PC) secure waveforms inside LANs for solving this securing problem.

## PRINCIPLES OF NETWORK DESIGN

In this section we study adaptive data communications with adaptive waveforms for biomedical and telemedicine networks, Figures 5-7 and Table 2. There are design principles for reducing blocking or delay times:
- Alternate routing.
- Increasing of channel capacities

Alternate routing is used both in telecommunication and Internet networks. Our network simulation model in Figure 4 had two alternate routes in the backbone network model. Adaptive modulation is a method to select wireless channel capacity by waveform selection. In the wireless world it means the selection of the digital modulation method (waveform) according to the channel characteristics. The selection of the error free modulation method is a key issue in the adaptive modem concept. In a mobile wireless environment we have time varying different channel characteristics (bandwidth, S/N) and thus it is advantageous to fit the digital modulation method to each channel condition.

### Selection of Waveform

Table 1 shows the simulation results using different channel bandwidths in the backbone network representing different wireless or wired technologies. We see the benefits of adaptive waveform selection data rates, Tables 1-2 and Figure 6.

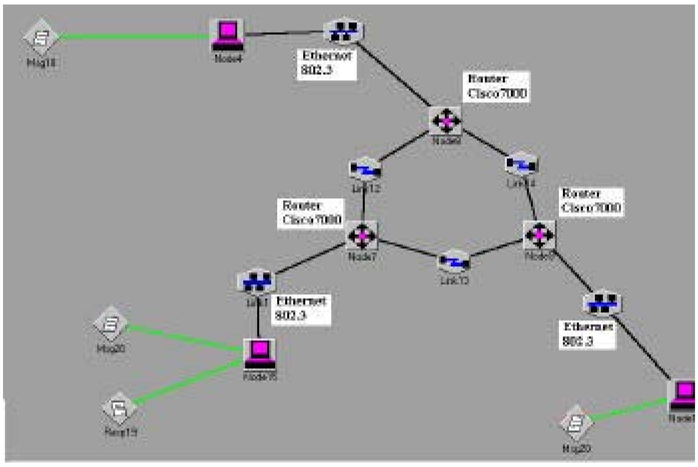

Figure 4: Example Network Model (Comnet 3)

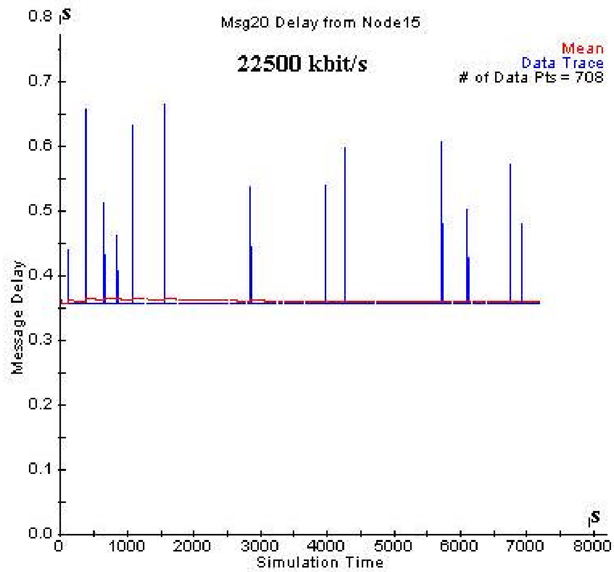

Figure 6: Message Delay (22500 bit/s Backbone)

Usually data network are based on international or industry standards and their data rates are fixed. In the simulation results we see that the selection of a non-standard 22.5 kbit/s adaptive waveform of a prototype modem (Lallo 2001) gives a lower average message delays 0.36 s than a standard 9.6 kbit/s standard cellular data modem 0.85 s, Table 1. This data rate is good enough to give also low deviation.

### Quality of Service (QOS)

A good measure of QOS is the standard deviation of the message delay or the maximum delay. Data bursts cause the deviation of the delay times, Figures 1 and 6. Bursts will disappear if we have more bandwidth for example 64 kbit/s, Figure 2. An important principle in network design is the use of delay deviation in monitoring and controlling the traffic versus the channel bandwidth (capacity in bit/s). Present data traffic and its growth is used as one of the main design factor in network capacity design. Knowing these factors we can predict the channel capacity needed in the future by delay simulations.

### Adaptive Multi-Carrier Waveforms

Knowing channel characteristics much better bit rates than with present standard systems discussed earlier are available using if the adaptive multi-carrier data communication is used, Table 2. Table 2 shows bit rate possibilities simulated with an adaptive modem worksheet simulator (Lallo 2001). The adaptive modem adapts to the available bandwidth using a proper number of carriers (channels 1-10 in Table 2). Each carrier uses the best available modulation method (QAM states in Table 2) adapted to the channel characteristics usually the S/N ratio. A software modem should select automatically the best downloadable software algorithm and modulation method and thus maximizes the bit rate in mobile band-limited wireless communication.

### Physical Security with Waveforms

We have made a proposal for a secure network model for biomedical or telemedicine communication needs, Figure 5. This proposal includes the use of adaptive modems as a data communication securing tool on OSI level one (physical).

### Transaction Rate

We investigated increasing transaction rates in a network using the 22.5 kbit/s adaptive waveform in the backbone channels. We increased gradually the network traffic from message sources having a fixed normal distributed message size (100 kilobyte mean, 10 kilobyte standard deviation) and arrival time as variable (10 sec - 160 sec). These arrival times gave us a practical transaction range of a biomedical institution with 65 000 to 260 000 transaction per year. The results of these simulations are in Figure 7. Delays in Figure 7 have an average (ave) and a standard deviation (std) value. We found that there is a transaction value limit about 250 000 per year after which the backbone network causes increasing delay time. In the evaluation of the simulated result the message size (100 kilobyte used) is a critical measure. If the messages include for example large images (1 Megabyte) the number of transaction limit may drop to 25 000 per year. However, it is possible to work with a low data rate band-limited backbone but with larger delays.

We have to take care about our data traffic culture (mean message size, transactions per day, rush hours etc). We can develop our principles for network design. We can predict the transactions and the future number of traffic sources. Simulations can be done using the system model with parameters according to the predicted situation. Then economical decisions can be made about the communication channel and network capacity.

In existing biomedical network structures telephone network and wired Ethernet 802.3 LAN are very often used, Figure 5.

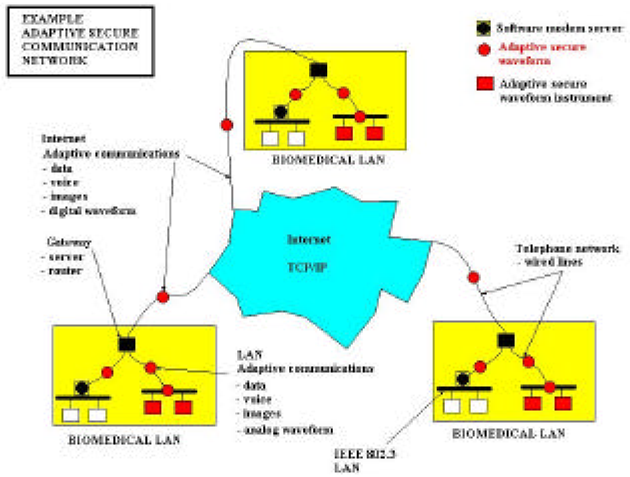


Figure 5: Adaptive Secure Network Model

Table 2: Adaptive Modem Bit Rates

| Symbol Rate | QAM | Channels | MFC-code frequencies | Bit/s |
|---|---|---|---|---|
| 1000 | 1*16 | 1 | (1 1) | 4000 |
| 1000 | 1*16 | 2 | (5 2) | 8000 |
| 2000 | 1*8 | 2 | (4 2) | 12000 |
| 2000 | 1*16 | 2 | (5 2) | 16000 |
| 2000 | 1*64 | 2 | (24 2) | 24000 |
| 3000 | 1*64 | 2 | (17 2) | 36000 |
| 3000 | 1*64 | 3 | (65 2) | 54000 |
| 3000 | 1*64 | 4 | (513 2) | 72000 |
| 3000 | 1*64 | 5 | (514 3) | 90000 |
| 3000 | 1*64 | 6 | (285 4) | 108000 |
| 3000 | 1*64 | 7 | (803 4) | 126000 |
| 3000 | 1*64 | 8 | (640 5) | 144000 |
| 3000 | 1*64 | 9 | (572 6) | 162000 |
| 3000 | 1*64 | 10 | (541 7) | 180000 |
| 3000 | 1*128 | 10 | (685 8) | 210000 |
| 3000 | 1*256 | 10 | (836 9) | 240000 |

In Figure 5 we have a proposal system for data transmission waveforms made with software algorithms (adaptive modem). A server in each LAN has an adaptive modem cluster (software package) that recognizes each individual instrument carrier frequency and thus the corresponding instrument. The adaptive modems are band-limited and they can be used inside the voice frequency band adapted to any type of communication channels (military radio, cellular phone, wired telephone network etc). We can connect secure waveforms over an analogue channel or over a digital voice channel (VoIP), where analog voice is coded into digital form. Thus the channels in Internet or in Public Switched Telephone Network (PSTN) are available for secure transmission on OSI level 1, Figure 5.

Passing adaptive waveforms over Internet or over telephone network to another LAN server we can build our own VPN tunnel channel with OSI level one securing. The securing is made in the adaptive modem with frequency hopping in the voice frequency band. This can be done with the adaptive modem software algorithm in the data modulation process. Theory is presented in Milcom 2002 Tutorial (Lallo 2001-2002).

Simulation of adaptive communication methods was not possible a couple of years ago but now it is due to the present processor power and computer programming systems. Details of this securing are based on the discrete Fourier theory but are not the subject of this paper.

## DISCUSSION

The channel bandwidth and the S/N are related to the channel capacity by Shannon's formula. With this metric we design wireless channel capacities (bit rates). We had earlier made a worksheet simulation process to compare modulation methods. With a selected adaptive software modem algorithm we can design an adaptive multi-carrier data communication system. We can select the proper modulation method (carriers, QAM states, secure coding, etc) and most suitable bit rate for different channels (S/N, bandwidth, etc). By traffic simulations we can check QOS of the network and we can design optimal channel capacities and select modulation methods for telemedicin data transmission networks.

Using data traffic simulations we have noticed message delays and by evaluating the deviation of the delay we found design limits for data transactions. Simulation with different message sizes can give the traffic capacity limit of the backbone network (Internet, tcp/ip).

Bit errors in the received data signal begin rapidly to increase at a waveform specific S/N-limit. Data transmission needs usually a good bit error rate (BER) associated with a high S/N value. In solving this problem we can use adaptive waveforms.

## SUMMARY

The subject is quite extensive. We have investigated and discussed one model of data networks with limited simulated examples, network design principles and the use of adaptive selection of the modulation method (waveform). The adaptive multi-carrier secure data communication system is an approach that can give wireless security with band-limited frequency hopping on the lowest OSI level and optimal throughput for different channels used with biomedical applications in telemedicin networks.

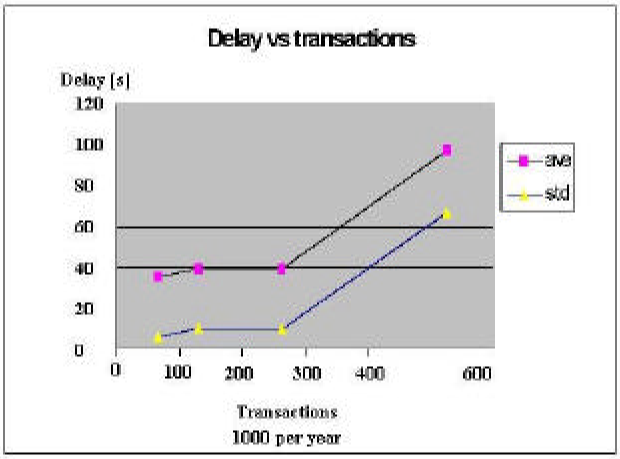

**Figure 7** Message Delay vs Transactions

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