Power Control MAC Protocol with Increased Throughput for MANETs

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Abstract

A mobile ad-hoc network is a collection of mobile nodes forming an ad-hoc network without the assistance of any centralized structure. Since the devices used in an ad hoc network are mostly battery powered, power conservation is a major issue of such networks. Power control is not related to any particular layer, since we can apply power conservation methods in all layers. But most of the power control mechanisms are working in MAC layer. In this paper we have designed a MAC protocol for reducing the power consumed by each and every node. This protocol also increases the aggregate throughput of the network.

1. Introduction

Power conservation is a major issue in Mobile Ad Hoc Networks, as most of the nodes are battery powered. The following principles may serve as general guidelines for power conservation in MAC protocols [1, 2]. First, collisions, a cause of expensive retransmissions should be avoided as far as possible. Second, the nodes should be kept in standby mode or sleep mode whenever possible. Third, instead of using the maximum power, the transmitter should use a lower power that is enough for the receiver node to receive the transmission. In this context we mentioned above, the MAC protocols can be classified into two: Power management protocols (using alternative sleep and wake up modes for nodes) [2, 5] and power control protocols (variation in transmit power) [6, 7]. The nodes in the ad hoc network remain in one of the three possible states: active, idle or sleep. Power consumption in sleep state is less compared to other two states. So we keep some of the nodes those are not participating in data transmission in sleep mode. In a network power is consumed during computation and transmission of packet, but computation power is negligible as compared to transmission power cost. Hence efforts are made to control the transmission power by incorporating different power control mechanisms.

2. MAC Protocols for Mobile Ad Hoc Networks

Nodes in an ad hoc network share a common broadcast channel. Since the bandwidth available for communication in such networks is limited, access to this shared medium should be controlled in such a manner that all nodes receive a fair share of the available bandwidth. A different set of protocols is required for controlling the access to shared medium in ad hoc networks, because they need to address unique issues such as mobility, limited bandwidth, hidden and exposed terminal problems etc.

2.1. Classification of MAC Protocols.

Based on different criteria such as initiation approach, time synchronization and reservation approaches, MAC protocol can be classified into 3 basic categories:

2.1.1. Contention Based Protocols: These protocols follow a contention based channel access policy. Nodes do not make any resource reservation a priori. Whenever it receives a packet to be transmitted, it contends with its neighbour nodes for access to the shared channel. This protocol does not guarantee the QoS. Contention based protocols can be further classified into sender initiated and receive initiated. Sender initiated can be further divided into single channel sender initiated and multi channel sender initiated. In single channel sender initiated, the node who wins the contention can use the entire bandwidth. But in case of multi channel, the available bandwidth is divided into multiple channels which enable several nodes to simultaneously transmit data, each using separate channel.

2.1.2. Contention Based Protocol with Reservation Mechanisms: Contention based protocols does not support real time traffic since nodes do not guarantee periodic access to the channel. For supporting such traffic, some protocols have mechanisms for reserving bandwidth a priori. These protocols can be classified into two: Synchronous protocols which require time synchronization among all nodes and asynchronous protocols which do not require any global synchronization among nodes.

2.1.3. Contention Based Protocol with Scheduling Mechanisms: These protocols focus on the packet scheduling at nodes, and also scheduling nodes for access to the channel. Node scheduling is done in such a manner that all nodes are treated fairly and no nodes are starved of bandwidth. Some scheduling schemes consider the battery characteristics while scheduling nodes for access to the channel.

2.2 IEEE 802.11 MAC Protocol.

IEEE 802.11 specifies two medium access control schemes, PCF and DCF. PCF is a centralized scheme, while DCF is a fully distributed scheme. DCF is based on CSMA/CA. When the station has packet to transmit, it senses the channel by Physical Carrier Sense (PCS) and Virtual Carrier Sense (VCS). PCS notifies the MAC layer if there is a transmission going on and VCS is NAV procedure. If NAV is set to a number, station waits until it resets to zero. Virtual carrier sensing uses the duration of the packet transmission included in the header of RTS, CTS and DATA frames. The duration included in each of these frames can be used to infer the time when the source node would receive an ACK frame from the destination node. The duration of RTS frame includes the time for CTS, DATA and ACK transmissions while that of CTS includes time for DATA and ACK transmissions. Similarly the duration field of DATA only includes the duration for the ACK transmission. Each node in IEEE 802.11 maintains a NAV, which indicates the remaining time of the ongoing transmission sessions. Nodes will update their NAV using the duration information in RTS, CTS and DATA packets after they receive a packet. The channel is considered as busy if either PCS or VCS indicates that channel is busy.

The time intervals between frames are specified as Inter Frame Spaces (IFS). IEEE 802.11 specifies four IFSs named SIFS, PIFS, DIFS and EIFS. The SIFS is the shortest among the IFS and is used after RTS, CTS and DATA frames to give the highest priority to CTS, DATA and ACK frames respectively. When a channel is idle, a node waits for DIFS duration before transmitting a packet. Nodes in the transmission range correctly set their NAVs when receiving RTS or CTS. Since nodes in carrier sensing zone is not able to decode the packet, they do not know the duration of the packet transmission. So, to prevent the collision at the source node with the ACK, the nodes set their NAVs for the EIFS duration. The purpose of EIFS is to provide enough time for a source node to receive the ACK. EIFS is obtained using the SIFS, DIFS and the length of time to transmit an ACK at physical layer's lowest mandatory rate. These process is shown in the following figure.

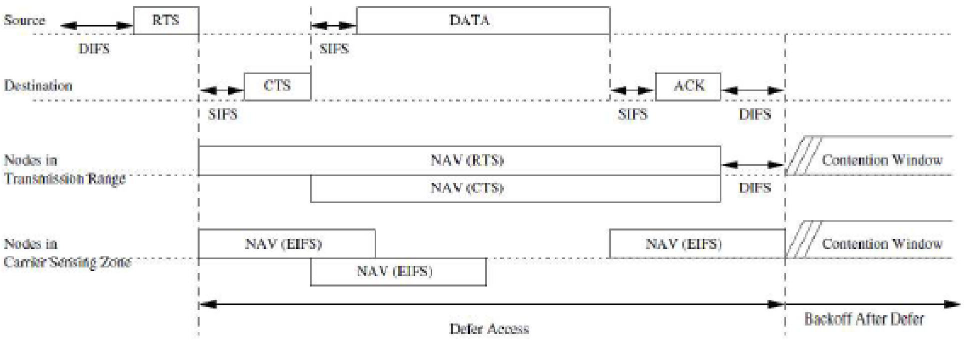


Figure 1: The nodes in the transmission range and carrier sensing range set their NAV

3. Power Conservation in MANET

3.1 Introduction

Since nodes in an ad hoc network are limited battery powered, power management is an important issue in such networks. Battery power is a precious resource that should be used effectively in order to avoid the early termination of nodes. Power management deals with the process of managing resources by means of controlling the battery discharge, adjusting the transmission power, and scheduling of power sources so as to increase the life time of nodes in the ad hoc networks. Battery management, transmission power management and system power management are three major methods to increase the life time of nodes.

3.2 Need for Power Management in Ad Hoc Networks

The main reasons for power management in ad hoc networks are the following:

Limited Energy Reserve: The main reason for the development of ad hoc networks is to provide a communication infrastructure in environments where the setting up of fixed infrastructure is impossible. Ad hoc networks have very limited power resources.

Difficulties in Replacing Batteries: In some situations, it is very difficult to replace or recharge batteries.

Lack of Central Coordination: The lack of central coordination necessitates some of the intermediate node to act as relay nodes. If the proportion of relay traffic is more, it may lead to a faster depletion of power source.

Constraints on the Battery Source: Batteries will increase the size of the mobile nodes. If we reduce the size of the battery, it will results in less capacity.

Selection of Optimal Transmission Power: The transmission power determines the reachability of the nodes. With an increase in transmission power, the battery charge also will increase. So it is necessary to select an optimum transmission power for effectively utilize the battery power.

Channel Utilization: The frequency reuse will increase with the reduction in transmission power. Power control is required to maintain the required SIR at receiver and to increase the channel reusability.

3.3 Power Conservation Approaches

Two mechanisms affect energy consumption: power control and power management [10]. If these mechanisms are not used wisely, the overall effect could be an increase in energy consumption or reduced communication in the network.

3.3.1 Power Control. The aim of communication-time power conservation is to reduce the amount of power used by individual nodes and by the aggregation of all nodes to transmit data through the ad hoc network. Two components determine the cost of communication in the network. First one is direct node to node communication or transmission. The transmission rate can be adapted by the sender [12]. Second is forwarding of data through the networks. In the first case we can use the power control techniques to conserve the power. Whereas in the second case we can use the energy efficient routing schemes.

Current technology supports power control by enabling the adaptation of power levels at individual nodes in an ad hoc network. Since the power required transmitting between two nodes increases with the distance between the sender and the receiver, the power level directly affects the cost of communication. The power level defines the communication range of the node and the topology of the network. Due to the impact on network topology, artificially limiting the power level to a maximum transmit power level at individual nodes is called topology control. MAC layer protocols coordinate all nodes within transmission range of both the sender and the receiver. In the MAC protocols, the channel is reserved through the transmission of RTS and CTS messages. Node other than the destination node that hears these messages backs off, allowing the reserving nodes to communicate undisturbed. The power level at which these control messages are sent defines the area in which other nodes are silenced, and so defines the spatial reuse in the network [14, 15]. Topology control determines the maximum power level for each node in the network. So topology control protocols minimize power levels increase spatial reuse, reducing contention in the network and reducing energy consumption due to interference and contention. The use of different power levels increases the potential capacity of the network.

Once the communication range of a node has been defined by the specific topology control protocol, the power level for data communication can be determined on a per-link or even per-packet basis. If the receiver is inside the communication range defined by the specific topology control protocol, energy can be saved by transmitting data at a lower power level determined by the distance between the sender and the receiver and the characteristics of the wireless communication channel [16].

Power aware routing reduces the power consumption by finding the power efficient routes. At the network layer, routing algorithms must select routes that minimize the total power needed to forward packets through the network, so-called minimum energy routing [17]. Minimum energy routing is not optimal because it leads to energy depletion of nodes along frequently used routes and causing network partitions.

3.3.2 Power Management. Idle-time power conservation spans across all layers of the communication protocol stack. Each layer has different mechanisms to support power conservation. MAC layer protocols can save the power by keeping the nodes in short term idle periods. Power management protocols integrate global information based on topology or traffic characteristics to determine transitions between active mode and power- save mode. In ad hoc networks, the listening cost is only slightly lower than the receiving cost [18]. Listening costs can be reduced by shutting off the device or placing the device in a low-power state when there is no active communication. The low-power state turns off the receiver inside the device, essentially placing the device in a suspended state from which it can be resumed relatively quickly. But the time taken to resume a node from completely off state is much more and may consume more energy. The aim of any device suspension protocol is to remain awake the node when there is active communication and otherwise suspend. Since both the sender and receiver must be awake to transmit and receive, it is necessary to ensure an overlap between awake times for nodes with pending communication.

Different methods such as periodic resume and triggered resume can be used when to resume a node to listen the channel. In periodic resume, the node is suspend the nodes most of the time and periodically resumes checking if any packet destined to it. If a node has some packets destined for it, it remains awake until there are no more packets or until the end of the cycle. In triggered resume method to avoid the need for periodic suspend/resume cycles, a second control channel can be used to tell the receiving node when to wake up, while the main channel is used to transmit the message.

4.Proposed Approach

4.1.Protocol Assumptions and System Model

In this model, nodes are randomly deployed in a geographical area. It is assumed that nodes are stationary, homogeneous and use Omni directional antenna for transmission. The other assumptions we used in our protocol are as follows. The gain between two nodes is same in both directions. The channel gain is stationary for the duration of the control and data packet transmission periods. The propagation model used is the two ray ground reflection model [19]. The relationship between transmitted power and the received power can be represented as follows:

*Pr = Pt * Gtr*

Where, *Gtr* is the gain from the transmitter to the receiver.

The received power at a distance d can be calculated as:

$$Pr=\frac{P_t G_t G_r H_t^2 H_r^2}{d^4 L}$$

Where, *Ht* and *Hr* are heights of transmitter and receiver antennas and is same for every antenna. L is the system loss factor which is set to 1.

4.2 Protocol Description

Our protocol is a power control MAC protocol with improved throughput. Our aim was to reduce the power consumption of each node in the network and in addition to it improve the aggregate throughput of the network. The protocol is organised as two phases. The first phase is used to reduce the power consumption of nodes and the second phase for improving the throughput of the network.

4.2.1 Reduce the power consumption. Like most of the power control protocols, here also the power can be reduced by send the packets with optimum power. All of the existing power control MAC protocols were sending the RTS and CTS packets with maximum (default) power and the DATA and ACK packets using the minimum power. The protocol discussed in [7], The PCMA protocol, allows different nodes to send packets with different transmission power levels. PCMA uses the busy tones instead of RTS-CTS scheme to avoid the hidden terminal problem. If a node wants to transmit a packet, it senses the channel for busy tones from other nodes. The strength of busy tones received by that node is used to determine the highest power level with which a node can send without interfering other transmissions.

Instead of this, here we send the RTS with default power and CTS, DATA and ACK packets with optimum power. This protocol requires the addition of a field to the RTS and CTS control packets. The structure of the existing and proposed RTS packet is as shown below:

Frame Control	Duration	RA	TA	CRC

RTS Format in PCM

Frame Control	Duration	RA	TA	CRC	P_{RTS}

RTS Format in Proposed PCMIT Scheme

Figure 2: Structure of RTS Frames

The Structure of the existing and proposed CTS packet is as shown below:

Frame Control	Duration	RA	CRC

CTS Format in PCM

Frame Control	Duration	RA	CRC	P_{Data}

CTS Format in Proposed PCMIT Scheme

Figure 3: Structure of CTS Frames

The working procedure of the protocol is described as follows:

- The transmitter send the RTS packet containing the value of P_{RTS} at a transmitted power level P_{RTS}.

• The receiver will receive the RTS frame at a received power *Pr*.
• The receiver will take the RTS transmitted power P_{RTS} from the received RTS packet.
• After determining the P_{RTS} and *Pr*, the CTS transmission power P_{CTS} and data transmission P_{Data} can be calculate.
• The receiver sends out the CTS containing the value of P_{Data} at a transmitted power P_{CTS}.
• The transmitter will send the data frames to the receiver at the transmitted power P_{Data} which is the value obtained from the P_{Data} field of the immediately previous CTS frame.
• The receiver after receiving the DATA frame will send an ACK frame with a power that is used to send the CTS frame. Using P_{RTS} and *Pr*, the CTS transmission power P_{CTS} can be calculated as follows:

$$P_{CTS} = \frac{P_{RTS}}{P_r} * R_{th}$$

Where, *Rth* is the receiving threshold (minimum signal strength at which the receiver can decode the signal)
After calculating the P_{CTS}, that value will assigned to the P_{Data} field of the CTS frame and the CTS frame will send with the power P_{CTS}

4.2.2 Improve the Throughput. In 802.11 virtual carrier sensing mechanism, if a node over hear an RTS or CTS packet, the node which over hear the packet assumes the channel as busy and set its Network Allocation Vector (NAV). Thus if that over heard node has any packet to send, it defer the transmission for a duration. Here we improved this virtual carrier sensing mechanism.

A node can over hear an RTS packet only or a CTS packet only or can overhear both RTS and CTS packet. In our protocol since the CTS transmission range is less compared to the RTS transmission range. So there is a chance that a node overhears RTS packets only. Suppose a node over hear the RTS packet only and it has a CTS packet to send, it will send that packet immediately. It is possible because it won't affect the ongoing transmission.

For example consider the following figure,

Here, node A has data to send to node B. So it sends an RTS packet to B. Since C is in the RTS transmission range of A, it will overhear the RTS packet. After receiving the RTS packet node send will respond by a CTS frame. Since the CTS transmission range of B is small, that CTS packet won't overhear by node C. So it won't set its NAV. So if C receives an RTS packet from D, it can respond immediately with a CTS packet. It will improve the spatial reuse, because more nodes can send packets at a time. Thus it will improve the throughput of the network. For this purpose we make some modifications in the VCS scheme present in the IEEE 802.11 MAC.

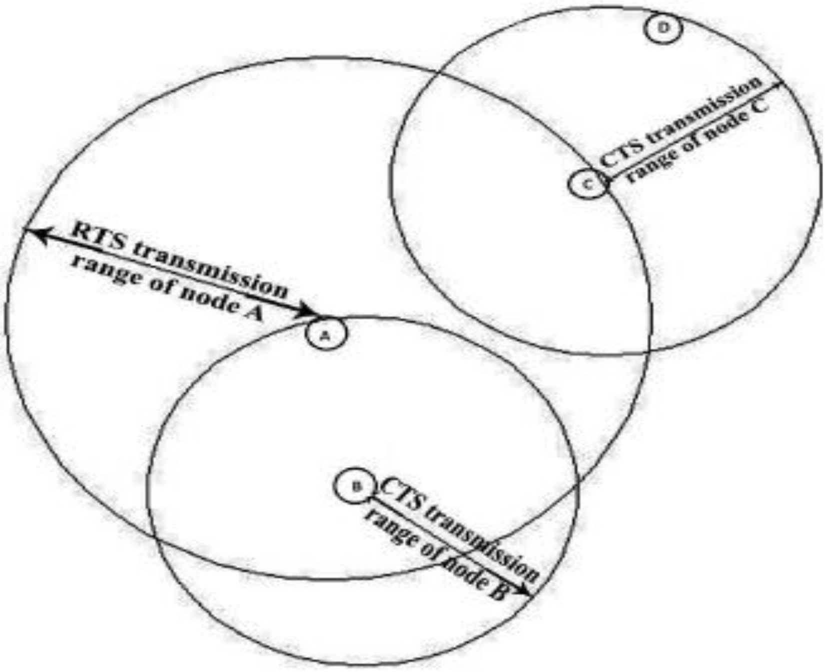


Figure 4: RTS and CTS transmission ranges

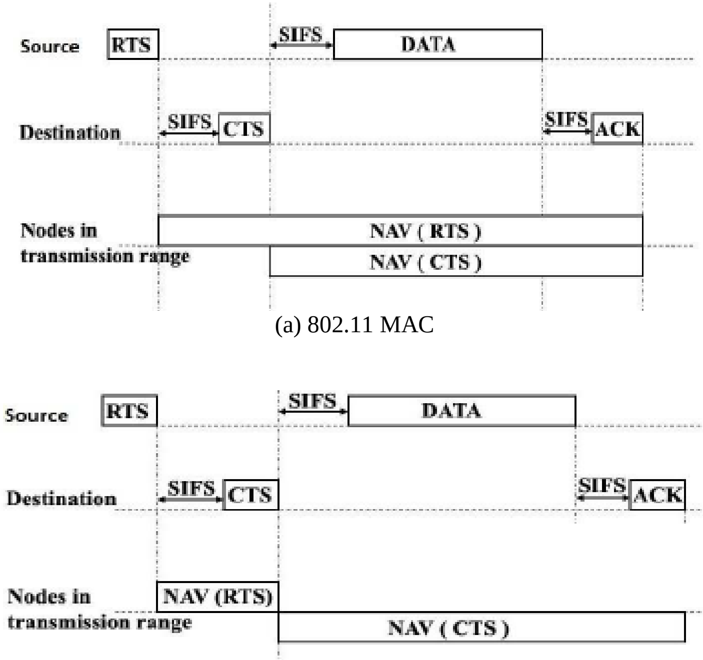
4.3. The Modified VCS Scheme

The Figure 4.4 shows the setting of NAV in 802.11 and proposed scheme. The modified Virtual Carrier Sensing Scheme is discussed as follows:

• In addition to NAV used in 802.11 MAC VCS, we use another parameter NAVR.
• If a node in the transmission range overhears an RTS frame, it will set its NAV to a slot time and the NAVR to the value in the duration field of RTS frame received. A

slot time is the time it takes a node to recognise a channel as busy or idle plus the time it takes to process a frame, prepare a response, and transmit it and for it to propagate to the receiving station.

• If the node overhears the CTS frame before the NAV expires, it will set the NAV using the value in the duration field of the CTS frame.
• If the node in the transmission range wants to send a frame, it will check the frame type.



(a) 802.11 MAC

(b) Proposed Scheme
Figure 5: Setting the NAV in 802.11 and proposed Scheme

• If it is an RTS frame it will check if NAVR expires or not. If NAVR expires, it can send the RTS frame. Otherwise it will wait for a back off time. If it is a CTS, DAT or ACK frame, it will check the NAV and if NAV expires to zero, it can send that frame.

5. Conclusion and Future Work

In this paper we have designed a power control MAC protocol for Mobile Ad Hoc Networks. We considered a network environment where every node participate in data transmission and applied a power control concept in that environment. The main goal of this work was to understand the different power conservation techniques in MANET and propose a protocol to achieve this goal.

Here we have proposed a power control MAC protocol for mobile ad hoc net- works which reduce the power consumption and increase the aggregate throughput. For that purpose we have made some modifications in the virtual carrier sensing scheme of 802.11 MAC.

In our work we consider a stable network environment. Mobility of the nodes did not take into consideration. In future works we can consider the mobility of the nodes to make it more suitable for mobile ad hoc networks.

6. References

[1] S. Singh and C.S. Raghavendra. Power Aware Multi-Access protocol with Signaling for Ad Hoc Networks. *ACM Comput. Commun*, 28(3):5, 26, 1998.
[2] A. Chockalingam and M. Zorzi. Energy efficiency of media access protocols for mobile data networks. *IEEE Trans. Commun*, 46(11):IEEE Trans. Commun, 1998.
[3] E.-S. Jung and N.H. Vaidya. An energy efficient MAC protocol for wireless LANs. *Proceedings of the IEEE INFOCOM*, June 2002.
[4] H.Woesner, J.P. Ebert, M. Schlager and A.Wolisz. Power saving mechanisms in emerging standards for wireless LANs: the MAC level perspective. *IEEE Person. Commun*, 5(3):40, 48, 1998.
[5] Y.-C. Tseng, C.-S. Hsu, T.-Y. Hsieh. Power-saving protocols for IEEE 802.11- based multi-hop ad hoc networks. *Proceedings of IEEE INFOCOM*, 2002.
[6] E.S. Jung, N.H. Vaidya. A Power Control MAC protocol for ad hoc net- works. *ACM International Conference Mobile Computing and Networking (MOBICOM)*, pages 36, 47, September 2002.
[7] J.P. Monks, V. Bharghavan, W. Hwu. A Power Controlled Multiple Access protocol for wireless packet networks. *Proceedings of the IEEE INFOCOM*, April 2001.
[8] Alexandre Andrade Pires, Jose Ferreira de Rezende and Carlos Cordeiro. ALCA: A New Scheme for Power Control on 802.11 Ad Hoc Networks. *IEEE WoWMoM*, June 2005.
[9] H. Cui, G. Wei, Z. Zhang and J. Zhang1. Medium access control scheme supporting real-time traffic with power control

in wireless ad hoc networks. *IET Commun.*, 4(4):377, 383, 2010.

[10] P.Mohapatra and S. Krishnamurthy. Ad hoc Networks, Technologies and protocols. Springer Science + Business Media, Inc., 2005.

[11] S.-L. Tsao, C. -H Huang. A survey of energy efficient MAC protocols for IEEE 802.11 WLAN. *Computer Communications*, 34:54, 67, 2011.

[12] Gavin Holland, Nitin Vaidya and Paramvir Bahl. A rate-adaptive mac protocol for multi-hop wireless networks. *7th Annual International Conference on Mobile Computing and Networking (MobiCom)*, 2001.

[13] Sunil Kumar, Vineet S. Raghavan and Jing Deng. Medium Access Control protocols for ad hoc wireless networks: A survey. *Ad Hoc Networks*, 4:326358, October 2006.

[14] T.-C. Hou and V. Li. Transmission range control in multihop packet radio networks. *IEEE Transactions on Commuications*, 34(1):38, 44, January 1986.

[15] C.-K. Toh. Associativity-based routing for ad hoc mobile networks. *Wireless Personal Communication*, 4(2):103139, March 1997.

[16] J. Gomez, A. T. Campbell, M. Naghshineh and C. Bisdikian. PARO: Supporting dynamic power controlled routing in wireless ad hoc networks. *Wireless Networks*, 9(5):443, 460, September 2003.

[17] L. M. Feeney. An energy consumption model for performance analysis of routing protocols for mobile ad hoc networks. *Mobile Networks and Applications*, 6(3):239, 249, June 2001.

[18] J.-P. Ebert, B. Burns and A. Wolisz. A trace-based aprroach for determining the energy consumption of a WLAN network interface. *In European Wireless*, 2002.

[19] Wireless Communications: Principles and Practice. *Theodore S. Rappaport*. Prentice Hall, 2nd edition, December 2001.