Performance Evaluation of an Interference-Aware Access Scheme for Point-to-Point Services in the ADHOC MAC Protocol

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***Abstract*- Mobile ad hoc networks require a complex management to efficiently exploit the networks resources. The capacity of these networks is determined by the capability of the medium access control mechanism to handle the access process and to achieve high resource reuse. The ADHOC MAC protocol allows to devise effective broadcast and point-to-point services for wireless ad hoc networks. However, this efficiency is lessened in a realistic interference scenario. In this paper we propose a dynamic strategy for reserving point-to-point resources capable of partially overcoming the problems stemmed from the realistic interfering nature of the shared wireless medium and we evaluate its performance through detailed simulation.**

***Keywords*- ad hoc networks, MAC protocols, point-to-point communications, interference-awareness**

I. INTRODUCTION

The fast growth that mobile communications have been experiencing in the last years and the increasing demand for new and flexible services have posed a great scientific and technical effort in order to provide prompt, reliable and efficient network architectures and protocols. Further on, in order to facilitate QoS support in ad hoc networks, it is very important to solve the tradeoff between guaranteeing the requirements for the QoS provision with the best efficiency in the use of the networks resources.

In ad hoc networks the complexity of resource management lies in the shared nature of the medium even more difficult to handle due to the dynamics of these scenarios. The scarcity in the wireless radio resources makes the network capacity highly dependent on the capability of the medium access control mechanism to handle the access process and to achieve high resource reuse [1].

ADHOC MAC [2] is a medium access control protocol recently introduced within the European Commission funded CarTalk2000 project [3] for providing connectivity in ad hoc inter-vehicles networks [4]. It works on a slot synchronous physical layer and implements a completely distributed access technique capable of dynamically establishing a reliable single-hop Basic broadcast CHannel (BCH) for each active terminal. Each BCH carries signalling information that provides a prompt and reliable distribution of layer-two connectivity information to all the terminals. This information provides a valuable basis for the efficient implementation of point-to-point data services and also supplies a prompt means to manage different QoS requirements for these services.

In [5] and [6] the performance of ADHOC MAC broadcast services in a static scenario and with users' mobility has been studied respectively, while in [7] an adaptive bandwidth allocation strategy was proposed to share the resources between broadcast and point-to-point communications in a dynamic situation. In [8], an access strategy for point-to-point connections based on resource reservation is proposed and evaluated through simulation in a distance-based model.

In this paper we evaluate the point-to-point service on a more realistic situation, where the interference produced by terminals out of decoding range is taken into account, proposing solutions to overcome the problems of this environment on the performance of the basic protocol.

The remaining of the paper is organized as follows. In Section II we briefly summarize the basis of the ADHOC MAC protocol and the access scheme for the point-to-point connections. The realistic interference model, its implications on the performance and the proposed solutions are described in Section III. In Section IV, the protocol is evaluated through simulation. Finally, in Section V some conclusions are provided.

II. THE ADHOC MAC PROTOCOL

A. Basic Operation

ADHOC MAC operates with a time slotted structure, where slots are grouped into virtual frames (*VF*) of length N, and no frame alignment is needed. For a correct operation, the ADHOC MAC needs that each active terminal has assigned a Basic CHannel (BCH), corresponding to a slot in the *VF*, which is a reliable single hop broadcast channel not suffering from the hidden-terminal problem.

In the BCH, each terminal broadcasts information on the status of the channel it perceives. The BCH contains a control field, the Frame Information (FI) field, which is an N-elements vector specifying the status of the N slots preceding the transmission of the terminal itself. The slot status can be either BUSY or FREE: it is BUSY if a packet has been correctly received or transmitted by the terminal, otherwise it is FREE. In the case of a BUSY slot the FI also contains the identity of the transmitting terminal. Based on received FIs, each terminal marks a slot, say slot k, either as RESERVED, if slot k-N is coded as BUSY in one FIs received in the slots from k-N to k-1 at least, or as AVAILABLE, otherwise. If a slot is AVAILABLE, it can be used for new access attempts.

Upon accessing an AVAILABLE slot, terminal *j* will recognize after *N* slots (a frame) its transmission either successful, if the slot is coded as "BUSY by terminal *j*" in all the received FIs, or failed, otherwise.

We define one-hop cluster (OH) as a group of mobile terminals all in the same cover range. The union of all OH-clusters with a common subset is denoted as two-hop (TH) cluster. The terminals belonging to the same OH-cluster see the same status (AVAILABLE or RESERVED) for all the slots; terminals belonging to different OH-clusters of the same TH-cluster mark as RESERVED all the slots used in the TH-cluster, whereas terminals belonging to disjoint OH-clusters usually see a different channel status. As a result, slots can be reused in disjoint OH-clusters, but can not be reused in the same TH-cluster and, therefore, the hidden-terminal problem can not occur [4].

B. *Point to point mode*

The BCH provides a reliable single hop broadcast channel which can be used both for signalling and for data traffic purposes. On top of this, point-to-point data communications among terminals can be effectively established by exploiting the distributed signalling provided by the FIs. To this end, each entry of the FI encloses a Point-To-Point (PTP) flag, which is handled as follows:

- A terminal sets the PTP flag of a given slot in the FI, if the packet received in the slot is a broadcast one or if it is destined to the terminal itself.

In order to set up a point-to-point communication, all the AVAILABLE slots can be used. Further on, even some RESERVED slots can be used according to this rule:

- A RESERVED slot can be accessed:
  - (i) if the PTP flag is signalled off in all the received FIs
  - (ii) and the FI received from the destination terminal signals the slot as FREE.

The whole set of slots that a terminal can select for PTP connections to a given destination will be referred as AVAILABLE PTP slots for that destination. The conditions above allow point-to-point transmissions to share the same slot when there is no collision at the receivers.

C. *A Book in Advance Scheme for Point-To-Point Links*

At the beginning of each virtual frame, a terminal must decide the number of slots to be allocated in the frame to give service to its current connections within the set of AVAILABLE PTP slots. In the basic operation mode, the terminal decides in which slots is going to transmit among the free ones and then directly access to them in the next Virtual Frame. Collisions can happen in the access since terminals choose randomly among the free slots leading to a reduction in the performance of the medium access.

On the other hand, the BCH capabilities can be used to signal the request before the access, in such a way that collisions can be theoretically avoided, according to the Book In Advance Scheme (BIAS) [8]. To this end, a new status, ACCESSING, must be included in addition to BUSY and FREE in the FI. Before transmitting its FI, a terminal marks in it all the new requests as ACCESSING, also containing its identity as in the BUSY status, and including in addition the identity of the destination.

Under these conditions, a terminal can receive several requests for a given PTP resource within its virtual frame, and not all of them have to be destined to the terminal itself. Upon receiving all the requests, it has to decide what to send in its FI. The decision must be consistent with the rest of neighbours. In a first approximation, it can choose the first received request and ignore the remaining. It has to include in the FI of that slot the status ACCESSING, the identity of the transmitter, and, if it is the destination, the PTP flag ON. After a frame, the transmitter must check the result of the requests. A reservation has been successful if:

- (iii) The slot is coded as ACCESSING by the transmitter in the FI of the destination terminal with the PTP flag ON
- (iv) and the PTP flag for that slot is not ON in the FI of any other terminal.

In any other case, the reservation has failed and must be re-attempted: if the slot is not coded as ACCESSING by the transmitter means that the receiver has chosen a different request, whereas if more nodes signal the PTP flag ON, they are waiting for receiving and, if established, this transmission would cause a collision. If the reservation has been successful, the transmitter terminal signals the slot as BUSY in its FI and it is able to transmit within the next virtual frame in a collision-free situation. Upon this, the slot will be maintained while it is necessary. This decision will be made in the next frame, during the scheduling process.

III. OPERATION IN AN INTERFERENCE-AWARE SCENARIO.

In a basic distance model scenario, connectivity among nodes is only based on Euclidean distances. In this situation, all nodes in the transmission range can correctly decode only one transmitted packet. If more than one neighbour transmits, a collision occurs. Transmissions one hop away are not sensed, which can lead to hidden and exposed terminal problems [9] but if the MAC signalling can avoid them, totally collision-free transmissions are possible and the reuse capability is theoretically maximized. In [8] it is shown that BIAS is an access scheme for the ADHOC MAC protocol that theoretically provides a collision free transmission, avoiding interference among terminals. However, in a more realistic scenario, where the actual interference produced by all the transmitting terminals is taken into account, collisions can still occur, leading to the loss of already reserved resources. As a consequence, a more exhaustive analysis must be carried out and additional procedures must be included. The received Signal to Interference Ratio (SIR) by a terminal in a slot is given by (1):

$$SIR^{k}_{rx,i,j} = \frac{P^{k}_{tx,i} \cdot L_{i,j}}{P_{int} + P_{noise}}, \quad P_{int} = \sum_{n \in N^{k}_{tx}, n \neq i} P^{k}_{tx,n} \cdot L_{n,j} \qquad (1)$$

where $SIR^k_{rx,i,j}$ is the received SIR by terminal j from terminal i in slot k, $P^k_{tx,n}$ is the transmitted power by user n in slot k, $L_{n,j}$ is the path loss between users n and j, P_{int} is the total interference produced by other transmitting terminals, N^k_{tx} is the set of transmitting terminals in slot k and P_{noise} is the thermal noise. A transmission is considered successful if $SIR^k_{rx,i,j}$ is higher than SIR_{th} (the minimum SIR required to decode the packet).

When a terminal, say j, is not decoding a packet or receiving in the FIs that some neighbour is transmitting in a given slot, say k, it signals this slot in its own frame information as FREE. If the PTP flag is signalled off in all the remaining received FIs of a potential transmitter, say i, this one can reserve this slot to transmit to terminal j. In this situation, terminal j can be suffering a certain level of interference from terminals that are not direct neighbours (it does not receive their FIs) that can lead to a collision if $SIR^k_{rx,i,j} < SIR_{th}$.

This problem can be lessened with the inclusion of a new status, DIRTY, in the FI of each terminal. A terminal set the status in a slot as DIRTY if it is neither decoding a packet nor receiving in the FIs that any neighbour is transmitting, but it is sensing an interference power. The interference power can be sensed if it exceeds a certain threshold, the Carrier Sense Threshold (CS_{th}). A terminal can not transmit in a slot that the potential receiver signals as DIRTY.

Anyway, in spite of the DIRTY slot, collisions can still occur, because even in a FREE slot, given a $P_{int} < CS_{th}$ it can still happen that $SIR_{rx} < SIR_{th}$, especially when two terminals are neighbours but with a little margin for additional interference. This situation can lead to persistent collisions, since the transmitter terminal always sees the slot as FREE, reserves it, and then collides. A list for each destination with the slots that have collided can be included in the transmitter in order to avoid them for a given number of frames although it observes as AVAILABLE.

Moreover, the inclusion of a new point-to-point connection can also produce a collision over an already ongoing connection, because the new one can increase the interference level P_{int} of the former, making that $SIR_{rx} < SIR_{th}$. This case is especially likely to occur when the receiver of the ongoing connection is near the new transmitter, but not enough to establish the BCH, i.e., to be neighbours. In this situation, since the potential transmitter does not receive the FI of the ongoing receiver, it does not realize the established connection and accesses, leading to a considerable increase in the interference level of the ongoing connection. This situation can be lightened with the inclusion of an additional short beacon preceding each data slot [10] that receivers of ongoing connections should transmit. A potential transmitter that observes a slot as AVAILABLE should check the beacon in that slot. In the case it senses some power level in the beacon it should not consider the slot as AVAILABLE in order to protect the already established connection. Again, collisions can still happen, since the interference of a new distant connection, whose transmitter does not sense the beacon, can be enough to make $SIR_{rx} < SIR_{th}$.

As it can be seen, the main problem in a realistic interference-aware scenario is that transmissions have influence not only on the one-hop neighbours, but on all the terminals in the network. We propose a basic power control procedure which adjusts the transmission power in each connection to mitigate this effect.

Terminal i wants to establish a connection with terminal j in slot k. In order to set up this connection, it needs to receive the FI of terminal j. We assume that the FI in the BCH is always transmitted at a fixed transmission power, $P_{tx\text{-}max}$. Supposing symmetrical links, the path loss from i to j can be estimated upon the received power in the BCH from j to i, $P_{rx,i,j}$

$$\hat{L}_{i,j} = \hat{L}_{j,i} = \frac{\hat{P}_{rx,i,j}}{P_{tx-max}} \tag{3}$$

If slot k is signalled as FREE, the transmitter assumes that the slot is interference-free, so it can adjust its transmission power for slot k, $P^k_{tx,i}$ according to:

$$P^k_{tx,i} = \begin{cases} \dfrac{SIR_{target} \cdot P_{noise}}{\hat{L}_{i,j}} & \text{if } P^k_{tx,i} \le P_{tx-max} \\ P_{tx-max} & \text{if } P^k_{tx,i} > P_{tx-max} \end{cases} \tag{4}$$

where SIR_{target} is the SIR used to estimate the transmission power and it must be chosen over the SIR_{th} in order to mitigate the effect of a possible interference level at the receiver below the CS_{th}.

Including in the FI additional information about the interference a terminal estimates in each slot can be used to extend this power control procedure to the DIRTY slots at the expense of increasing the control information sent in the BCH. In a situation where there are not FREE slots, the transmitter can check if the interference suffered for the receiver can be overcome in a DIRTY slot k with the available transmission power.

If (5) is fulfilled, the transmitter can access in the DIRTY slot k.

$$P^k_{tx,i} = \frac{SIR_{target} \cdot \left(P_{noise} + \hat{P}^k_{int}\right)}{\hat{L}_{i,j}} \le P_{tx-max} \tag{5}$$

IV. Performance Evaluation

We have built up an event driven simulator in C++ which implements all the functionalities of the ADHOC MAC. The topology in each simulation is configured with terminals randomly positioned within a square area with edge equal to 1 Km. As first step of analysis, we simplify the physical layer assuming neither fading nor shadowing in the calculation of the received power. Interference among users is considered in the physical level. The connectivity among terminals is determined by the ability of decoding the BCH transmissions according to the received SIR.

In this paper, we assume a static frame subdivision that guarantees the access requirements for BCH [7]. A frame with N slots is divided into N_{BCH} and N_{PTP} slots for BCH and PTP communications. For this assumption, a slot and frame time synchronization of each terminal in the network is required, which can be obtained with the Global Position System (GPS) or other solutions [11].

Terminals are generated at the beginning and remain active through all the simulation. Upon generation, each terminal tries to acquire a BCH, thus after a certain transient time, all of them have acquired their BCHs and a stationary scenario is arranged. This allows to evaluate the proposed PTP access scheme without interacting with failures in the BCH.

Under these conditions, each terminal generates PTP communications according to a Poisson process with intensity X (PTP connections/s). The source of each point-to-point communication is randomly chosen among the users with an active BCH, while the destination is randomly chosen among the source's neighbours. The duration of each point-to-point communication is exponentially distributed with mean D (frames). Likewise, each connection generates 1 packet per frame (CBR). The parameters X and D define the point-to-point offered traffic by each terminal.

We define a common framework of simulation by setting the length of a frame F = 100 ms, with a number of slots N = 50 (N_{BCH} = 25, N_{PTP} = 25). The number of terminals in the system is set to 100. The maximum transmission power, $P_{tx\text{-}max}$, is set in such a way that $SIR_{rx} = SIR_{th}$ at a distance R = 100 m when there is just thermal noise in the receptor. This will allow to compare the results in the SIR scenario with the ones obtained in a distance-based scenario with a coverage radius R = 100 m. The propagation model is given by (6). SIR_{th} is set to 5 dB, the thermal noise, P_{noise}, is -103 dBm and CS_{th} is 1dB over P_{noise}. The modification of the simulation parameters only impacts on the absolute values of the performance figures, whereas the comparative results obtained in this paper still hold.

$$L = 128.1 + 37.6 \cdot \log_{10}(d) \qquad d \text{ in Km} \qquad (6)$$

Since the FI of the receiver provides the acknowledgement for each packet, a retransmission strategy (selective repeat ARQ) has been implemented. Packets are retransmitted until they are correctly received or they exceed the maximum tolerable delay in the transmitter (Discard Time).

TABLE I
STRATEGIES DESCRIPTION FOR FIGURE LABELS.

Strategies	Description
BASIC	No specific SIR procedures
AD	Avoiding DIRTY slots
UD	Using DIRTY slots
L10fr	List for excluding slots during 10 frames
BC	Receiver Beacon
PCndB	Power Control. SIR_{target} = n dB

Figure 1 reports the outage probability for BCH. The solid curves show the outage in a distance based model for different values of N_{BCH}. The dotted ones represent the same in the SIR model. Results show that in a more realistic environment, more resources are required to obtain the demanded performance. In order to evaluate point-to-point connections in this scenario, this effect must be taken into account to properly dimension the frame.

The collision-free property of the reserved slots, theoretically provided by the access scheme [8] is not ensured any more due to the potential distant nodes interference. Fig. 2 shows the impact over the packet collision probability of the different strategies explained in Section III. The corresponding effect on the point-to-point throughput can be observed in Fig. 3. This figure also shows the significant performance degradation when compared to the distance model. The inclusion of the DIRTY status (AD), the list of slots with recent failures (L10fr) and the receiver beacon (BC) lead to a remarkable reduction in the packet collision probability, providing a more reliable resource reservation. However, at high load conditions, the PTP throughput drops under the BASIC mode, given that these strategies limit the set of available slots when some of them could be successfully accessed.

The power control mechanism reduces the interference, since it adjusts the transmitted power to provide reliable communications with the different destinations trying to minimize the impact over distant terminals (AD-PC). As a result, collision probability is lessened. Moreover, the network throughput is increased on reducing the set of DIRTY slots. The inclusion of interference information in the FIs to efficiently use the DIRTY slots (UD-PC) slightly improves the overall performance, because thanks to the power control, the set of additional DIRTY slots that can be successfully accessed is very low.

The selected SIR_{target} value has been set to 10 dB. In order to choose this value there is a trade-off between minimizing the interference to distant terminals and providing a margin over the SIR_{th} to tolerate additional interference. Fig. 4 and Fig. 5 show this trade-off. A SIR_{target} of 7.5 dB near SIR_{th} forces links with a little interference margin that lead to a higher collision probability. On the other hand, increasing in excess the SIR_{target} (15 dB) brings the transmission power near $P_{tx\text{-}max}$ then making this situation analogous to the operation without power control. For the set of simulation parameters, a SIR_{target} of 10 dB seems to provide a lower collision probability also increasing the PTP throughput.

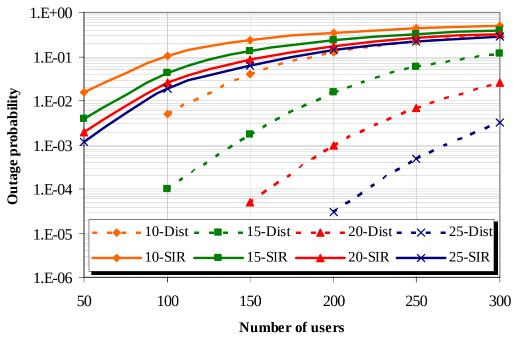

Figure 1. Outage probability for new accesses. Distance and SIR model.

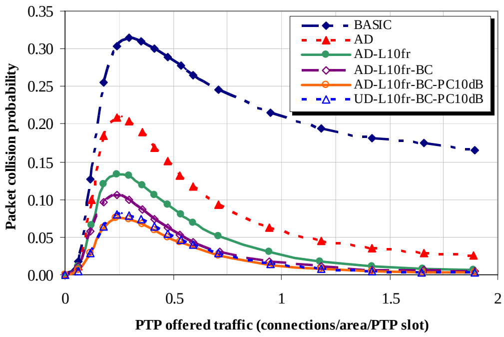

Figure 2. Packet collision probability versus point-to-point offered traffic for different strategies

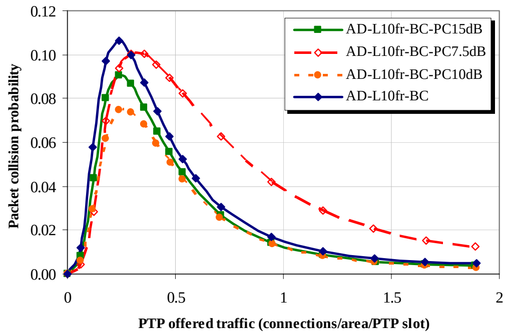

Figure 4. Packet collision probability versus point-to-point offered traffic for different *SIRt*$_{ar}$ values with power control.

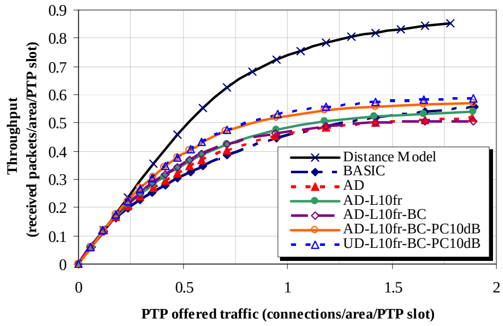

Figure 3. Point-to-point throughput versus point-to-point offered traffic for different strategies

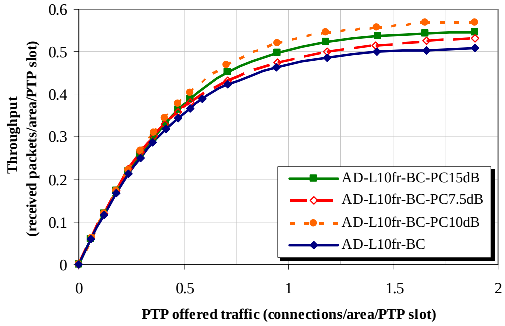

Figure 5. Point-to-point throughput versus point-to-point offered traffic for different *SIRt*$_{ar}$ values with power control.

V. Conclusions

In this paper, a point-to-point access scheme for the ADHOC MAC protocol has been evaluated through simulation with a realistic model that takes into account the actual interference among users instead of only the distances ranges.

In this situation, the interference power can affect the ongoing transmissions then reducing the reuse capability and the network capacity, leading to a performance degradation with regard to the ideal distance-based model.

However, the inclusion of additional procedures which are aware of the interference level allows to partially mitigate this degradation.

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References

[1] T. Rappaport, Wireless Communications: Principles and Practice, Prentice Hall, New Jersey, 1996.

[2] F. Borgonovo, A. Capone, M. Cesana, L. Fratta “ADHOC MAC: a new MAC Architecture for ad hoc Networks Providing Efficient and Reliable Point-to-Point and Broadcast Services”. *Wireless Networks*. Jul. 2004, vol. 10, issue 4, pp. 359-366.

[3] CarTALK2000 Home page: www.cartalk2000.net

[4] M. Aoki, “Inter-vehicle communication: technical issues on vehicle control applications”. *IEEE Communication Magazine*. Oct. 1996, vol. 34, pp. 90-93.

[5] F. Borgonovo, L. Campelli, M. Cesana, L. Coletti, “MAC for ad-hoc inter-vehicle network: service and performance”. in *Proc. IEEE VTC fall 2003*, Orlando, USA, Oct. 2003.

[6] F. Borgonovo, L. Campelli, M. Cesana, L. Fratta, “Impact of User Mobility on the Broadcast Service Efficiency in ADHOC MAC Protocol”. in *Proc. IEEE VTC 2005 Spring*, Stockholm, Sweden, May 2005.

[7] J.R. Gállego, L. Campelli, M. Cesana, A. Capone, F. Borgonovo, A. Hernández-Solana, M. Canales, A. Valdovinos, “Efficient Bandwidth Allocation for Basic Broadcast and Point-to-point Services in the AD-HOC MAC Protocol” in *Proc. IFIP PWC 2005*, Colmar, France, Aug. 2005.

[8] J.R. Gállego, M. Canales, A. Hernández-Solana, L. Campelli, M. Cesana, A. Valdovinos, “Performance Evaluation of Point-to-Point Scheduling Strategies for the ADHOC MAC Protocol” in *Proc. WPMC 2005*, Aalborg, Denmark, Sep. 2005.

[9] Z.J. Haas and Jing Deng, “Dual busy tone multiple access (DBTMA) –a multiple access control scheme for ad hoc networks”, *IEEE Transactions on Communications*. vol 50, issue 6, pp 975–985, 2002.

[10] J.C. Fang and G.D. Kondylis, “A Synchronous, Reservation Based Medium Access Control Protocol for Multihop Wireless Networks” in *Proc. IEEE WCNC 2003*, New Orleans, USA, Mar. 2003.

[11] A. Ebner, H. Rohling, M. Lott, and R. Halfmann, “Decentralized slot synchronization in highly dynamic ad hoc networks”. in *Proc. WPMC 2002*, Hawaii, USA, Oct. 2002.