Power Control in Ad Hoc Networks: An Overview

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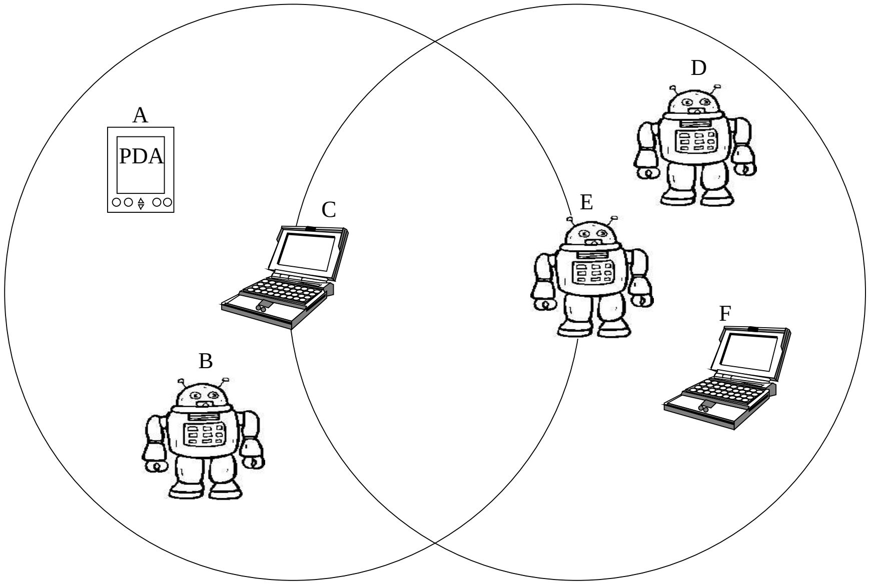
Overview

- Introduction
- Power control directions
- Signal quality
- Proposed power control
- Simulation results
- Conclusion

Introduction

- Node A may communicate to node D, through nodes C and E.
- Suppose that node E is receiving message from node D. Node C will not be able to sense that there is transmission in progress and if it tries to transmit to node E, without access control, collisions will occur (this is known as the *hidden node problem*).
- Also, nodes A and C cannot communicate together if nodes D and E are communicating.



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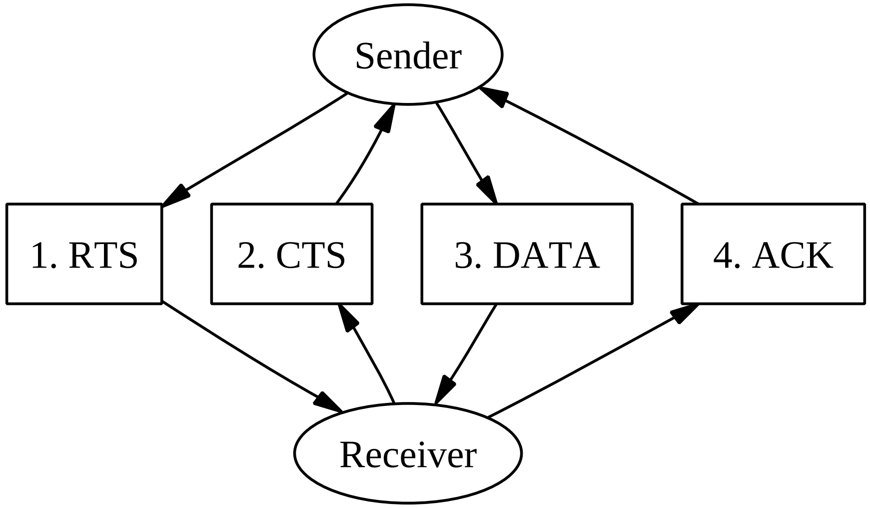
Medium Access Control

IEEE 802.11 uses the following signaling protocol: Every time a signal is to be sent,

1. A request-to-send (RTS) message is send.
2. If the receiving node is free, it will broadcast a clear-to-send (CTS) message.
3. If the transmitting node hears the CTS, it will proceed to transmit its data (DATA), otherwise collision will be assumed and it will back off for a certain amount of time before trying again.
4. After DATA is transmitted the receiving node will transmit an acknowledgment (ACK).
5. Any node that can hear those signals, RTS-CTS-DATA-ACK, will have some information about the occupation of the channel and for how long.



Power Control Directions

- The first direction is concerned with finding an optimal transmission power to maintain the connectivity of the network or parts of it, or is concerned with adjusting the transmission power such that the number of one-hop neighbors is bounded.
- The second direction is to design power efficient routing.
- The third direction is concerned with modifying the MAC layer to allow nodes to turn off or go to sleep mode.

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Signal Quality

Communication systems based on spread spectrum are limited in capacity predominantly by interference. The goal of the power control algorithms is to fi nd the transmission power of each node such that the following is satisfi ed:

$$\gamma_i = \frac{G_{ki} p_i}{\sum_{j \neq i}^{Q} p_j G_{kj} + n_i} \geq \gamma_i^*, \quad (1)$$

where γ_i is the signal-to-interference ratio (SIR) for node i, G_{ki} is the communication gain between node i and node k that it is communicating with, γ_i^* is the desired SIR level for the ith node with receiver noise n_i and transmission power p_i which is constrained as follows

$$p_{i\_\min} \leq p_i \leq p_{i\_\max}, \quad (2)$$

where $p_{i\_\max}$ and $p_{i\_\min}$ are the maximum and minimum transmission powers of node i, respectively.

Proposed Power Control

View each node-to-node connection as a separate subsystem as shown by

$$s_i(n+1) = \frac{p_i(n) + u_i(n)}{I_i(n)} = s_i(n) + v_i(n), \tag{3}$$

where $I_i(n) = \sum_{j=1}^{Q} p_i(n) w_{ij}(n) + \frac{n_i}{G_{ki}(n)}$, Q is the total number of nodes in the network, w_{ij} is the normalized interference, $v_i(n) = u_i(n)/I_i(n)$ and by definition $p_i(n)/I_i(n) = s_i(n)$. The input $u_i(n)$ to each subsystem depends only on the total interference produced by the other nodes.

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Proposed Power Control (2)

A new state is added to the system. This state represents an integrator of the error $e_i(n) = s_i(n) - \gamma_i^*$. A discrete time integrator is nothing more than a summation of the previous values, therefore

$$\zeta_i(n+1) = \zeta_i(n) + e_i(n) = \zeta_i(n) + s_i(n) - \gamma_i^*. \quad (4)$$

Let us define $x_i(n)$ as

$$x_i(n) = \begin{pmatrix} \zeta_i(n) \\ e_i(n) \end{pmatrix}. \quad (5)$$

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Proposed Power Control (3)

The system can now be expressed as a second-order linear state-space system by

$$x_i(n+1) = \begin{pmatrix} \zeta_i(n+1) \\ e_i(n+1) \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 0 & 1 \end{pmatrix} x_i(n) + \begin{pmatrix} 0 \\ 1 \end{pmatrix} v_i(n), \qquad (6)$$

and we then choose the feedback controller:

$$v_i(n) = -\begin{pmatrix} k_\zeta & k_e \end{pmatrix} x_i(n). \qquad (7)$$

In the steady state, $x_i(n+1) = x_i(n)$. Therefore, we have $\zeta_i(n+1) = \zeta_i(n) + s_i(n) - \gamma_i^*$, and in the steady state $s_i(n) = \gamma_i^*$.

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Power Control Algorithm

Once K is found, the new power command can be computed as follows

$$p_i(n+1) = \min\left\{p_{i\_\max}, \max\left\{p_{i\_\min}, s_i(n+1)\cdot I_i(n)\right\}\right\}. \quad (8)$$

state $s_i(n+1)$ in Equation (3). The *min* and *max* operators in Equation (8) ensure that the power levels are within the permissible range defined in Equation (2).

Simulation Environment

- The discrete event network simulation, NS version 2.26, will be used.
- In 1995, NS development was supported by DARPA through the VINT project.
- Because of the CMU Monarch project extensions, NS supports the IEEE 802.11 MAC standard which executes above a wireless RF (radio frequency) physical layer.
- The four different ad-hoc routing protocols currently implemented for mobile networking are DSDV, DSR, AODV and TORA.
- NS is written using Tcl/C++.

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Limitations of NS

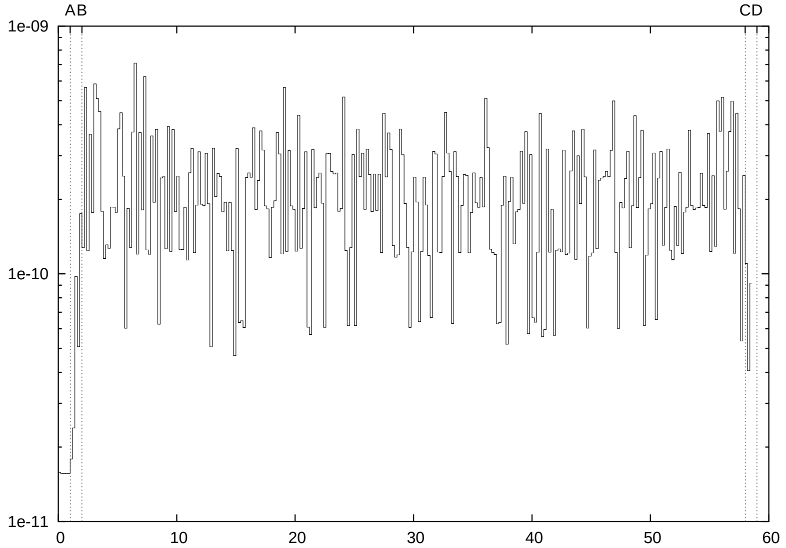
- No systems for adaptive control over transmission power
- Interference model too simple
  - Assumes constant noise floor, regardless of active transmissions
  - Collision only checks two power levels, not all power levels (the level of the packet being received and the interfering packet)

Our NS Modifications

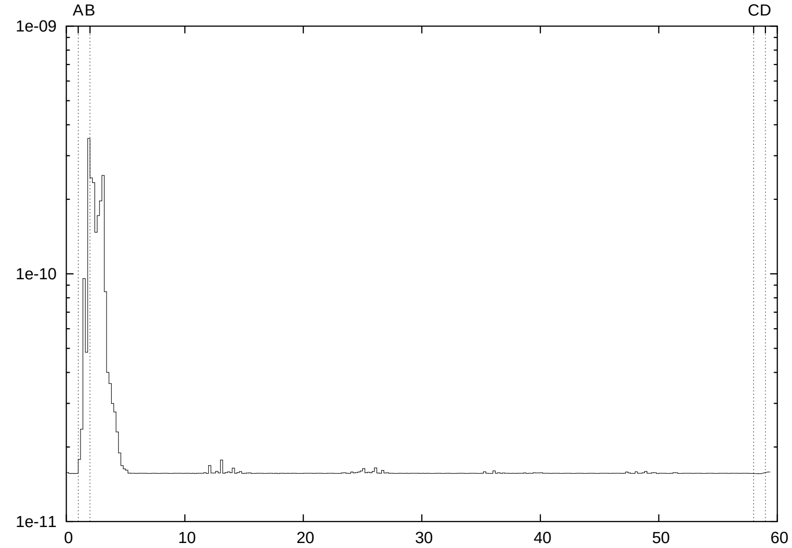
- Added classes that allow convenient modulation of transmission power for power control purposes
- Interference is now computed from all transmissions
- Required hooking and overriding portions of the Mac and Phy layers in NS

Simulation Results

Interference Level



with no power control



with power control

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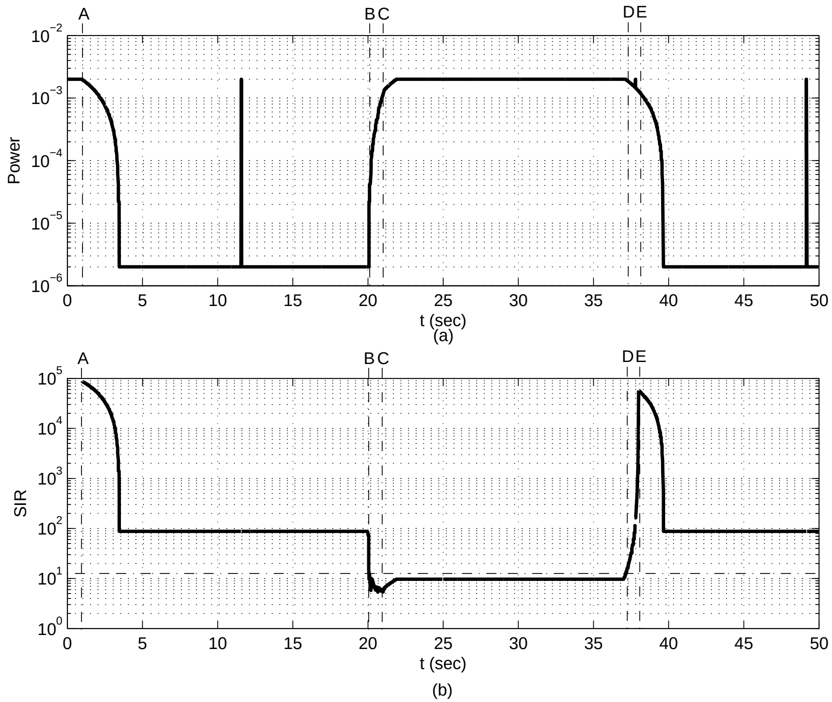
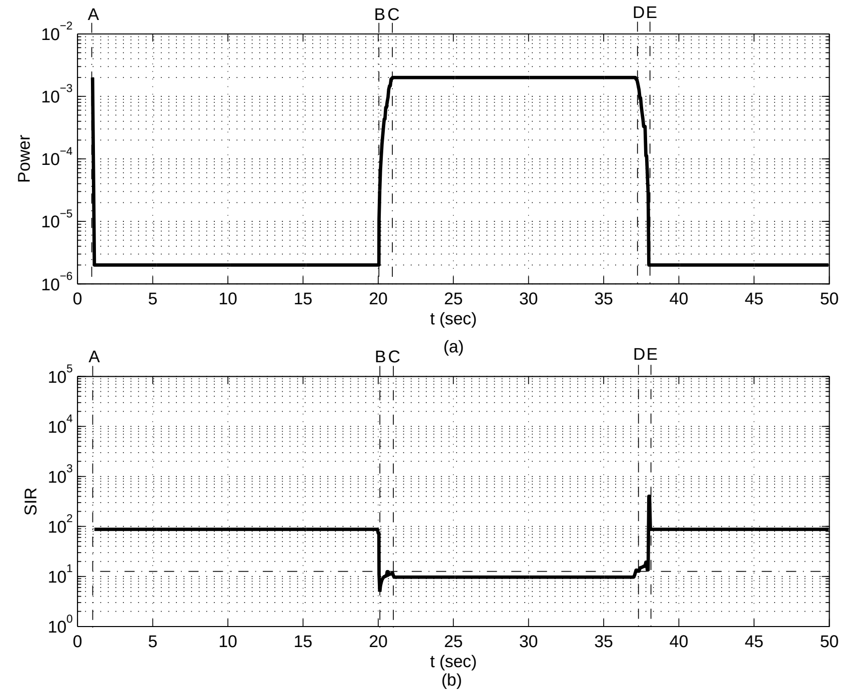
Simulation Results

Received Power and SIR Levels



BASIC power control



Proposed power control

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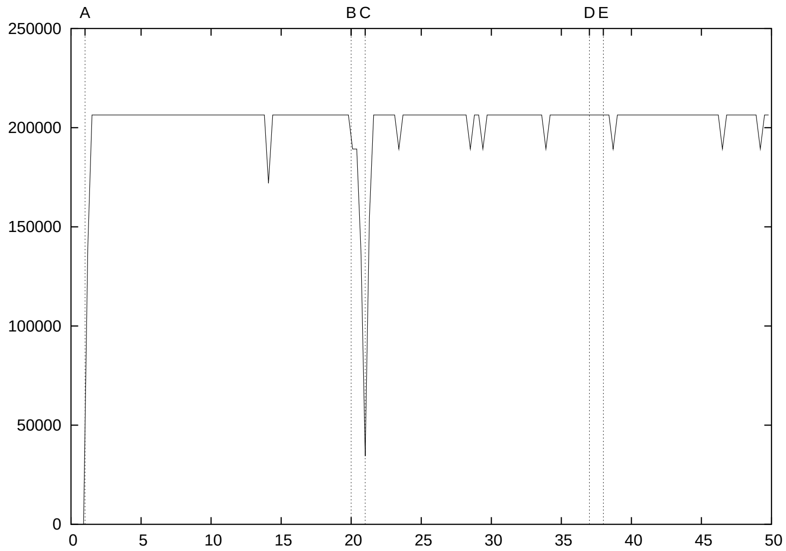
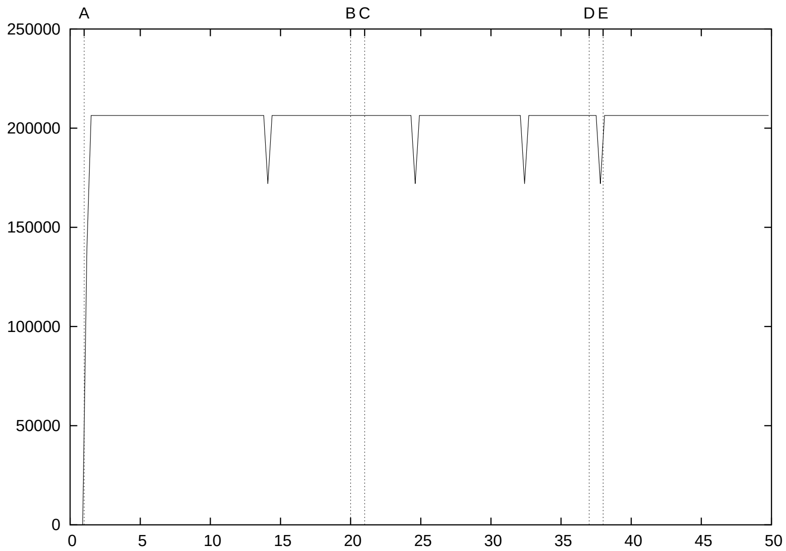
Simulation Results

System Throughput



BASIC power control



Proposed power control

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Conclusion

- Overview of Mac functions
- Adapted NS to simulate power control and model interference
- Demonstrated effectiveness of power control at minimizing interference levels
- Successfully designed a new power control algorithm employing modern control theory
- Comparison showed the effectiveness of new power control algorithm over BASIC approaches