CDMA-Based MAC Protocol for Wireless
Ad Hoc Networks

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Today’s Presentation

- Introduction
- The Near-Far problem
- Protocol design
- Protocol description
- Simulation
- Results and Evaluation
- Conclusion and future work

Introduction: Motivation

- Mobile Ad hoc NETworks (MANETs)
- Ability to provide temporary wireless networking capability; low throughput
- Challenge: Increases overall n/w throughput maintaining low energy consumption
  - Harsh characteristics of channel
  - Contention based nature of MAC
- Focus: CDMA based design of MAC protocol to improve n/w throughput

Intro: CDMA?

- Code Division Multiple Access
- Bandwidth = Scarce
- Traditional methods: transmit using least b/w
- Eg. TDMA, FDMA
- CDMA based on Spread Spectrum: Each user occupies entire available b/w.
- Transmitter B1 bits/s *spread* with pseudo-random noise (PN) B2 bits/s

Intro: CDMA!

- B2/B1 >> 1 (processing gain)
- PN statistically random but can be exactly reproduced through precise math rules
- Using locally generated PN receiver *de-spreads* signal; recovers original info
- Several independently coded signals can occupy the same channel b/w provided each signal has diff PN code

Intro: CDMA Propaganda

- 3G’s choice
- 6 times capacity of TDMA, FDMA
- Graceful signal degradation
- Multi-path resistance
- Interference rejection
- 802.11 spreads signals with common PN code at physical layer
- Thus not allowing concurrent transmissions
- Diagram

Intro: Code Assignment Issues

- Absence of centralized control (base station)
- Code assignment protocol: diff codes to diff terminals
- Trivial in small n/ws
- Not feasible for MANET’s time async systems
- Spatial code reuse necessary

Intro: Spreading Code protocol

- Which codes to use for packet transmission and monitoring for packet reception
- 3 types
  - Receiver based
  - Transmitter based
  - Hybrid

Intro: Receiver based

- Transmitter uses code of intended receiver to spread packet
- Idle node will monitor its own code only
- Advantages:
  - Simple receiver circuit
- Disadvantage:
  - Primary collision can happen
  - Broadcast requires transmitter to unicast to each receiver
- Diagram

Intro: Transmitter based

- A different code is assigned to each node
- But, the receiving node must listen to all codes
- Advantages:
  – Avoids Primary Collision
  – Simplified Broadcast
- Disadvantage:
  – Increased complexity of the receiver

Intro: Hybrid based

- Prevalent Approach
  - Fields of the packet are spread using a common code
  - Other fields are spread by a receiver or a transmitter based mechanism
- In the reservation based schemes:
  - a code is used for RTS/CTS
  - Another code for data exchange
- Receivers will listen to the common code
  - If a receiver was intended by the transmitter
  - Switch to own (or transmitter) code to receive the signal
- Example: RA-CDMA

Intro: RA-CDMA

- Guaranteed free of primary collisions
- However, non-zero cross-correlation causes multi-access interference; MAI
- Results in secondary collision at receiver (collisions between transmissions using diff codes)
- This is known as Near-Far problem; the bane of MANETs

The Near-Far problem in RA-CDMA

- System is time-sync if signals originate from same transmitter. Eg downlink in cellular CDMA
  - Common time reference, diff receivers, same path and same time delays
  - Complete orthogonal codes
- System is time-async if signals originate from multiple transmitters. Eg uplink in cellular or MANETs
  - No common time reference, diff transmitters, diff path and diff time delays
  - Not possible to have orthogonal codes

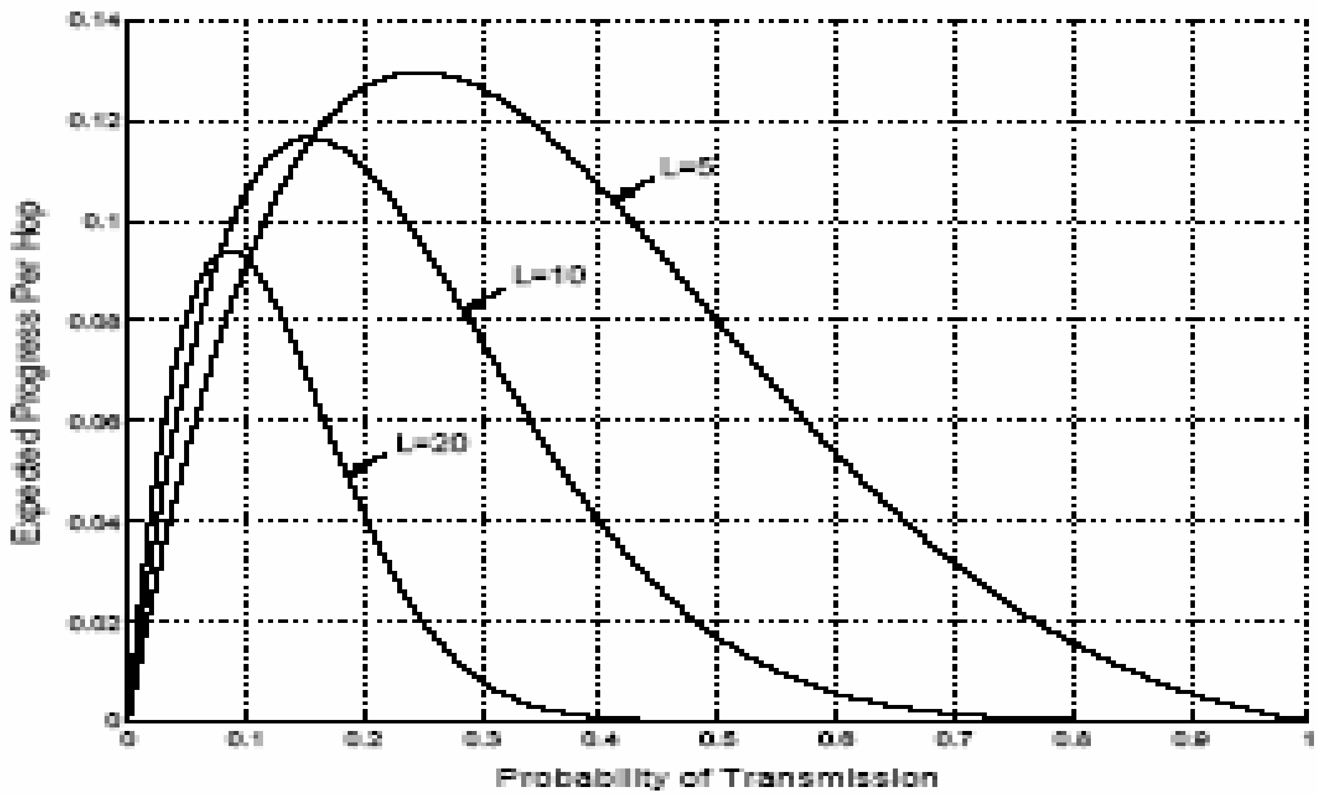
The Near-Far problem in RA-CDMA

- CDMA codes suffer from non-zero cross-corr
- Receiver computes cross corr between signal and local PN
- If PN same message intended for this receiver
- Else 0 or non-zero depending if sync or async
- Near-Far severe consequence of MAI: receiver trying to detect signal of one is closer to another
- Transmission power equal, closer signal→ higher power→ incorrect decoding. Collision
- Diagram

NFP: Impact

- d0=distance between receiver and intended transmitter
- Calculations show that if there is only 1 interferer at distance < 0.38 d0 from receiver, secondary collision will occur
- p=probability that terminal is transmitting in a given slot
- L=number of nodes within a circle centered at transmitter radius d0

NFP: Impact

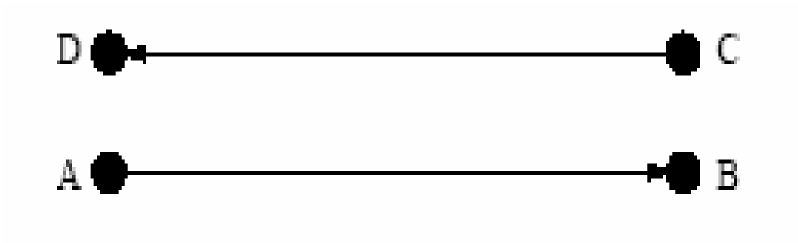


0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Expected Progress Per Hop
Probability of Transmission
L=5
L=10
L=20

Proposed protocol

- Main Goals:
  - To provide a CDMA-based MAC solution that addresses near-far problem
  - A Protocol that can achieve enhanced throughput keeping the same energy requirement
- Basic idea
  - a distributed admission and feedback among nodes
- Diagram

Proposed protocol



Suppose that A wants to communicate with B using a given code and C wants to communicate with D using a different code. Suppsoe that $dAB \approx dCD$, $dCB << dAB$, and $dAD << dCD$. Then, the MAI caused by C makes it impossible for B to receive A's transmission. Similarily, the MAI caused by A makes it impossible for D to receive C's transmission.

Comparison

SS protocol

Decides which PN code used to Spread the signal

Doesn't solve contention on the medium

MAC Protocol

Responsible for minimizing or eliminating collisions

Even if a terminal has an available spreading code, it may not be allowed to transmit

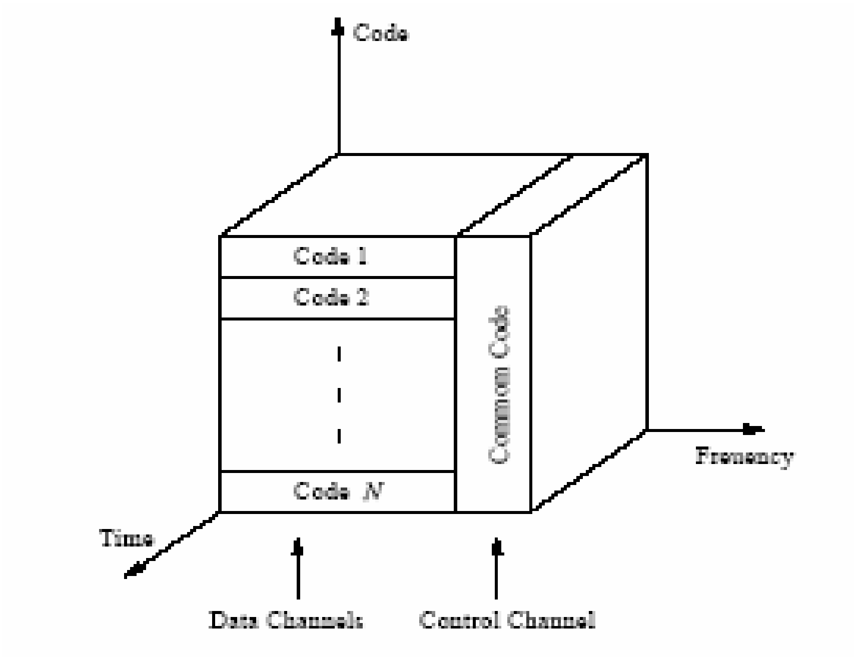
Design Goals

- Asynchronous, distributed, scalable solution for large Networks (Matches MANET environment)
- Receiver stage shouldn't be overly complex (Receiver Based spreading code)
- Adapt to channel characteristics and mobility patterns
- Able to coupe with incorrect code assignment "code assignment is left to the upper layers"

Design Architecture

- Two Separate Frequency channels (FDM-like partitioning) - one for the RTS/CTS and the other for data exchange
- Common Spreading Code for the control channel
- Receiver Based spreading codes for the data channel
- Codes are not assumed to be orthogonal
- Control and data channels are completely orthogonal
- Diagram

Design Architecture



Protocol Assumptions

- Control and data channels are completely orthogonal
- Channel gain is stationary for the duration of the control and data packet Transfer
- Gain is same in both directions
- Data packets between pair of terminals observe similar gain
- The radio stage can provide a feedback to the upper MAC layer (about the interference level) “both ways”

Protocol Description

- Contention based. Uses a variant of RTS/CTS reservation scheme
- RTS and CTS are spread using a common code and transmitted over the control channel using fixed power *Pmax*
- RTS and CTS are heard by potentially interfering nodes, however, these nodes are allowed to transmit based on some constraints
- For the Data channel, Receive and Transmitter should agree on:
  - Spreading Code: “code assignment is dealt with at upper layers”
  - Transmit Power
- Choice of power is critical and represents a trade-off between link quality and max allowable interference

More protocol description

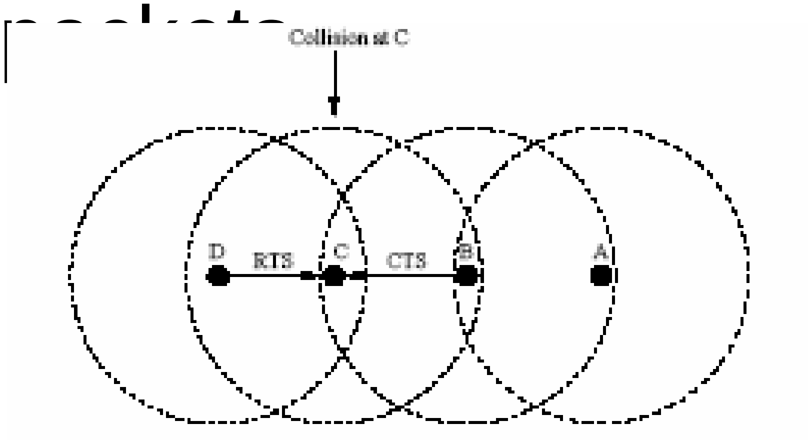
- In addition, the protocol incorporates an **Interference Margin** into the power computation. Allows nodes at some distance from a receiver to start new transmissions in the future
- Nodes exploit the knowledge of the power level of the overheard RTS and CTS transmissions to compute this margin
- A transmitter can decide when and at what power it can transmit without disturbing ongoing transmissions in its surrounding and at the same time ensuring enough power at the receiver given the current “MAI at the receiver”.
- Distribute feedback to neighbors, through the CTS messages.

Channel Access Mechanism

- Transmissions that cause neither primary nor secondary collisions
- RTS/CTS provide 3 functions:
  - Allow nodes to estimate channel gains between transmitter and receiver
  - A receiver uses CTS to notify its neighbors of the additional interference noise "allowable noise rise" it can accept without impacting its current reception
  - Each terminal keeps listening to the control channel regardless of the signal destination

Protocol recovery

- When transmission and propagation times of control packets are long high probability of collision of CTS and RTS of another contending terminal leading to collision with data packets
- Eg



Code Assignment

- N/w topology continuously changing
- Diff to guarantee correct code assignment
- Duty of MAC to reduce/eliminate contention

(see previous slide)

Simulation

- Used CSIM programs
- Focused on 1 hop throughput
- Data packets have fixed size
- Transmission periods for RTS, CTS, data, ACK in tens of ms
- Used random grid and clustered topologies
- M=number of mobile hosts. Assume 36 Length 3 km
- CA-CDMA 280% throughput increase over 802.11. Due to simultaneous transmissions
- Uses shorter links to save energy

Graphs

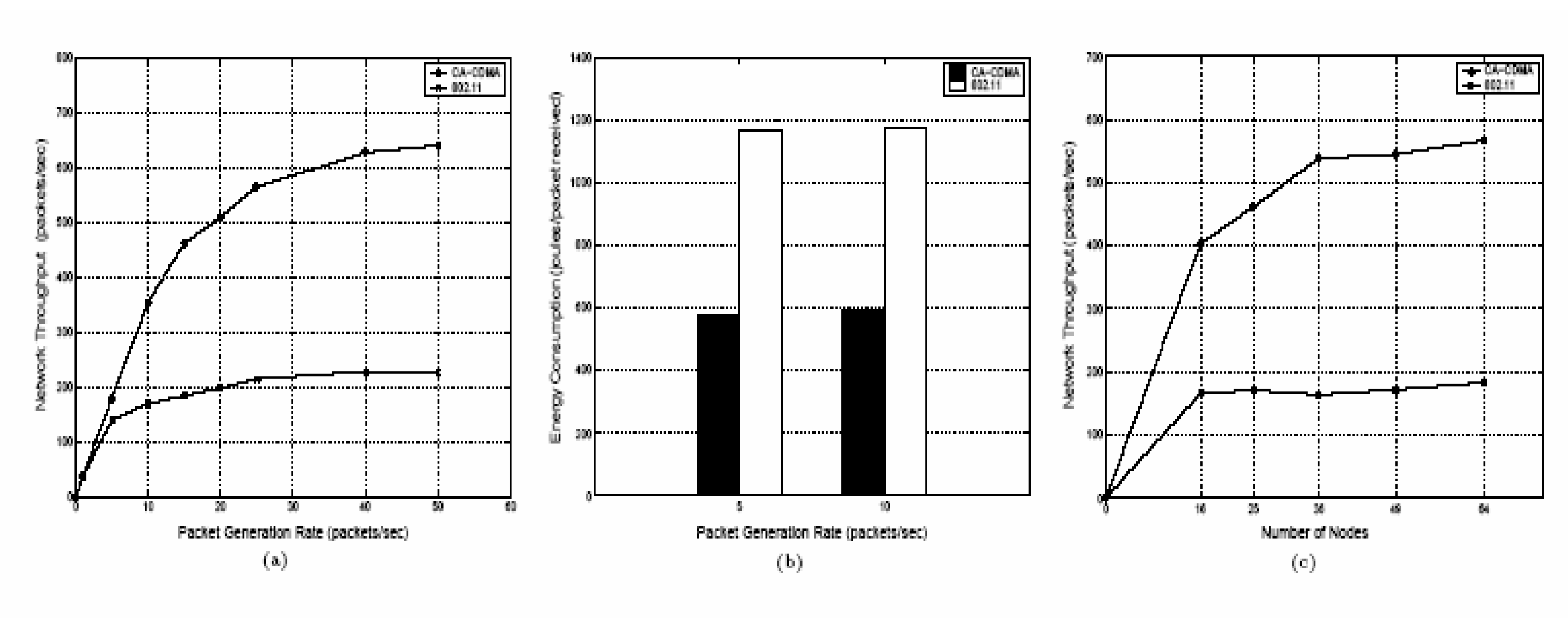


Figure 8: Performance of the CA-CDMA and the 802.11 protocols (random grid topologies).

Conclusion & Future Work

- Conclusion:
  - CA-CDMA is a distributed power control CDMA based MAC protocol.
  - CA-CDMA provides an enhancement for the throughput in MANETs through addressing the near far problem
- Future Work:
  - Combine CA-CDMA with other capacity optimization schemes. E.g. directional antennas
  - Multi-rate support is also another opportunity for capacity optimization
  - Devise better schemes for access control over the control channel

Thank you!

PS: I hope I get a good grade!