IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 5, NO. 11, NOVEMBER 2006

DUCHA : A New Dual-Channel MAC Protocol for Multihop Ad Hoc Networks

Hongqiang Zhai, *Student Member, IEEE*, Jianfeng Wang, *Student Member, IEEE*, and Yuguang Fang, *Senior Member, IEEE*

Presented by Richard Chang

March 16, 2007

Outline

- Introduction
- Background
- Problems and the Desired Protocol Behavior
- DUCHA:A New Dual-Channel MAC Protocol
- Performance Evaluation
- Conclusions

Introduction

- CONTENTION-BASED medium access control (MAC) protocols have been widely deployed for wireless networks due to the low cost and easy implementation..
- However, IEEE 802.11 MAC has been shown to be quite inefficient in the multihop mobile environments.

Introduction

- The **hidden terminals** introduce collisions and the **exposed terminals** lead to low spatial reuse ratio.
- The **receiver blocking problem** is more severe in the multihop environments and results in packet dropping, starvation of some traffic flows or nodes, and possible network layer re-routing
- Furthermore, for multihop flows, **the contentions or interferences from the upstream and downstream nodes** and other flows could lead to poor packet delivery performance.

Introduction

- This paper utilizes two channels (dual-channel) for control packets and DATA packets, separately.
- Negative CTS (NCTS) is used to solve the receiver blocking problem and is also transmitted in the control channel.
- An outband receiver-based busy tone is used to solve the hidden terminal problem.
- Furthermore, this protocol has an inherent mechanism to solve the intra-flow contention and could achieve optimum packet scheduling for chain topology.

Background

$$SINR_i = \frac{P_i}{\sum_{k \neq i} P_k + N} \geq \beta$$

$$P_r = P_o \left(\frac{d_o}{d} \right)^{\alpha} ; \alpha \geq 2$$

$$\left(\frac{P_r}{P_i} \right) > CP_{Thresh}$$

$$d_i = d_r \left(\frac{P_r}{P_i} \right)^{1/\alpha} > d_r \times CP_{Thresh}^{1/\alpha} = \Delta_c \times d_r$$

$$d_{i\min} = \Delta_c \times d_t$$

$$d_s == \Delta_s \times d_t, \Delta_s > \Delta_c$$

$$CP_{Thresh} = 10dB$$

$$\Delta_c \cong 1.78, \Delta_s \cong 2.2$$

$$CP_{Thresh} = 6dB$$

$$\Delta_c \cong 1.41, \Delta_s \cong 2.2$$

The radius of the sensing / interference range is about twice of the transmission range

Problems and the Desired Protocol Behavior

- Hidden and Exposed Terminal Problem
- Limitations of NAV Setup Procedure
- Receiver Blocking Problem
- Intra-Flow Contention
- Inter-flow Contention
- Desired Protocol Behavior
- Limitation of IEEE 802.11 MAC Using a Single Channel

Hidden and Exposed Terminal Problem

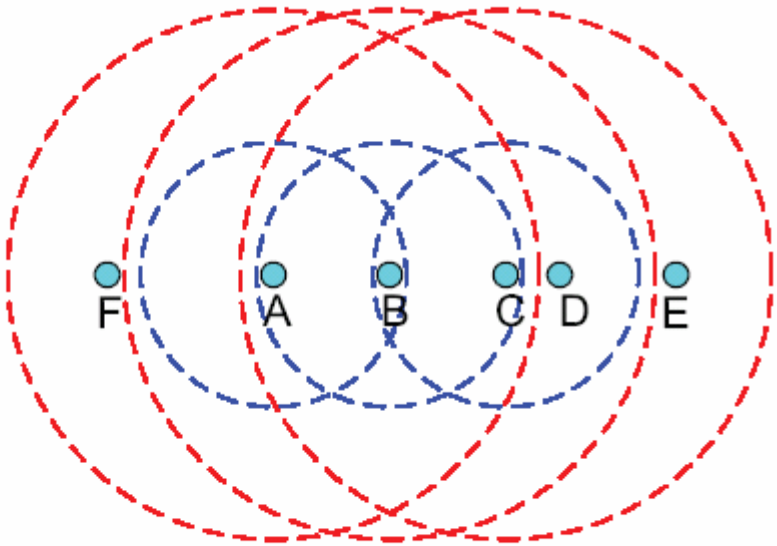
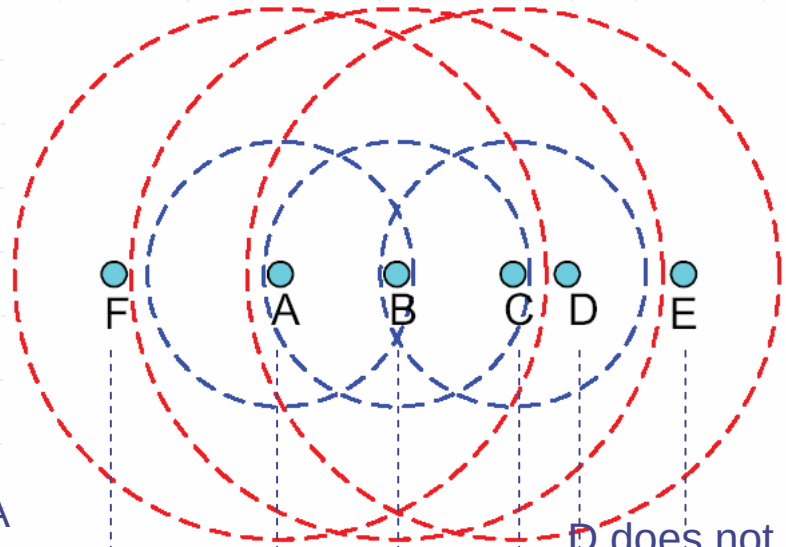


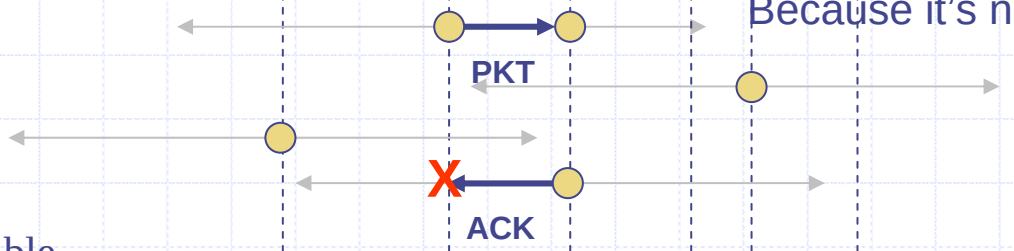
Fig. 1. A simple scenario to illustrate the problems.

Hidden and Exposed Terminal Problem



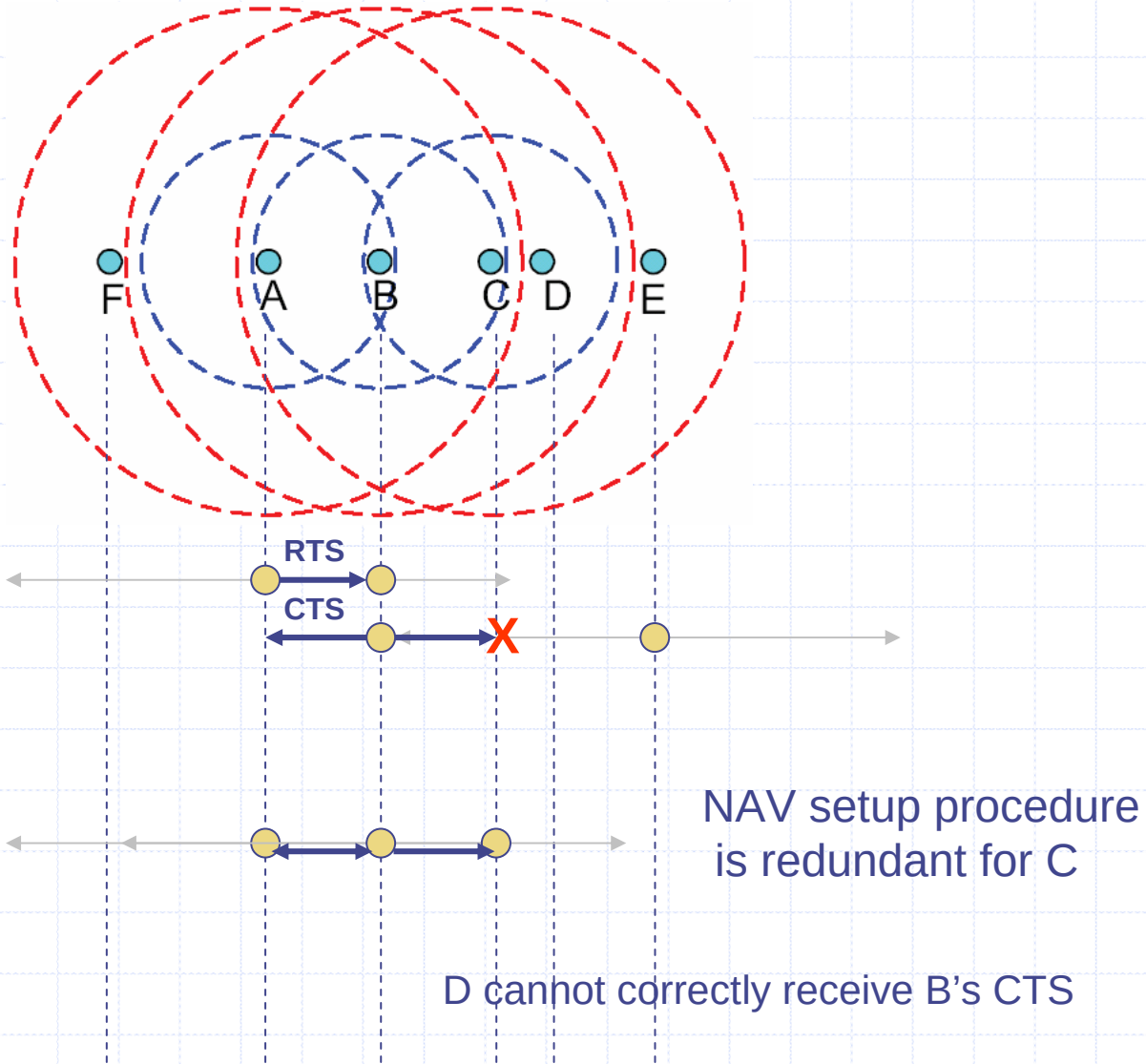
F is the exposed node of A
F also is the hidden node of B

D does not receive the correct CTS from B,
Because it's not in B's transmission range

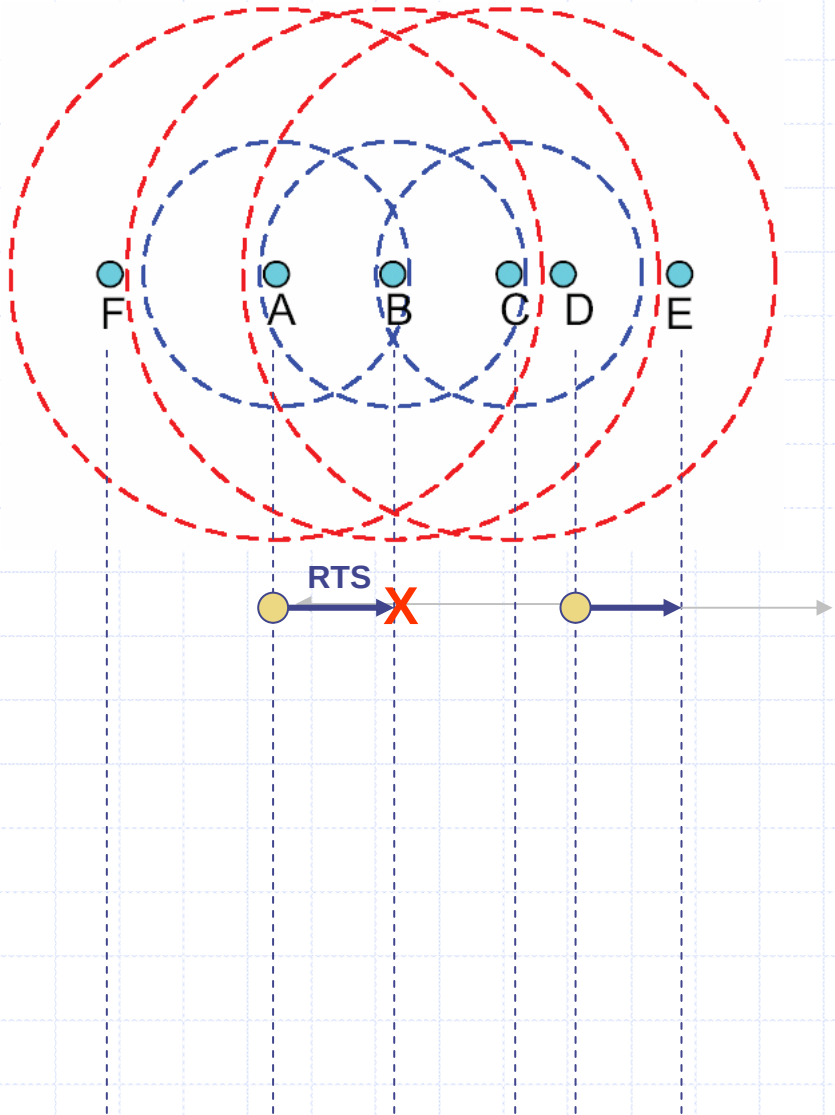


Sender F will possible
collision to the ACK's Reception of A

Limitations of NAV Setup Procedure



Receiver Blocking Problem



Inter/Intra-Flow Contention

Intra-Flow Contention

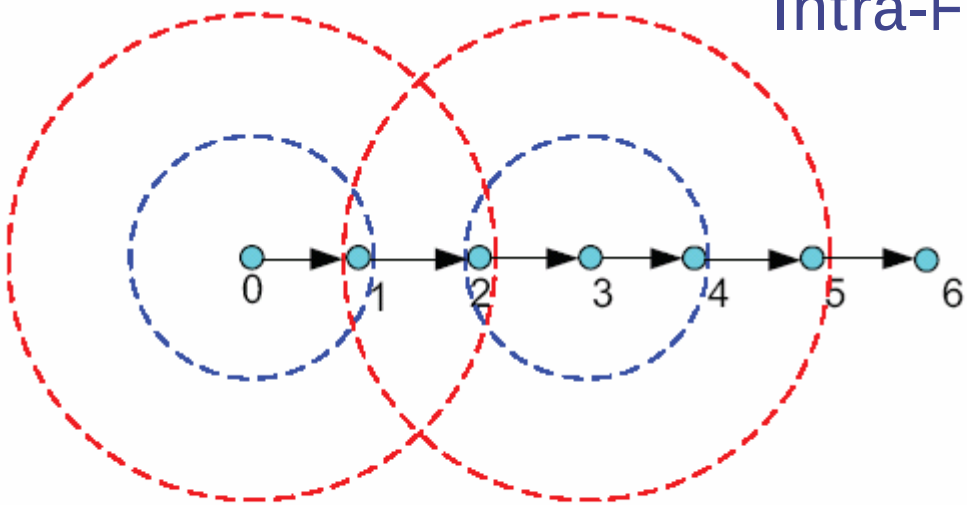


Fig. 2. Chain topology.

Desired Protocol Behavior

- It should guarantee that there is only one receiver in the range of a transmitter and only one transmitter in the range of a receiver.
- The exposed nodes can start to transmit in spite of the ongoing transmission.
- The hidden nodes cannot initiate new transmissions but may receive packets
- it should allow **multiple receivers** in the range of any receiver to receive and **multiple transmitters** in the range of any transmitter to transmit.
- The transmitter should also know whether its intended **receiver is blocked** or is **outside of its transmission range** when it does not receive the returned CTS to avoid discarding packets and the undesirable behavior at the higher protocol layer, such as false alarms of route failures.

Limitation of IEEE 802.11 MAC Using a Single Channel

- Many aforementioned problems cannot be solved if a single channel is used in the IEEE 802.11 MAC protocol.

DUCHA:A New Dual-Channel MAC Protocol(1)

- This protocol utilizes **dual channel** for DATA and control packets, separately.DATA is transmitted over the data channel. RTS and CTS are transmitted over the control channel.
- **Negative CTS** (NCTS) is used to solve the receiver blocking problem and is also transmitted on the control channel.
- An **outband receiver based busy tone** is used to solve the hidden terminal problem.

DUCHA:A New Dual-Channel MAC Protocol(2)

- **ACK is unnecessary** here because this protocol can guarantee that there is no collision to DATA packets.
- To deal with wireless channel errors, this paper introduces a **NACK signal** which is a continuing busy tone signal when the receiver determines that the received DATA packet is corrupted.

DUCHA:A New Dual-Channel MAC Protocol

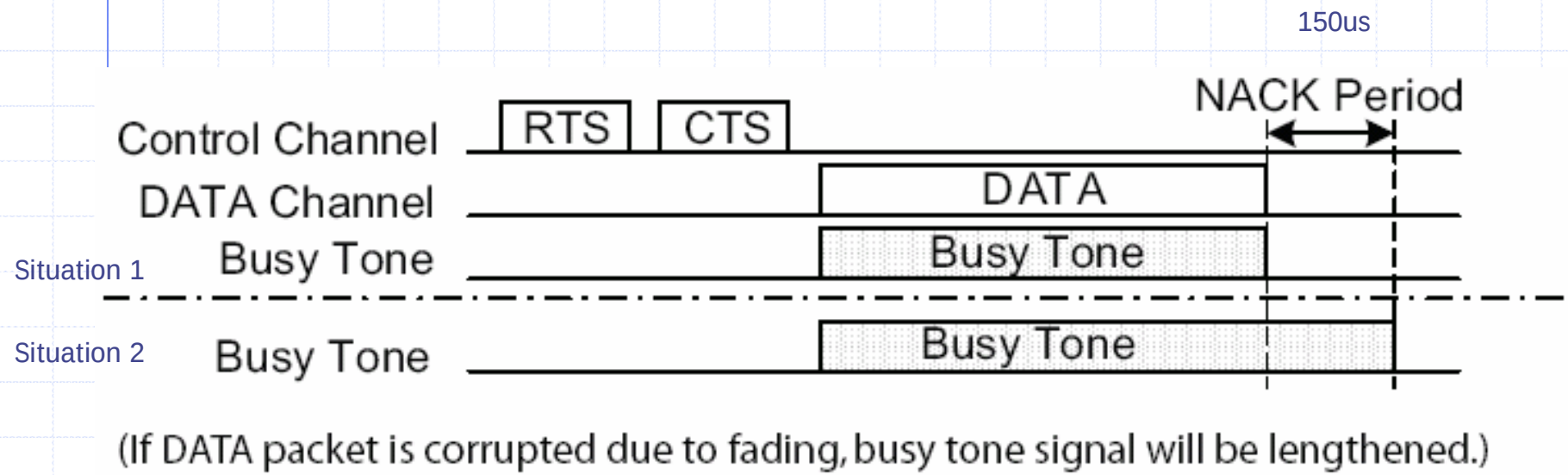


Fig. 3. Proposed protocol.

Basic Message Exchange- RTS

- Before initiating a new transmission of an RTS, any node must sense the *control channel idle* at least for DIFS and sense *no busy tone signal*.
- If it senses the noisy (busy) control channel longer than or equal to the RTS period, it should defer long enough (at least for SIFS + CTS + 2 *x* max-propagation-delay) to avoid possible collision to the CTS's reception at some other sender.

Basic Message Exchange- CTS/NCTS

- Any node correctly receiving the RTS should return CTS after SIFS spacing regardless the control channel status if the DATA channel is idle.
- If both control and DATA channels are busy, it ignores the RTS to avoid possible interference to the reception of CTS at other transmitter.
- If the control channel has been idle for at least one CTS packet long and the DATA channel is busy, it returns NCTS.
  - The NCTS provides the estimate for the remaining DATA transmission time in its duration field

Basic Message Exchange-Data

- A transmitter, after correctly receiving the CTS should start DATA transmission if no busy tone signal is detected.
- If the transmitter receives an NCTS, it defers its transmission according to the duration field of NCTS. Otherwise, it assumes that there is a collision, will then double its backoff window and defer its transmission.

Basic Message Exchange- Busy Tone

- The intended receiver begins to sense the data channel after it transmits CTS.
- If the receiver does not receive signal in the data channel in the due time (for the first few bits of the DATA packet), it will assume that the sender does not transmit DATA.
- Otherwise, it transmits the busy tone signal to prevent hidden terminals from possible transmissions.

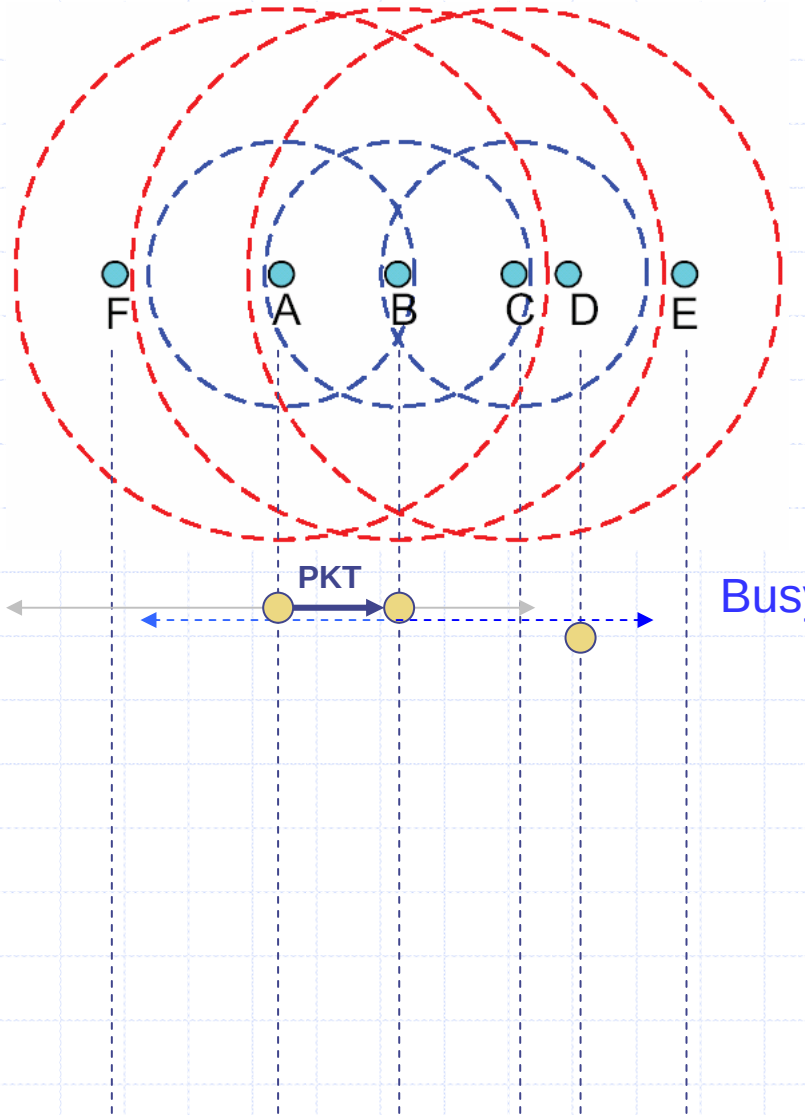
Basic Message Exchange- NACK

- This protocol does not use ACK here because there is no collision to the ongoing DATA packet
- The intended receiver has a timer to indicate when it should finish the reception of the DATA packet according to the duration field in the previously received RTS.
- If the timer expires and has not received the correct DATA packet, it assumes that the DATA transmission fails and **sends NACK by continuing the busy tone signal for an appropriate period.**
- If it correctly receives the DATA packet, it stops the busy tone signal and finishes the receiving procedure.

Solutions to the Aforementioned Problems

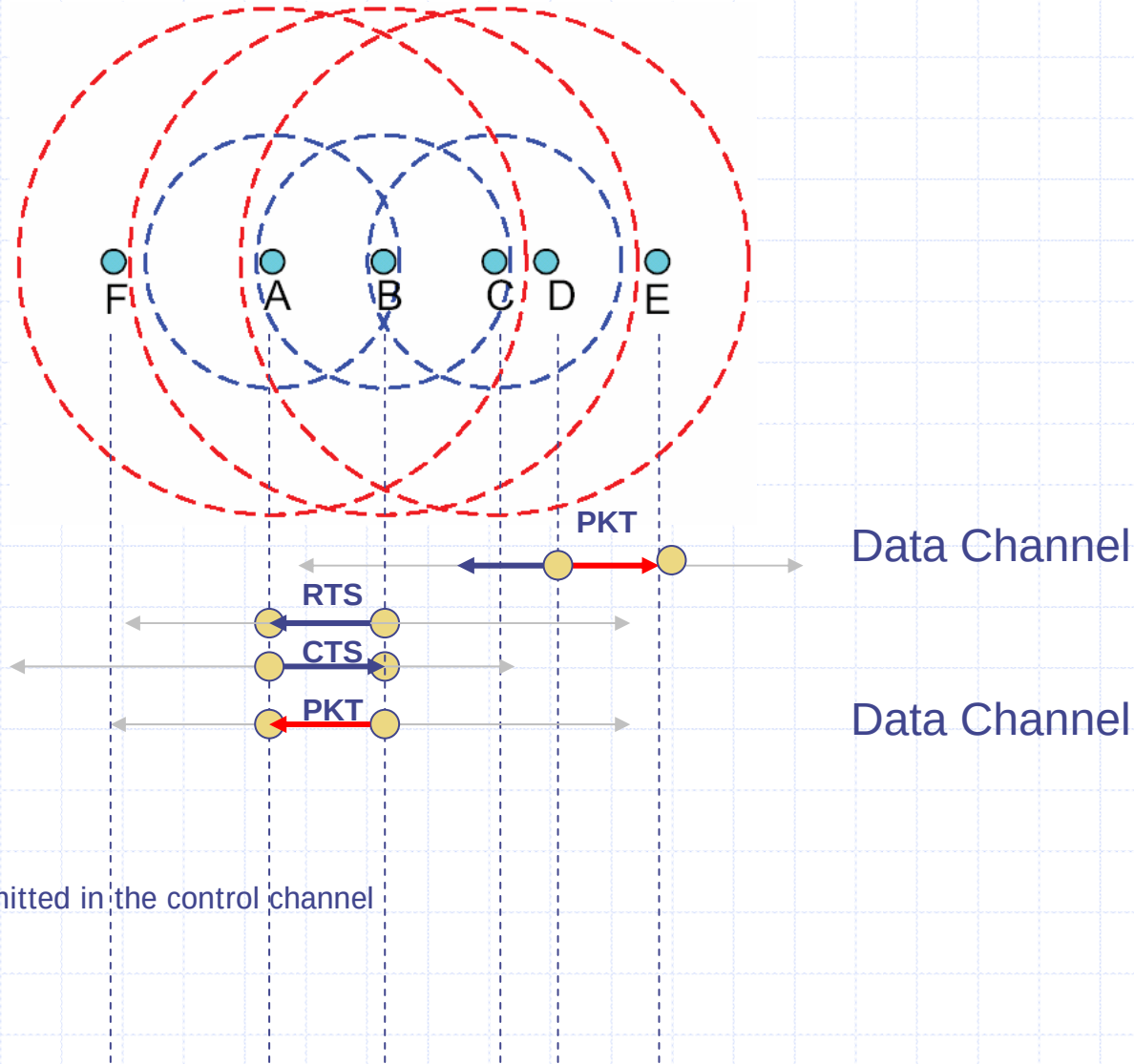
- Solution to the Hidden Terminal Problem
- Solution to the Exposed Terminal Problem
- Solution to the Receiver Blocking Problem
- Improvement of Spatial Reuse
- Inherent Mechanism to Solve the Intra-Flow Contention Problem

Solution to the Hidden Terminal Problem



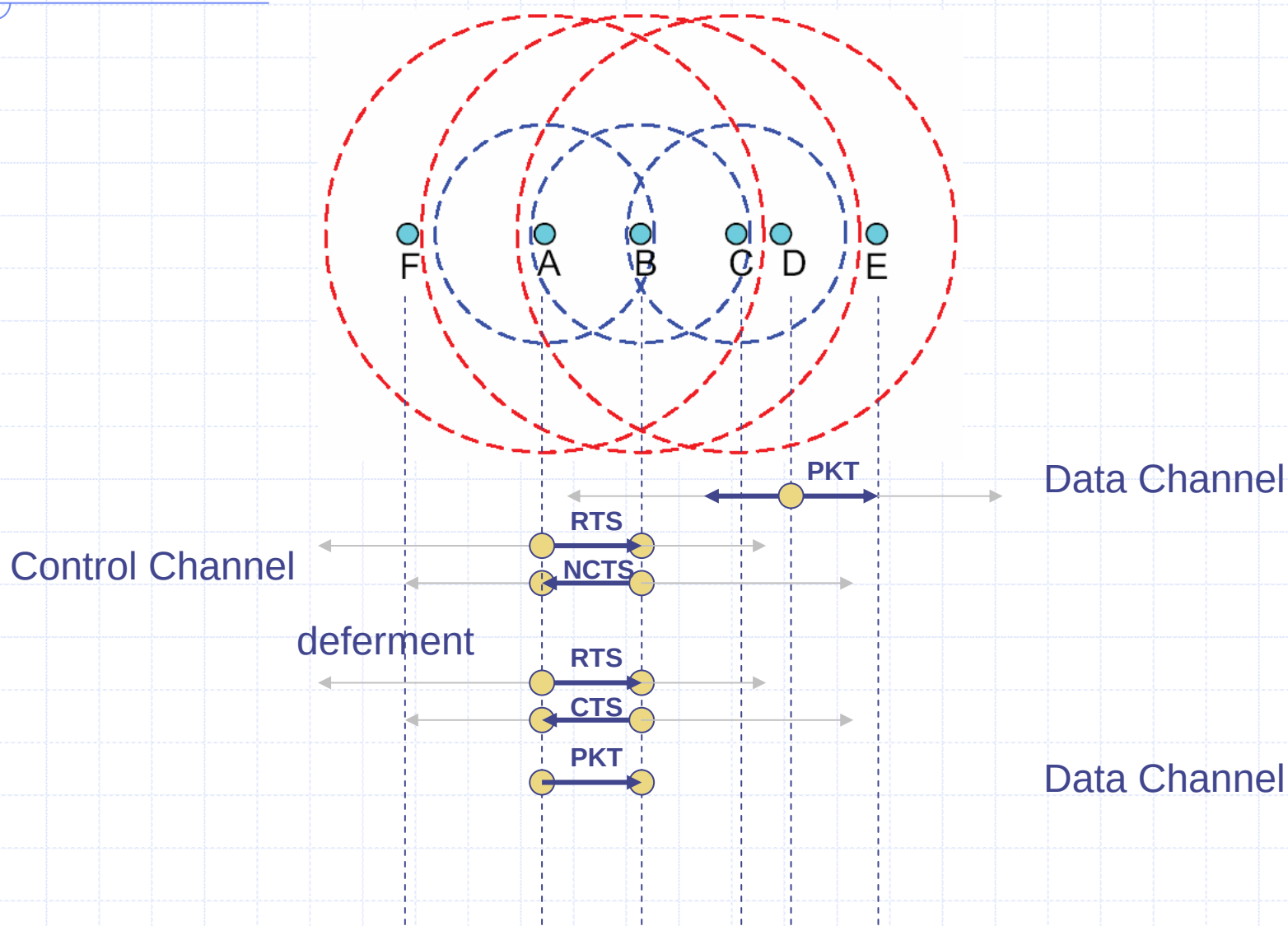
Busy tone signal

Solution to the Exposed Terminal Problem

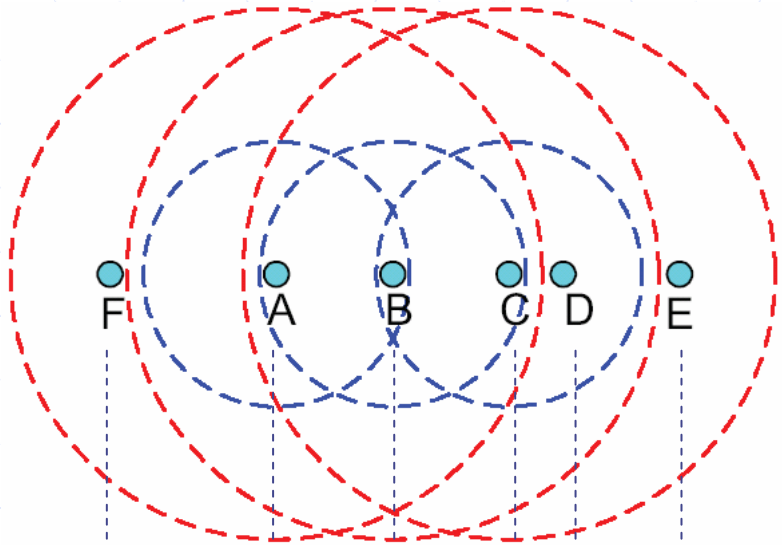


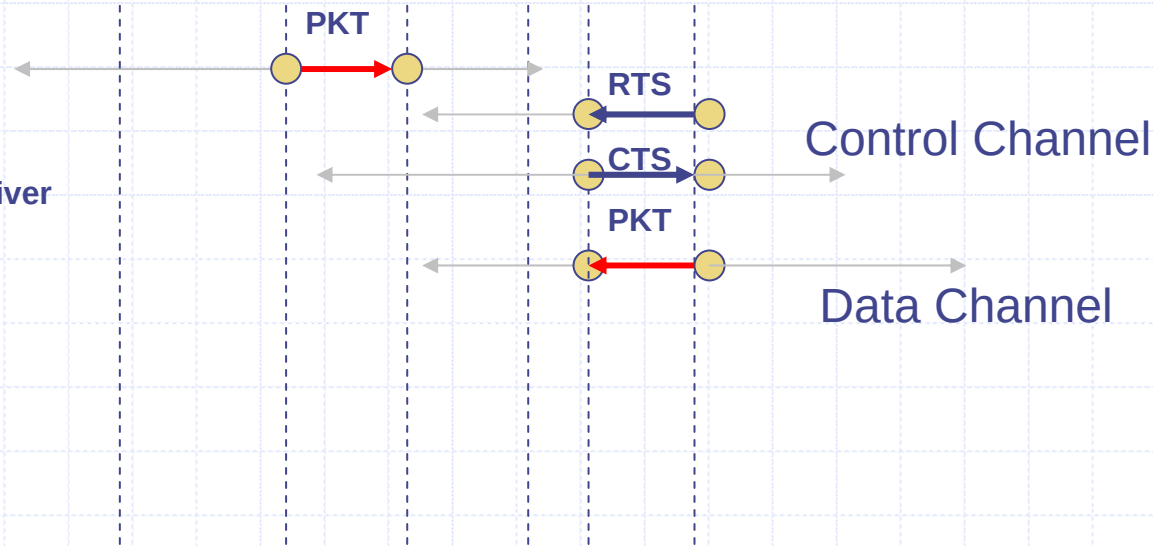
1. RTS/CTS control signal transmitted in the control channel
2. No ACK message

Solution to the Receiver Blocking Problem



Improvement of Spatial Reuse





Not use ACK in receiver

Inherent Mechanism to Solve the Intra-Flow Contention Problem

- In the DUCHA protocol, the receiver of DATA packets have the highest priority to access the channel for next DATA transmission.

Performance Evaluation

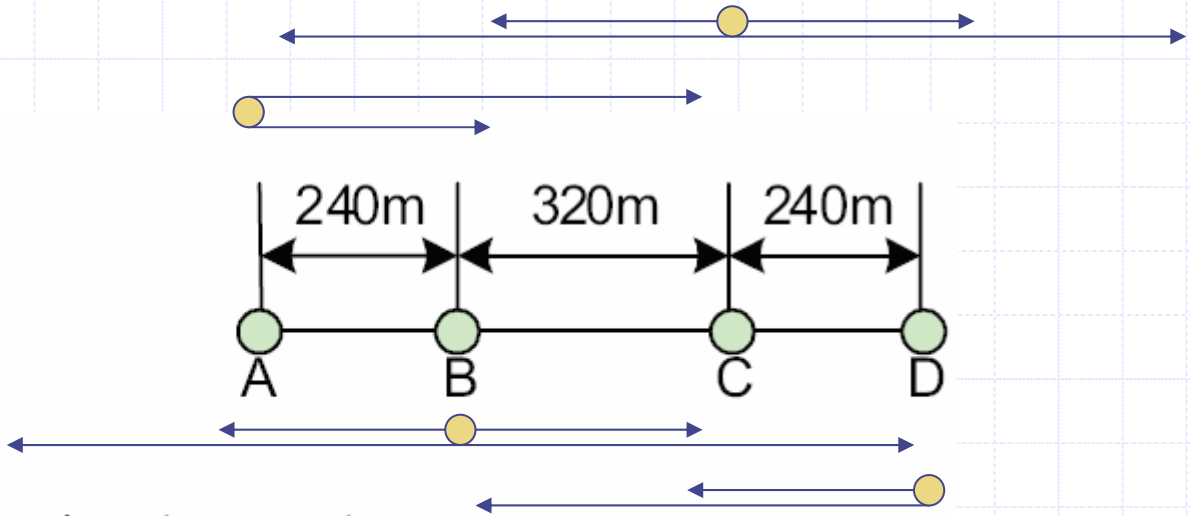
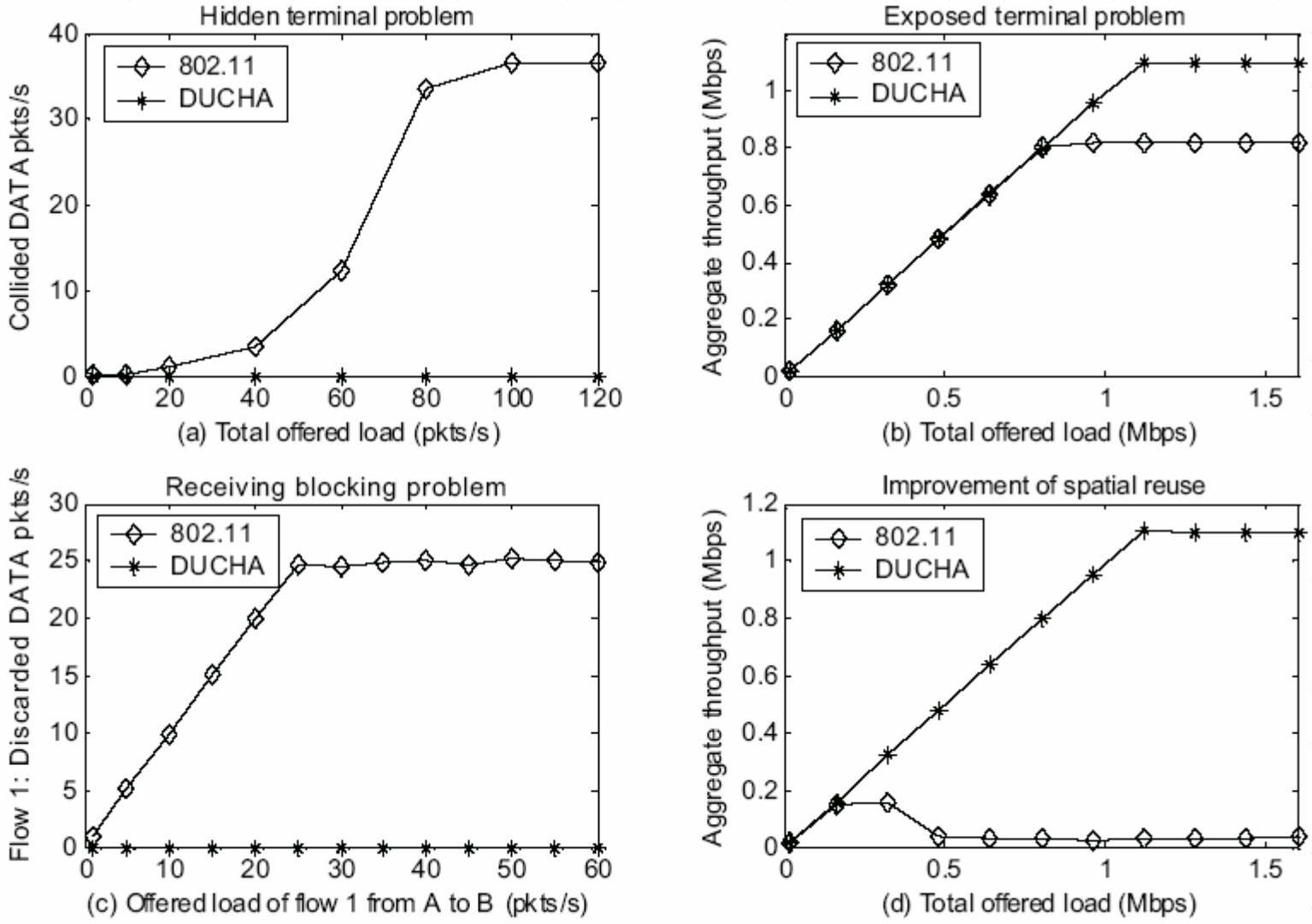


Fig. 4. One simple topology.

Performance Evaluation



5. Simulation results for the simple topology.

Performance Evaluation

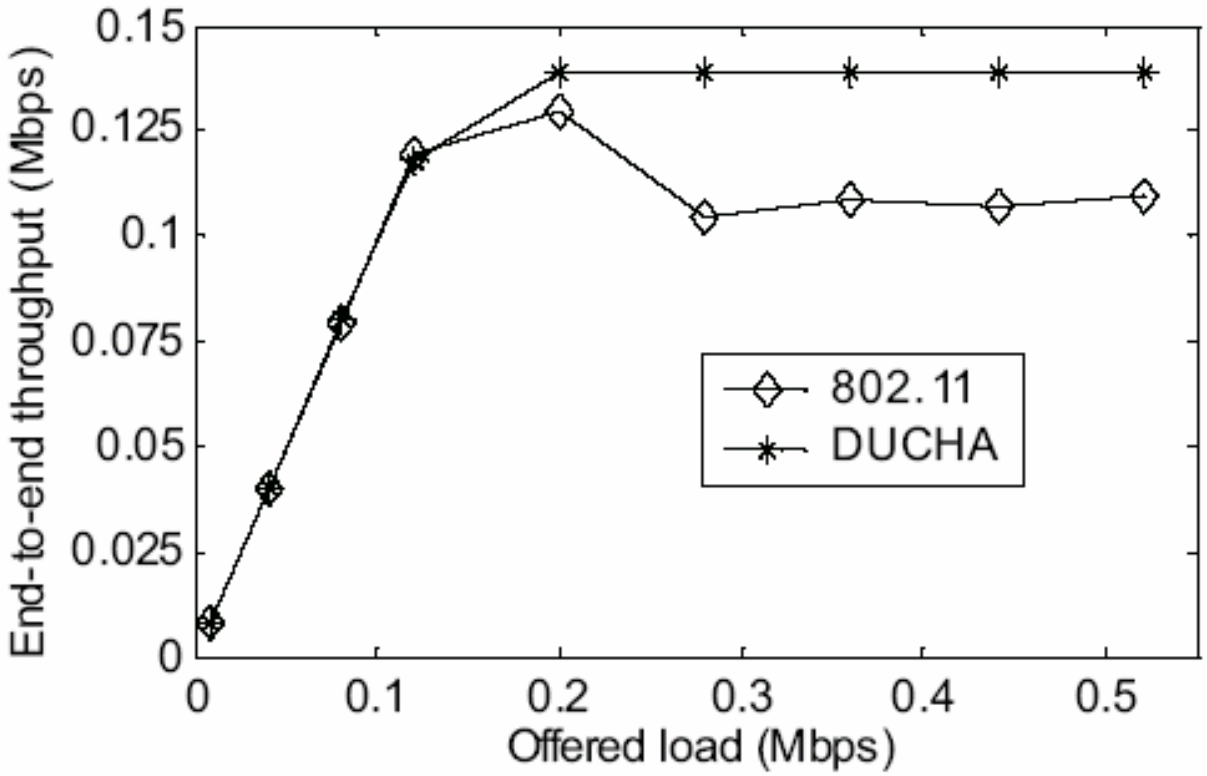


Fig. 6. End-to-End throughput for the 9-node chain topology.

Performance Evaluation

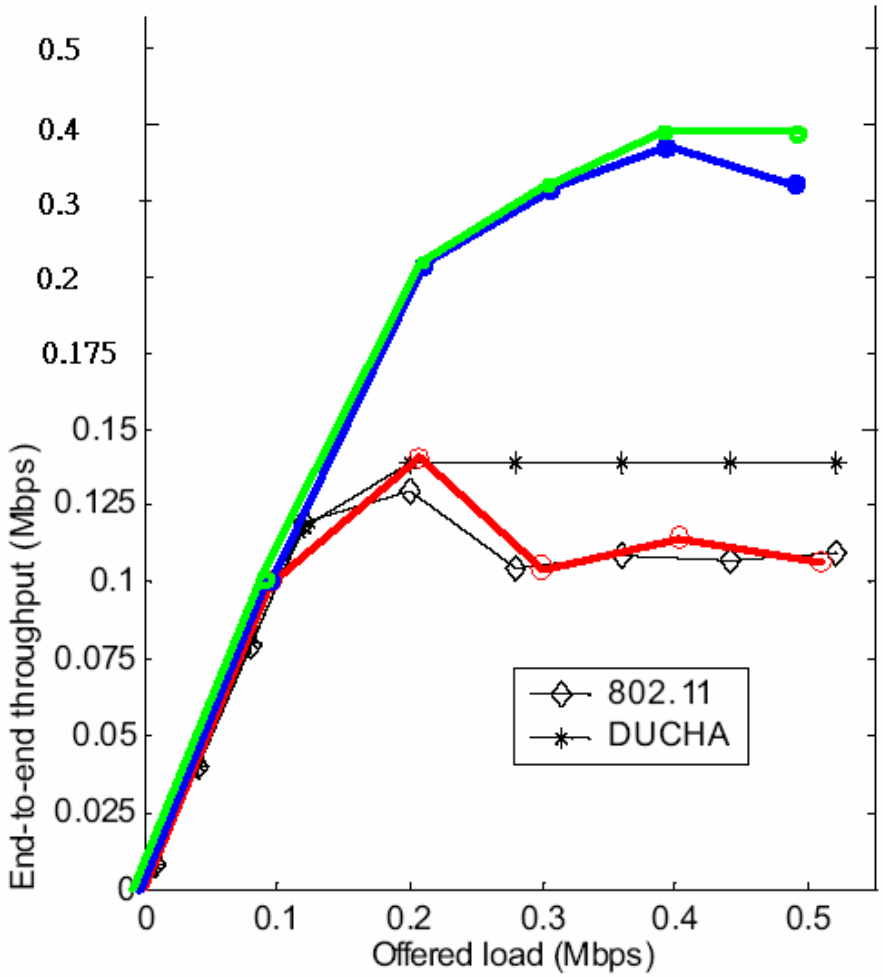


Fig. 6. End-to-End throughput for the 9-node chain topology.

Performance Evaluation

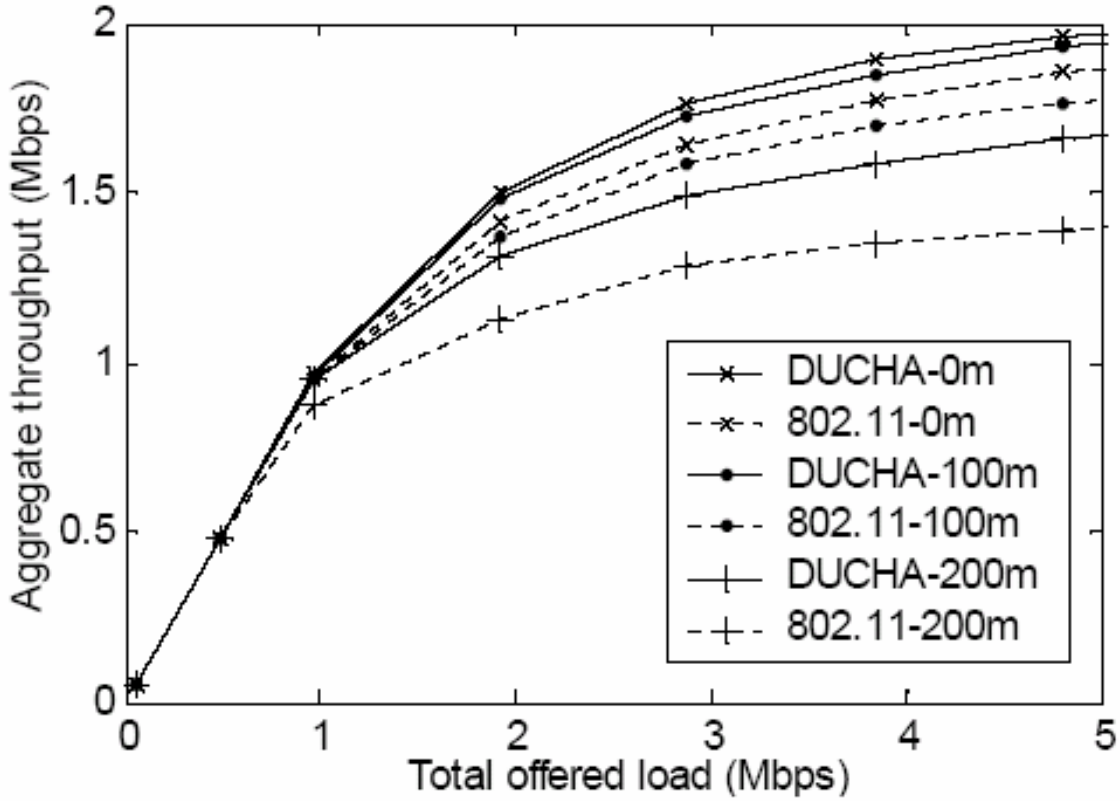
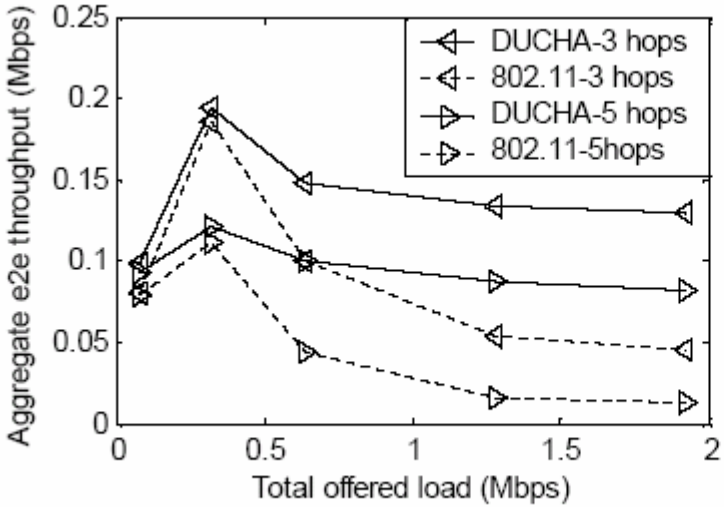
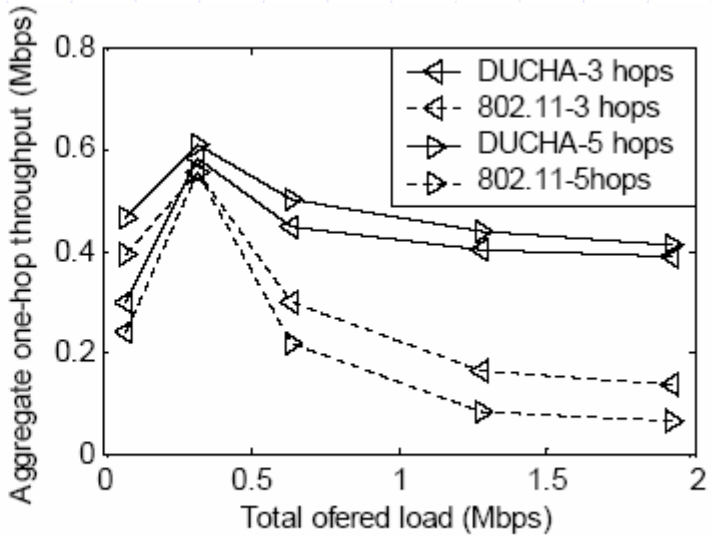
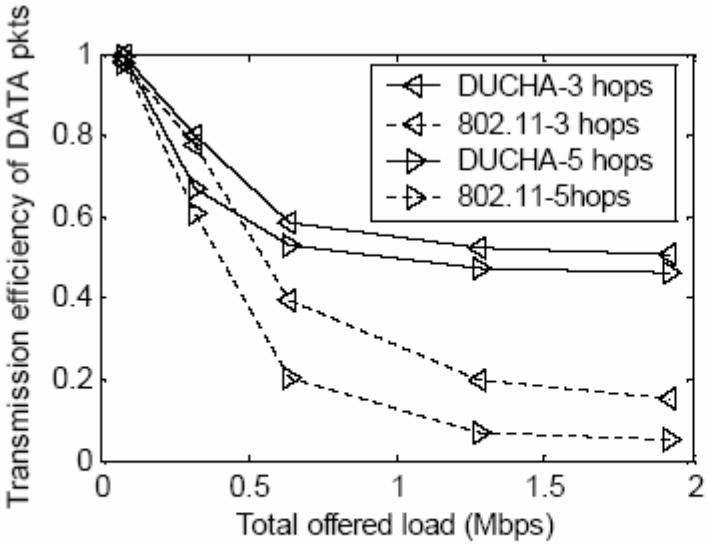


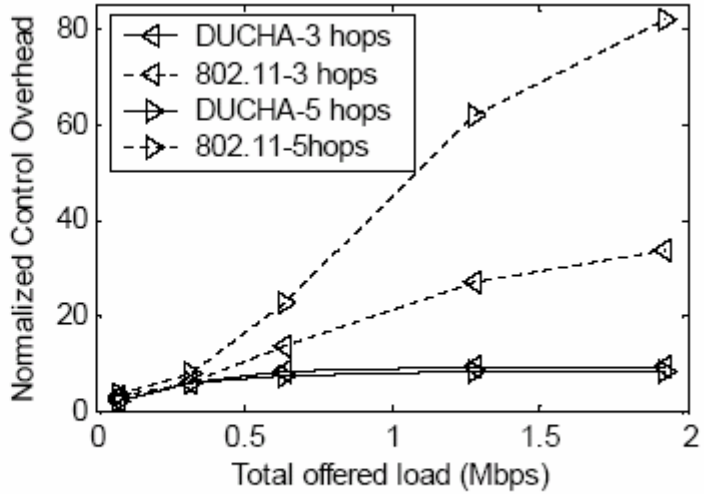
Fig. 7. Simulation results for random one-hop flows with different minimum one-hop distance.

Performance Evaluation









8. Simulation results for multihop flows in random topology.

Conclusions

- This paper proposed a new MAC protocol DUCHA using dual channels, one is for control packets and the other is for DATA packets.
- Busy tone signal is used to solve the hidden terminal problem and also used to transmit the negative ACK (NACK) signal if necessary.
- This paper uses the negative CTS (NCTS) to notify the sender that its intended receiver is blocked and cannot receive DATA packets.
- DUCHA protocol simultaneously solves the hidden terminal problem, the exposed terminal problem, the receiver blocking problem and also the intra-flow contention problem, and has much higher spatial reuse ratio than the IEEE 802.11 MAC.