A MAC Protocol for Multi-hop WLAN Using Smart Antennas

2004/07/30

Te-Wei Ho

OUTLINE

- Introduction
- Problem Definition
- Proposed Scheme
- Theoretical Analysis
- Simulation Results
- Conclusion and Future Work

Introduction

Motivation

- Romit Roy Choudhury, et al. in [4] declared that even though smart antenna technology can increase the system capacity of multi-hop WLAN, it gives birth to new channel access problems: *Hidden Terminal Due to Asymmetry in Gain*, *Hidden Terminal Due to Unheard RTS/CTS*, *Shape Control of Silenced Regions* and *Deafness Problem*.

Problem Statements

- Hidden Terminal Due to Asymmetry in Gain:
  - Antenna omni-directional gain is much smaller than antenna directional gain. If some node listens to the channel omni-directionally, there will be possible loss of network control messages and hence this node will become a hidden node.

Problem Statements (cont.)

- Hidden Terminal Due to Unheard RTS/CTS:
  - Each node equipped with smart antennas is insensitive to other directions when its smart antennas is beam-forming to one direction. It will possibly miss important network control messages and hence become a hidden node.

Problem Statements (cont.)

- Shape Control of Silenced Regions:
  - Because the shape of silenced regions affects the overall network performance, we must control the shape of silenced regions to optimize the network performance. This optimizing problem is referred as *Shape Control of Silenced Regions*

Problem Statements (cont.)

- Deafness Problem:
  - When some node is beam-forming to one direction, RTS from other directions will be unheard. Those nodes receiving no responding CTS from this node retransmit RTS until the retry limit has been reached. As a result, the network throughput is degraded. We refer to this phenomenon as *Deafness Problem.*

Problem Definition

Two-ray Model

- We use two-ray model [9] as the path loss model where transmitted signal traverses the air its power level decreases at a rate of 40dB/decade:

$$P_R = P_T \cdot G_T \cdot G_R \frac{h_T^{\,2} \cdot h_R^{\,2}}{D^4}$$

Maximal Communication Range

- If we rearrange the Two-ray model equation, and let P_R equal the minimal power level required at receiver, $P_{R,\,min}$, we will get the expression of the maximal communication range:

$$D_{max} = \sqrt[4]{\frac{P_T}{P_{R,\,min}} \cdot h_T^{\,2} \cdot h_R^{\,2}} \cdot \sqrt[4]{G_T \cdot G_R} = K \cdot \sqrt[4]{G_T \cdot G_R}$$

Communication Range & Interfering Range

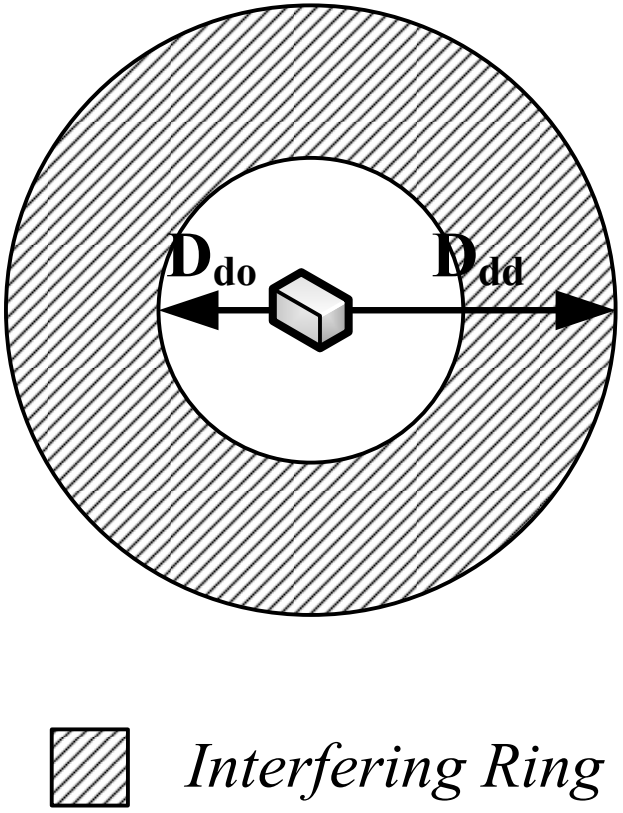
- Communication Range:

$$D_{do} = K \cdot \sqrt[4]{G_d \cdot G_o}$$

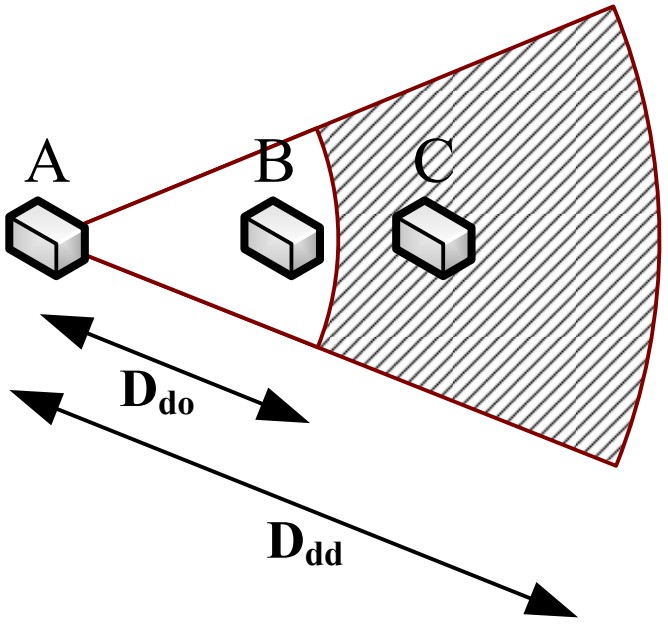
- Interfering Range:

$$D_{dd} = K \cdot \sqrt[4]{G_d \cdot G_d} = K \cdot \sqrt{G_d}$$

Interfering Ring



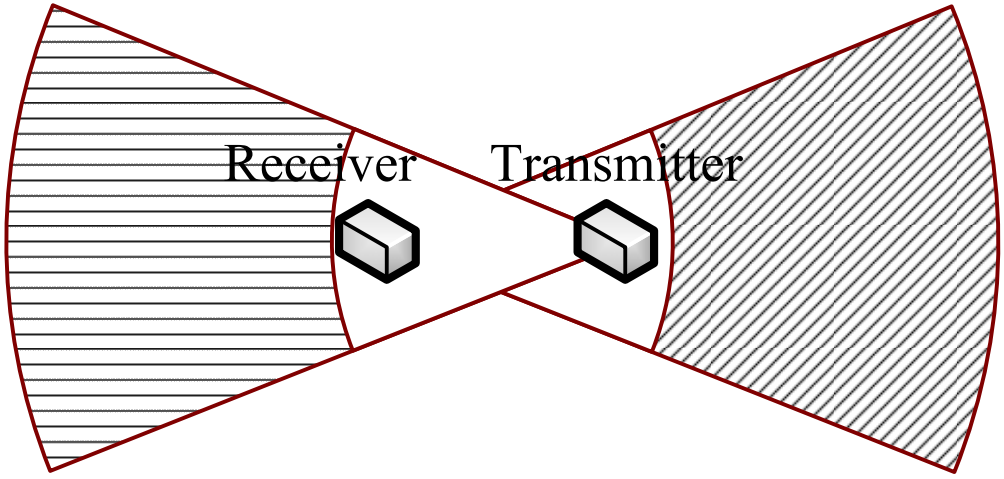
Interfering Ring (cont.)



RTS/CTS coverage of A

partial *Interfering Ring* of A

Dangerous Areas



Transmitter Dangerous Area (TDA)

Receiver Dangerous Area (RDA)

RTS/CTS coverage

Proposed Scheme

Cautioning the Hidden Nodes

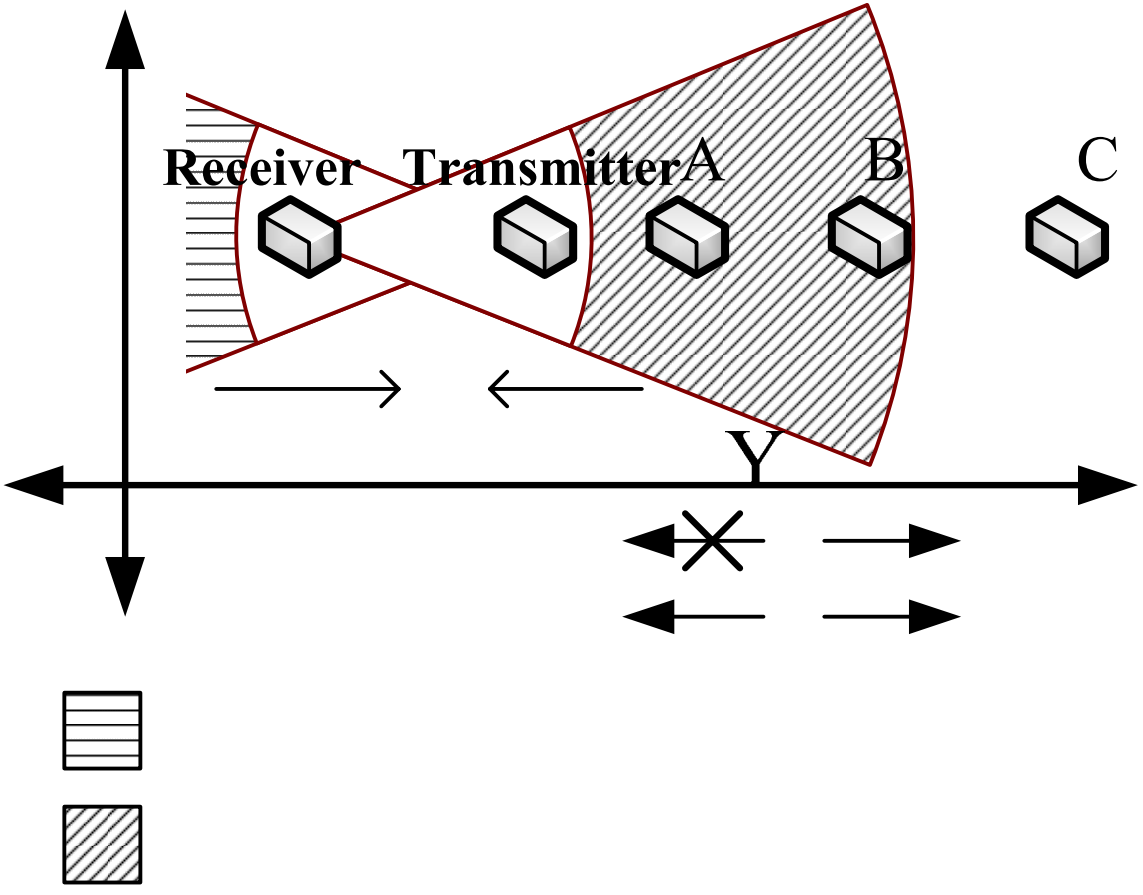
- If we rearranged maximal communication range equation and let D_{max} and G_R equal D_{dd} and G_o respectively, we can get the appropriate gain to transmit RTS/CTS, $G_{RTS/CTS}$:

$$G_{RTS/CTS} = \frac{G_d^{\,2}}{G_o}$$

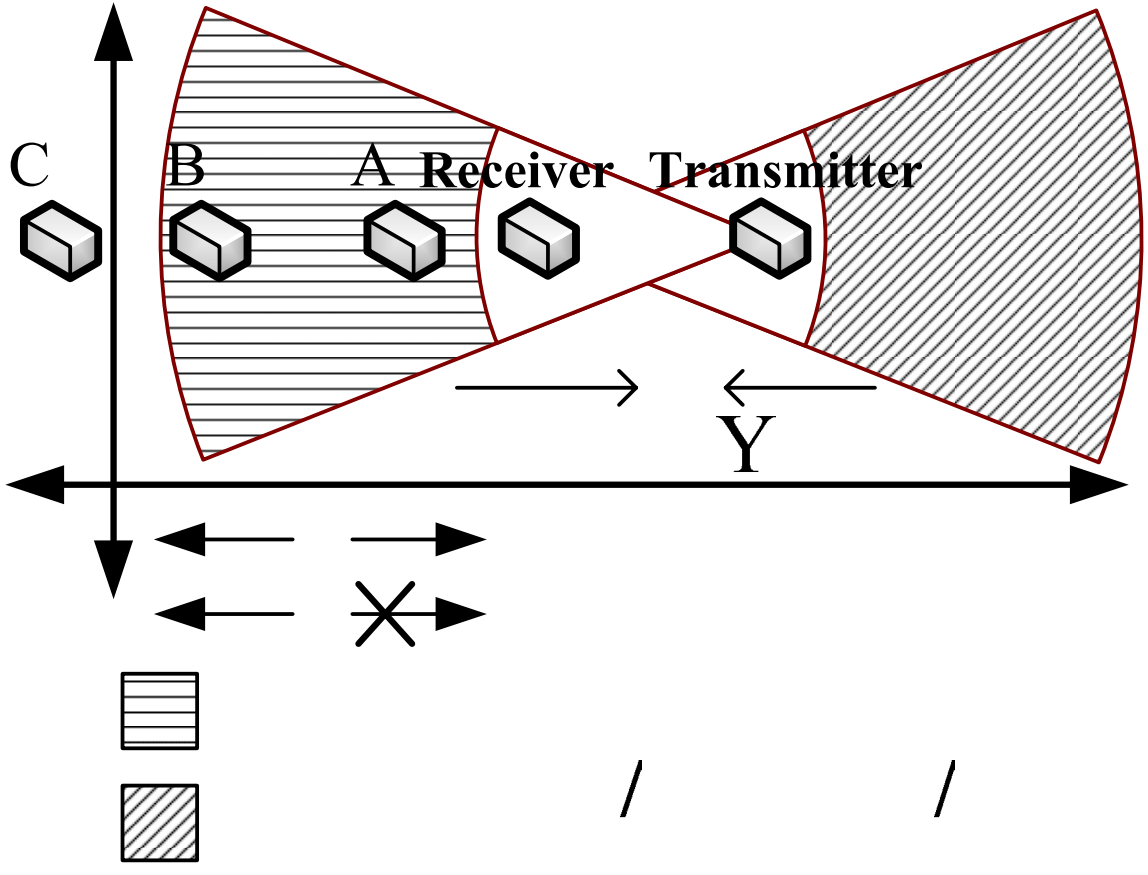
Limiting the Hidden Nodes

- Limitations of the hidden nodes in RDA
  - To forbid them to transmit any packet in the direction of receiver.
- Limitations of the hidden nodes in TDA
  - To forbid them to receive any packet in the direction of transmitter.

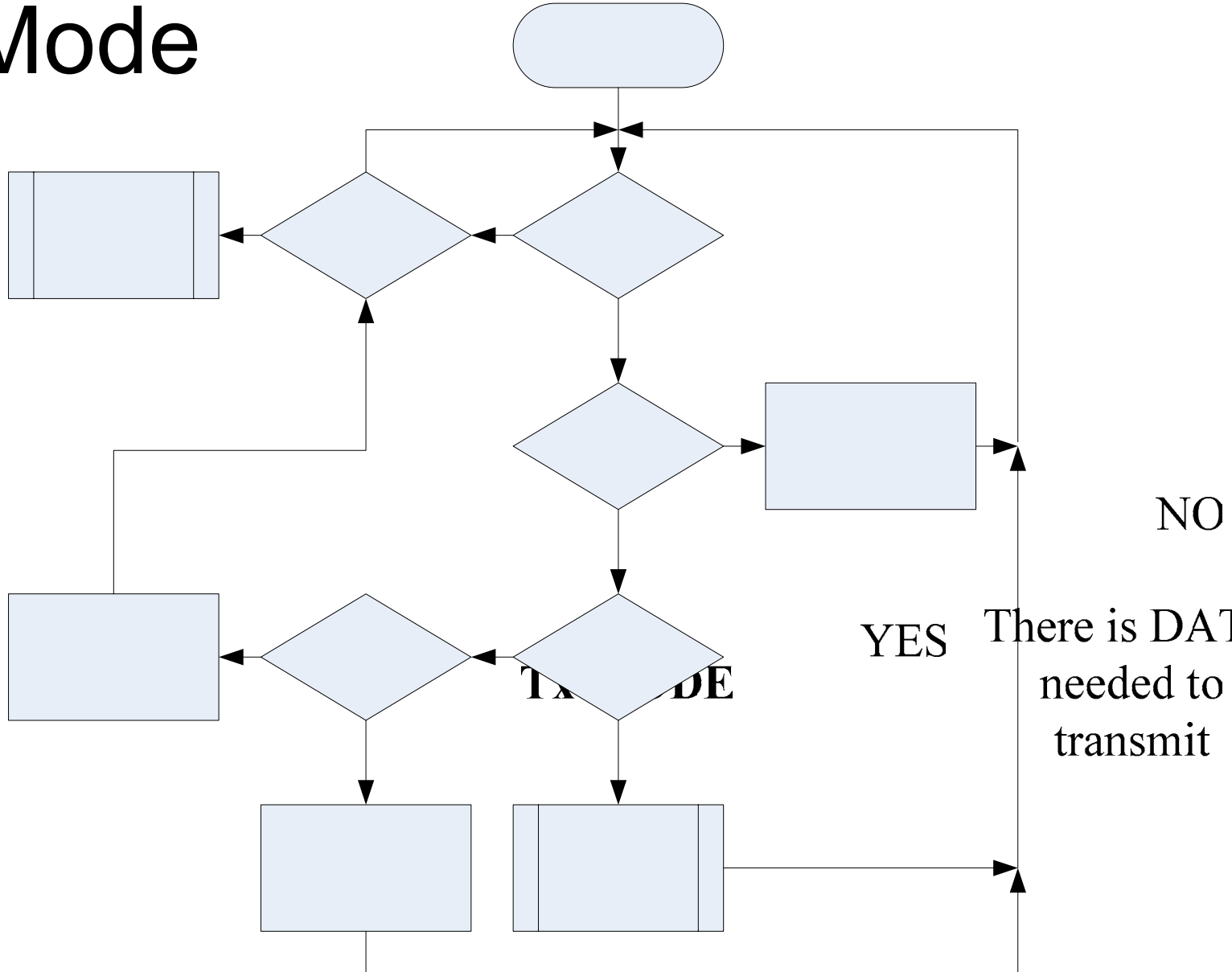
Limitations of RDA nodes



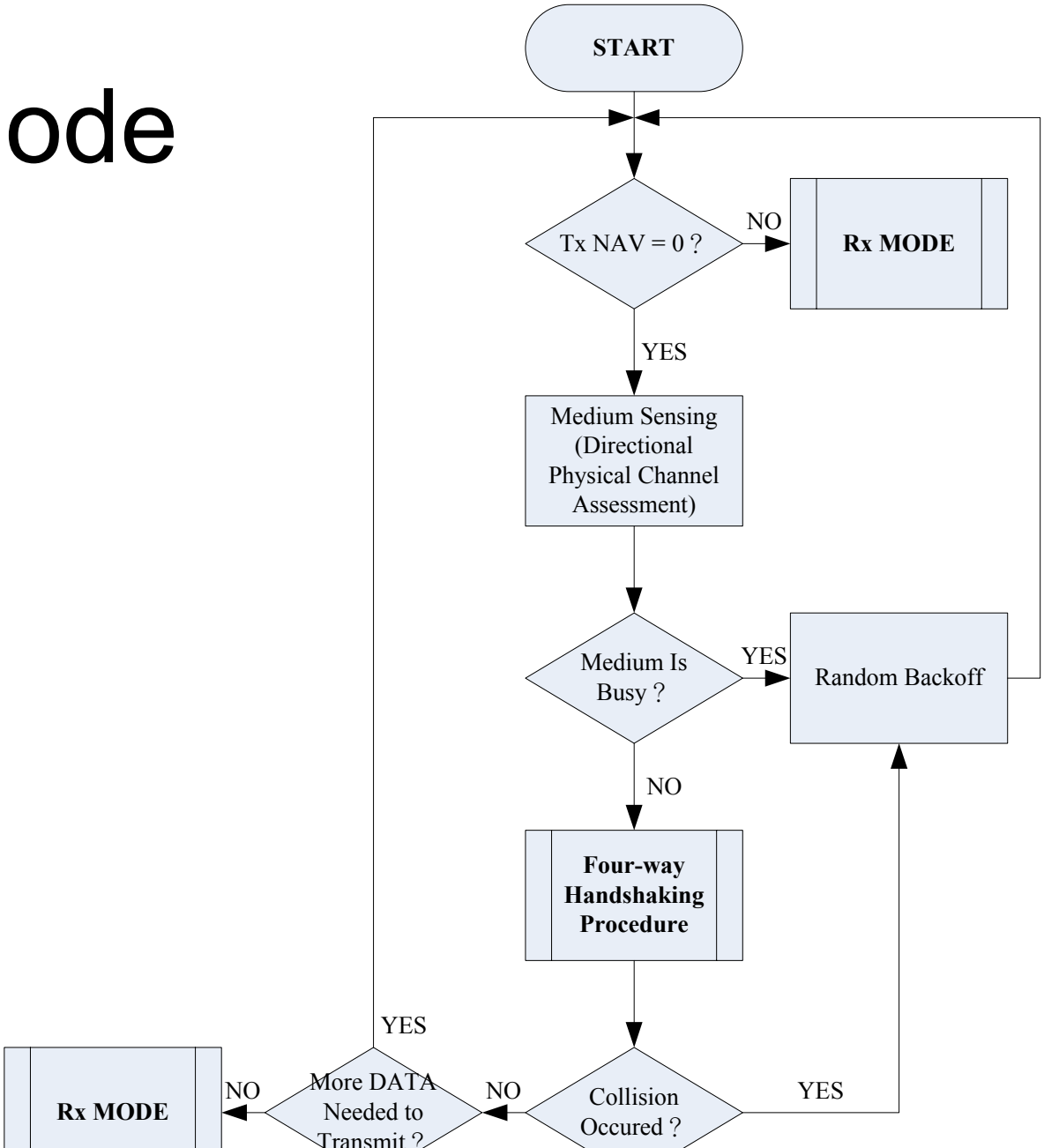
Limitations of TDA nodes



Rx Mode



Tx Mode


START
Tx NAV = 0 ?
NO
Rx MODE
YES
Medium Sensing (Directional Physical Channel Assessment)
Medium Is Busy ?
YES
Random Backoff
NO
Four-way Handshaking Procedure
Collision Occured ?
YES
NO
More DATA Needed to Transmit ?
NO
Rx MODE
YES

Theoretical Analysis

Theoretical Analysis

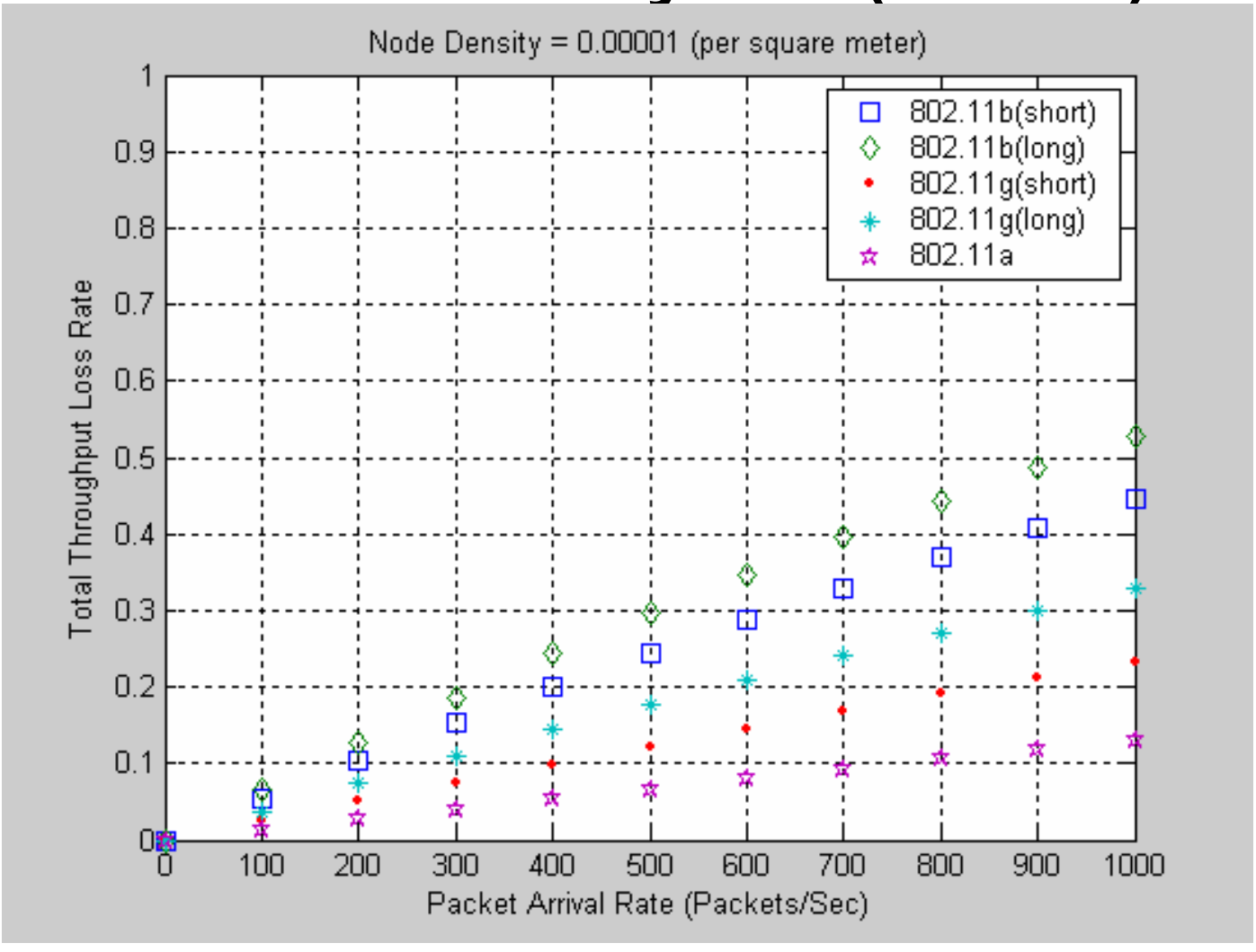
- The expectation value of total throughput loss rate of each transmitter-receiver pair due to *Hidden Terminal Due to Asymmetry in Gain*, R_{loss} is:

$$E\{R_{loss}\} = 2 - e^{-\lambda' \times T_{tot}} - e^{-\lambda'' \times T_{tot}}$$

- When $\lambda' \times T_{tot} << 1$ and $\lambda'' \times T_{tot} << 1$,

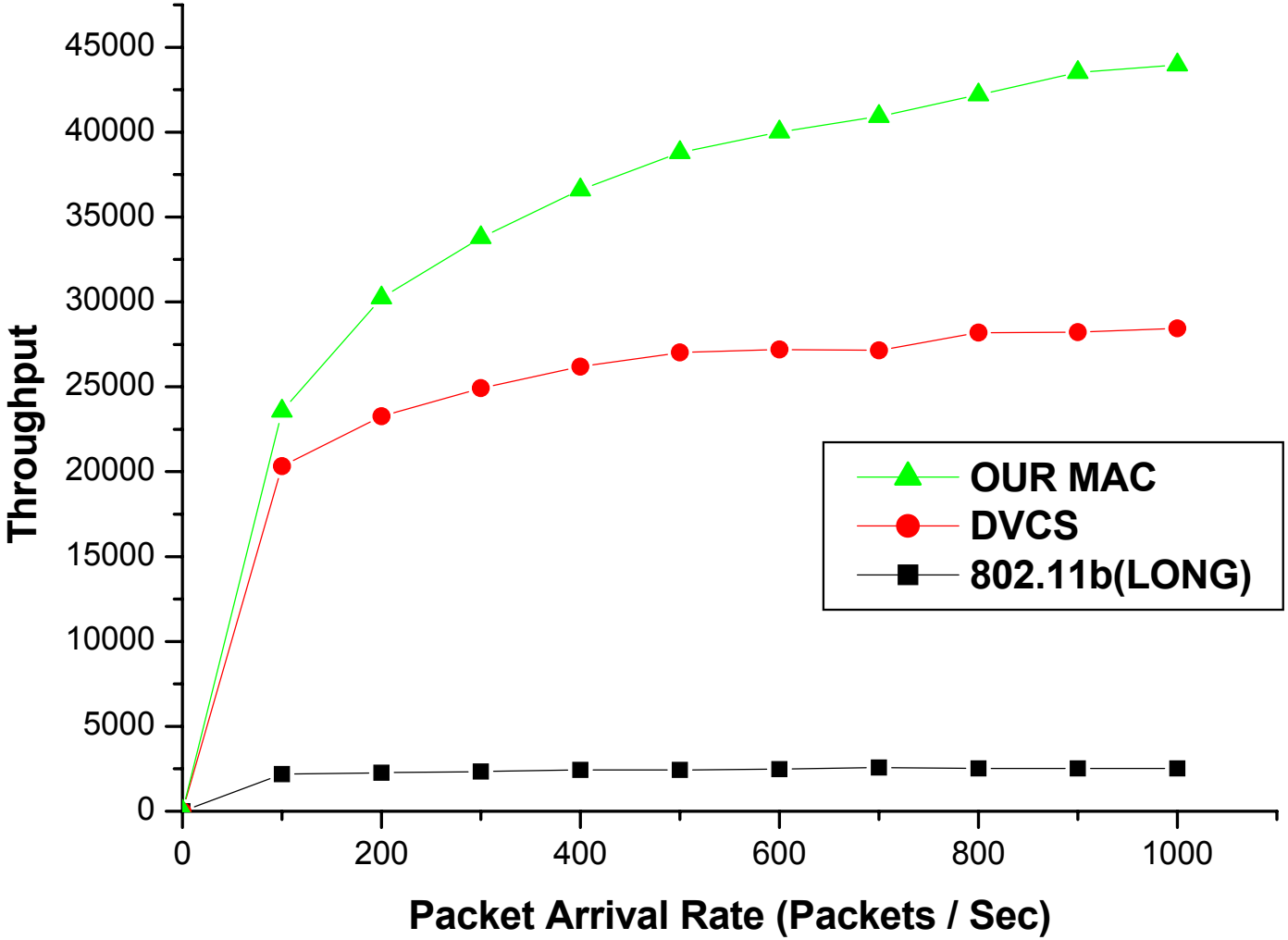
$$E\{R_{loss}\} = (\lambda' + \lambda'') \times T_{tot}$$

Theoretical Analysis (cont.)

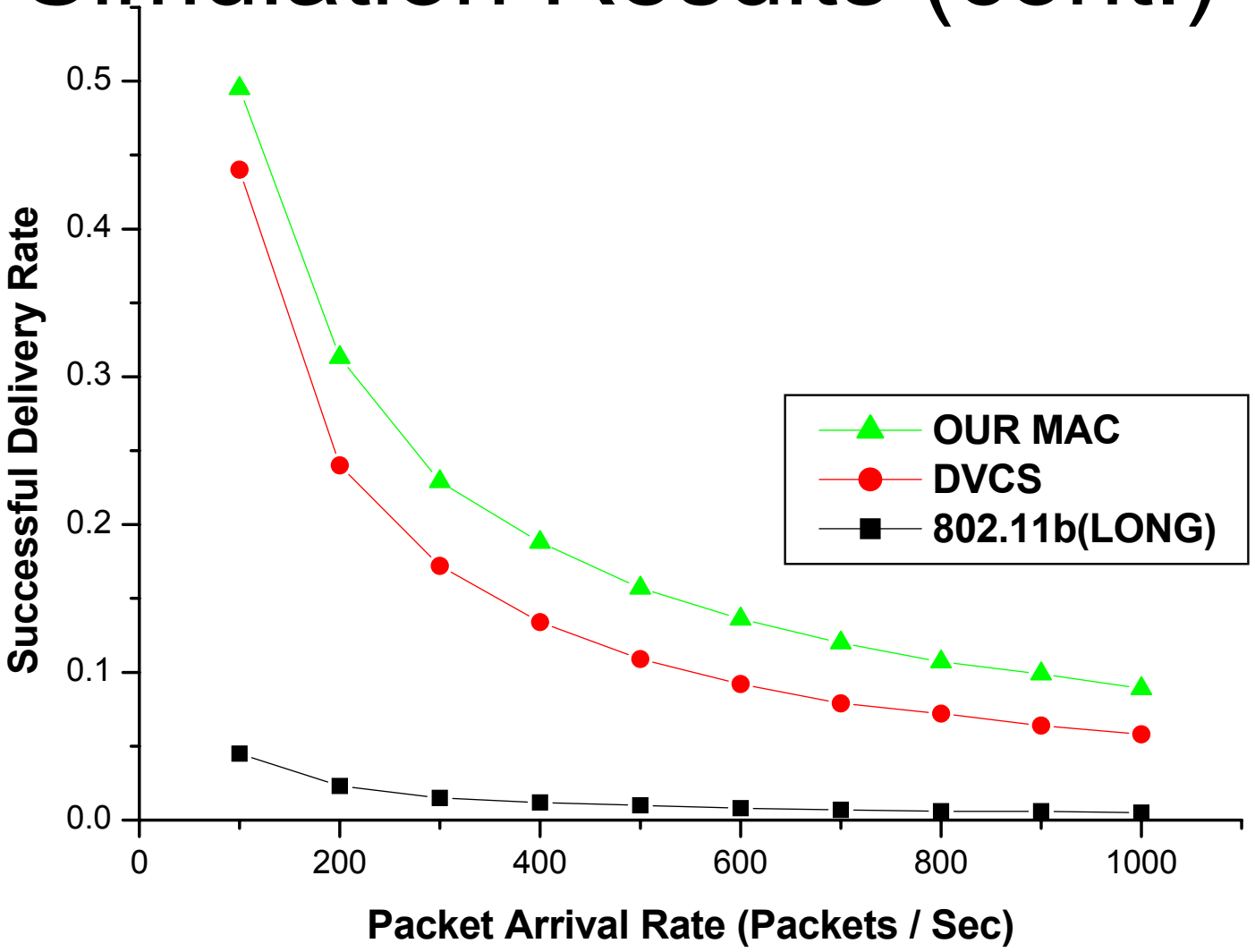


Simulation Results

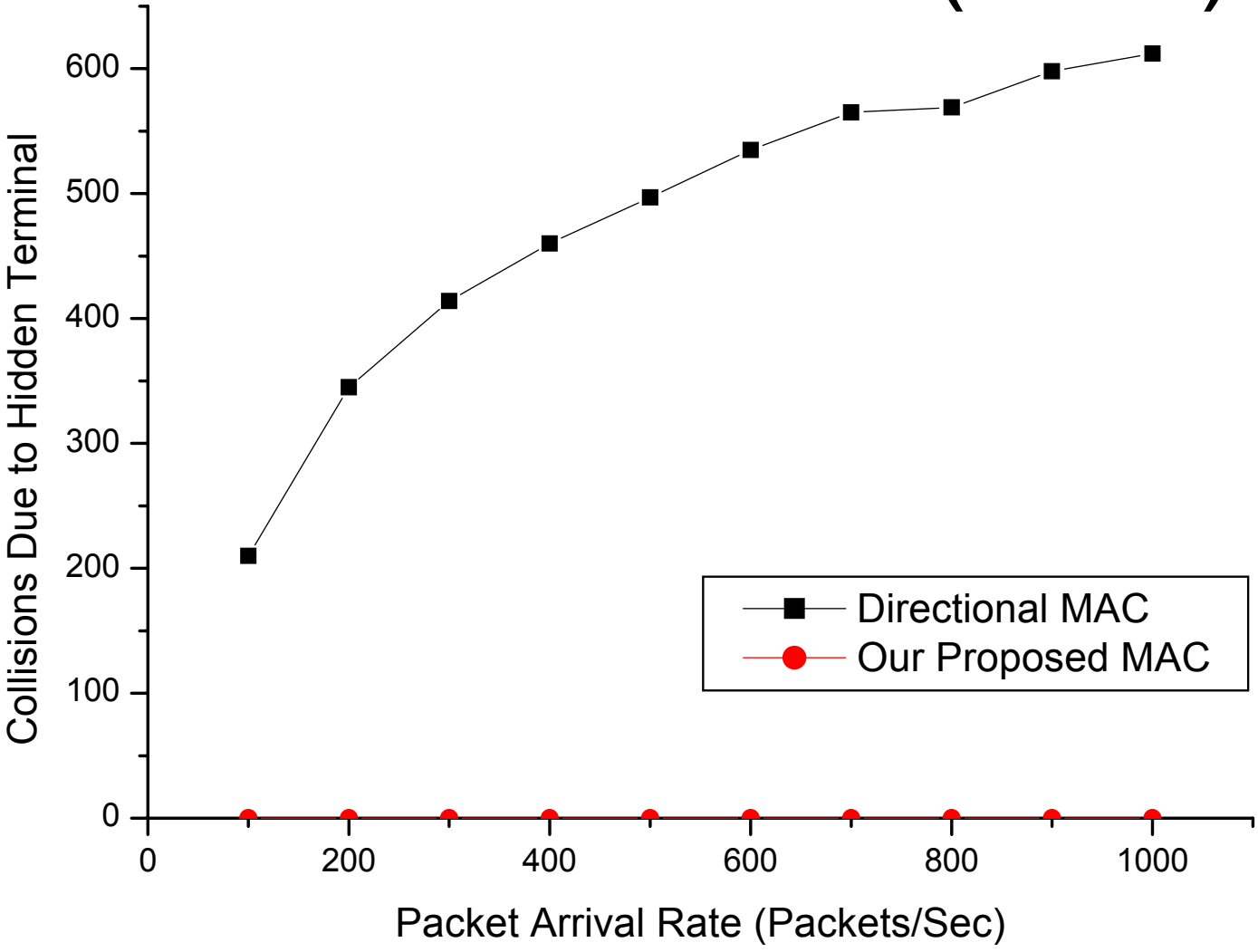
Simulation Results



Simulation Results (cont.)



Simulation Results (cont.)



Conclusion and Future Work

Conclusion

- In this paper, a solution to *Hidden Terminal Due to Asymmetry in Gain* is given. The proposed scheme has the following features: firstly, the gain used to transmit RTS/CTS is different from the gain used to transmit DATA/ACK; Secondly, those nodes which receive RTS/CTS must obey some limitations according to our proposed protocol; finally, NAV timer of our MAC protocol should be separated into two parts, Transmitting NAV and Receiving NAV.

Future Work

- In the future, we will study on how to resolve other channel access problems: *Hidden Terminal Due to Unheard RTS/CTS*, *Shape Control of Silenced Regions* and *Deafness Problem*. Besides, an efficient method to get neighbors' location must be provided. Further more, a routing strategy along with our MAC protocol must be provided, too, because an efficient MAC protocol would not be able to guarantee good performance, unless a proper routing strategy is used.

References

- [1] Mineo Takai, Jay Martin, Aifeng Ren and Rajive Bagrodia, “Directional Virtual Carrier Sensing for Directional Antennas in Mobile Ad Hoc Networks,” in ACM MobiHoc, June 2002.
- [2] S. Bandyopadhyay, K. Hasuike, S. Horisawa, S. Tawara, “An Adaptive MAC Protocol for Wireless Ad Hoc Community Network (WACNet) Using Electronically Steerable Passive Array Radiator Antenna,” in IEEE GLOBECOM, Volume: 5, 25-29 November 2001, Pages: 2896-2900 vol. 5.
- [3] S. Bandyopadhyay, K. Hasuike, S. Horisawa, S. Tawara, “An Adaptive MAC and Directional Routing Protocol for Ad Hoc Wireless Network Using ESPAR Antenna,” in ACM MobiHoc, 4-5 October 2001.
- [4] Romit Roy Choudhury, Xue Yang, Ram Ramanathan and Nitin H. Vaidya, “Using Directional Antennas for Medium Access Control in Ad Hoc Networks,” in ACM MOBICOM, September 2002.
- [5] Thanasis Korakis, Gentian Jakllari and Leandros Tassiulas, “A MAC Protocol for Full Exploitation of Directional Antennas in Ad-hoc Wireless Networks,” in ACM MobiHoc, June 2003.

References (cont.)

- [6] Siuli Roy, Dola Saha, S. Bandyopadhyay, Tetsuro Ueda and Shinsuke Tanaka, “A Network-Aware MAC and Routing Protocol for Effective Load Balancing in Ad Hoc Wireless Networks with Directional Antenna,” in ACM MobiHoc, June 2003.
- [7] Arup Acharya, Archan Misra and Sorav Bansal, “High-Performance Architectures for IP-Based Multihop 802.11 Networks,” in IEEE Wireless Communications [see also IEEE Personal Communications], Volume: 10, Issue: 5, October 2003, Pages: 22-28.
- [8] Arup Acharya, Archan Misra and Sorav Bansal, “MACA-P: A MAC for Concurrent Transmissions in Multi-hop Wireless Networks,” in IEEE PerCom, 23-26 March 2003, Pages: 505-508.
- [9] T. S. Rappaport, “Wireless Communications: Principles & Practice,” Prentice Hall, 1996.
- [10] J. C. Liberti and T. S. Rappaport, “Smart Antennas for Wireless Communications: IS-95 and Third Generation CDMA Application,” Prentice Hall, 1999.

Q&A