

A new multichannel MAC protocol for ad hoc networks based on two-phase coding with power control (TPCPC)

Zhang, Lili; Soong, Boon Hee; Xiao, Wendong

2003

Zhang, L., Soong, B. H., & Xiao, W. (2003). A new multichannel MAC protocol for ad hoc networks based on two-phase coding with power control (TPCPC). Joint Conference of the Fourth International Conference on Information, Communications and Signal Processing, 2003 and the Fourth Pacific Rim Conference on Multimedia, pp.1091-1095.

<https://hdl.handle.net/10356/94481>

<https://doi.org/10.1109/ICICS.2003.1292628>

© 2003 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works. The published version is available at: <http://dx.doi.org/10.1109/ICICS.2003.1292628>.

Downloaded on 09 Apr 2024 12:15:39 SGT

A New Multi-Channel MAC Protocol for Ad Hoc Networks Based on Two-phase Coding with Power Control (TPCPC)

"Lili Zhang, "Boon-Hee Soong, "Wendong Xiao

*"School of Electrical and Electronic Engineering Nanyang Technological University, Nanyang Ave
Singapore*

Abstract

This paper presents a new CDMA-based multi-channel medium access control protocol for ad hoc networks, which is named as two-phase coding multi-channel protocol with power control. The first phase code is used to broaden the area reuse and the second phase code is employed to distinguish between different nodes in one specific area. This algorithm efficiently eliminates hidden terminal and exposed terminal problems during data transmission and greatly increases the throughput. In addition, it has good scalability and can be easily accomplished with GPS. Although many multi-channel MAC protocols adopting CDMA techniques have been presented, few have addressed the near-far problem. We incorporate power control in our algorithm and reduce the near-far interference. The implementation of two-phase coding with power control is discussed, and the primary simulation result demonstrates that the proposed protocol offers better performance.

1. Introduction

Widely accepted MAC protocol IEEE 802.11 [1] DCF is based on the single channel model. When the number of mobile nodes increases, it is accompanied with more contentions and collisions. As a result, the throughput is decreased and the latency increases. Multi-channel is one approach in dealing with this kind of problem. The maximum throughput can be increased by simultaneous transmissions. Meanwhile, the data packet can arrive at the destination with lower latency since it does not need to wait until the shared bandwidth is available. In both single channel and multi-channel approaches for MANET, the most researchers address the hidden and exposed terminal problems. Many protocols such as MACAW [4], FAMA [2], DBTMA [3] and MACA-BI [5] have been dedicated in solving it. Recently, many multi-channel protocols have been investigated that offer better throughput performance, reduce collision and relieve hidden and exposed terminal problems. Such protocols include multi-channel CSMA [12], SEEDEx [8], TBMAC [9] and SNMS [11].

Multi-channel CSMA protocol presented by A. Nasipuri in [12] assumes that there are n channels and each mobile node has n receivers concurrently listening on all n channels. It concentrates on frequency division, i.e. adjusting their receiver to multiple frequency band channels. But with larger N , hardware cost may become prohibitive. More bandwidth will be wasted for guarding between two adjacent frequency channels. In SEEDEx algorithm [8], it requires nodes to exchange the seeds of their pseudo-random number generators within the two-hop distance to know schedules of each other. This algorithm does not require reservation for

each packet. However, to avoid the hidden terminal and exposed terminal problems [4], each node must know the information of its neighbors within two hops in time to schedule ahead. A large amount of update messages are also needed. In TBMAC [9], it employs the cellular structure to differentiate frequency bands distribution between the cells. In each cell any node that wants to exchange data packets contends for its time slot in contention period, and data exchange is finished in contention free period. Yu-chee Tseng [10] proposes a dynamic channel allocation scheme with location awareness in ad hoc networks and utilizes static GRID awareness. In SNMS [11], sender-based data transmission strategy is used to promote multicast transmission. It assumes that the channels of any two nodes are different and have been successfully pre-assigned in the networks. How to assign these channels is not addressed and this is a difficult issue in multi-channel MAC.

Basically, the problems are attributed to two factors:

- How to assign different channels such as different codes to different nodes?
- How to resolve the contention and collision problems, in particular the hidden and exposed terminal problems?

In the proposed protocol, we utilize two-phase coding [6] strategy with power control to increase the simultaneous transmission and reduce the delay. The first phase code is used to differentiate between different cells that are distributed according to hexagonal cellular structure and the second phase code is used to differentiate between nodes in the same cell.

The features of this new protocol are:

- It efficiently deals with the scalability since the map can be broadened unlimitedly;
- It takes the near-far problem into account, which few have addressed before;

As shown in Fig. 1, node A and node C transmit data to node B at the same time with different modulated codes. If they use the same transmit power level 1, the receiving signal strength from C to B will be much bigger than that from A to B. As a result, the packets from A are lost under this interference. This is known as the near-far problem. So we incorporate power control and the receiver will inform different transmitters to dynamically adjust the transmit power according to the receiver's current signal strength. In the end C use the TxPr level 2 to send data and A use the TxPr level 1 to send.

- Each node exchanges control packets with its cell leader (CL) in the common control channel (CCC) to obtain its unique code in its specific cell;
- Contention only happens in CCC during their contending to obtain the second phase codes. In data channel (DC) no contention and collision will exist since in a specific cell different nodes take their unique codes with them. As shown in Fig. 2, hidden and exposed terminal problems will be completely eliminated. Moreover we complement power control to deal with near-far interference.

In Fig. 2 (a) A is hidden from C. A also transmits to B while C is transmitting to B, then collision happen. However, in TPCPC A and C transmit using different link codes, so there is no collision. In Fig. 2 (b) C is exposed to B. When C wants to transmit to D, it is deferred unnecessarily due to B is transmitting to A. However, in TPCPC, B->A pair and C->D pair can transmit simultaneously.

This paper is organized as follows. In section 1, we briefly review the history and introduce the related work. In section 2, we propose some assumption and concentrate on concrete protocol design. In section 3 primary simulation result and performance analysis are discussed. Section 4 concludes and present future work.

2. Protocol Design

2.1 Assumption

Assuming that there is a map that defines cells according to the geographical position. Besides the map defines the 1st-phase codes distribution similar to frequency channel allocation and reuse in hexagonal cellular system. Each node knows its approximate geographical position from GPS and hence which cell it is in according to the map. Therefore, it knows its 1st-phase code. It is also assumed any one-hop neighbors know the codes of each other through broadcast. The whole channel is divided into one common control channel and one data channel. CCC has the characteristic of 1st-phase codes and data channel has the characteristic of 1st-phase and 2nd-phase codes.

2.2 Two-phase coding Protocol Description

- 1st-phase codes selection

Each moving node knows its 1st-phase codes according to the geographic position and the map. When it handoff from one cell to another cell, it tune its transmitting and receiving corresponding to different 1st-phase codes inherent in that cell. If it is near cross-cell area, it also has to keep the former 1st-phase codes. This is to ensure the communication in cross-cell area. As shown in Fig. 3, different numbers from 0 to 6 represent different 1st-phase codes, and the whole figure show the 1st-phase distribution. The central part, which is denoted by shadowing part, means that the area in which the cell leader mostly stay in.

- 2nd-phase codes selection

We define the size of each cell according to Poisson distribution and the number of the whole available codes. Therefore there are enough codes available in a cell and all nodes in a cell can be differentiated according to their unique codes in a cell. In the worst case, we can employ borrowing mechanism to make the silent node staying for a long timer to lend its unique code to accommodate the node in demand.

Each node is amounted with a receiver, which can be adjusted to two frequency bands (CCC and DC) and in each frequency band adjusted to multiple codes. As a result, it can obtain the correct data packet according to the orthogonality of PN codes.

Each node entering a new cell sends out Code Request Signal (CRS) to cell leader. If it is not in cross-cell area, the cell leader will allocate a unique code to this node and response with Code Allocation Reply (CAR). Else the cell leader will send its updated available code set (ACS) to this node. This node will listen to all responses from the adjacent cell leaders and select from the

intersection of these ACSs. After that, it sends out ACK Signal to all cell leaders so that they can timely update the ACS. The CRS and ACK Signal are modulated with different specific orthogonal codes in addition to implicit 1st-phase code of this cell, while the Code Allocation Reply is transmitted with only 1st-phase code. This is to ensure the correct reception of negotiation information. That is, the cell leader can receive ACK and CRS from different sources at the same time.

Any sender is allowed to ask for its unique code in CCC for 3 times. The transmitting power level is increased gradually. This is to avoid the extreme situation, in which the cell leader appears in borderline instead of central part of this cell. If it still cannot receive CAR, it follows 802.11 back off mechanism and the maximum count is set as three.

Nodes, which have move into other cells, must release old code before attempting a new code. They try to contend for the response from cell leader when there is collision from other nodes that are trying to obtain new code for themselves. If there is no communication during a period, it should release the code hold.

If there is no response when maximum back off count is reached, a node will assume itself as the first node appearing in the current cell and upgrade as the cell leader. Then it picks up its unique code randomly and updates the whole code set.

- Cell leader

Any node that is in control of ACS right should check if it is still in the former area. When the cell leader is not near central part of this cell, it sets *want_to_retire_signal* in broadcast signal, and the receivers will judge if they are suitable to assume this task. The former cell leader can turn its leader role to the responding receiver. Any node that is in central part, should also consult if current cell leader is willing to hand over this right. The cell leader adjust transmit power to send CAR according to its receiving signal strength and current transmitting power from the demanding nodes. The ACS is sent when source is in cross-cell area while allocated code is sent when it is not. Altogether, there are two kinds of access to CCC, one is to release code and the other is to obtain code. When code is released, it is added into ACS hold by the cell leader; when code is obtained, cell leader update the latest ACS.

- Data Communication

Transmitter-initiated [7] data transmission is adopted in our algorithm. Whenever any node has data to send, it transmits directly according to its unique code in this cell. After data transmission is finished, the receiver sends ACK to the transmitter in CCC. Thus, data exchange is successfully finished.

2.3 Cross-Cell Area

The cross-cell area means the area in which adjacent nodes in different cells are in demand to communicate. First nodes know approximate geographic position from GPS and know 1st-phase information according to map. Then these nodes adjust to multiple 1st-phase codes at the same

time and listen to response from multiple cell leaders in CCC and select from intersection of multiple ACSs. We can deal with transmitter-receiver pairs cross-cell.

Sources wait for a period when it is in cross-cell area so that it can hear enough information from different cell leaders. The number of different cell leaders is not more than 3. Source selects its unique code from heard ACSs and sends out ACK to inform relevant cell leaders to update ACS.

2.4 Discussion

Each channel has the characteristic of 1st-phase codes and DC has the characteristic of 2nd-phase codes. 7 1st-phase codes are needed to differentiate between different cells, and m 2nd-phase orthogonal codes are needed in each cell to identify different nodes. All 1st-phase and 2nd-phase codes are orthogonal.

In distributed transmission scheduling using code-division multiple access [13], each node communicates with its neighbors using unique code, which can be reused only if two nodes are more than two hops away. Each node obtains its code according to messages from the neighbors within two hops distance. This algorithm faces the collision from control messages that it cannot ensure that the same code appears at least two hops away. That is, nodes select codes according to incomplete information of neighbors codes used. Besides, with high mobility, it can't prevent the same coded node from coming into one hop distance. If it complement with more updating information, the system will have some update burden.

In our approach, we try to avoid this kind of phenomena by selecting codes from one ACS, which is obtained from the cell leader. Certainly in our approaching, we are trying to utilize spatial reuse of codes. However since codes are selected randomly from ACS and not according to inter-relation, we add 2nd-phase codes. 1st-phase codes are reused similar to frequency reuse in cellular system and 2nd-phase codes are used in each cell with inherent 1st-phase codes. Through this approach, even nodes with the same 2nd-phase codes within one hop separation can communicate with each other because of different 1st-phase codes. It is better than TBMAC since simultaneous transmission of multiple nodes is accomplished and traffic throughout is increased. The design complexity is also decreased compared with the algorithm in [12] since the multi-codes receiver is more easily to be accomplished than multi-frequencies receiver. The demand for positioning accuracy is lower than grid access in [10].

3. Performance Evaluation

We have done a primary simulation on two-phase coding multi-channel protocol in ideal scenario compared with 802.11. We simulated near-far interference from different coded data traffic and compare it with the elimination of interference through power control. Performance is evaluated through aggregate and average throughput versus offered network load.

3.1 Simulation Model

For simulations, we use ns-2 with the CMU wireless extension. We use 1 Mbps for the bandwidth. Packet size is 512 bytes. Traffic type is CBR. The propagation model is two-ray ground. Initial transmission range is the default 250m using omni-directional antenna. Our primary model consists of 20 nodes with 10 communicating flows randomly distributed within a 600mx600m area. The nodes are randomly moving. The scenario will be broadened in the future. All simulation results are the average of 10 runs. Each simulation runs for 200 seconds of simulation time. The receiver informs the sender according to current receiving signal strength and the transmitter adjusts and changes to suitable transmitting power. The basic interference threshold is set as 16. Based on this threshold, we compute out several transmit power (TxPr) levels according to Friis and free space propagation formula. The adjustable power are divided into 6 levels and the corresponding distance levels are 250m, 1251n, 46m, 12m, 4m and 1m. Different levels are corresponding to different TxPr.

3.2 Throughput Analysis

Fig. 4 and Fig. 5 show how the throughput varies with increasing offered load on ideal two-phase coding algorithm compared with 802.11. With the network load increasing, the average throughput and the aggregate throughput of two-phase coding algorithm are significantly higher than 802.11. Based on this, we simulated interference from near-far problem. In Fig. 6 and Fig. 7, the throughput is low with near-far interference. However, through applying power control, it is significantly increased. Moreover it is better than ideal two-phase coding algorithm since the power control eliminated the interference.

4. Conclusion and Future

We have demonstrated a new multi-channel protocol, which is based on two-phase coding and power control. It achieves much higher throughput than 802.11 and is robust. There is no collision between data packets with two-phase codes modulated and hidden and exposed terminal problems are completely eliminated. Besides the cost is not high since it does not need receivers for multiple different frequency bands. No frequency band is wasted when distribution is not well-proportioned. Moreover it owns good scalability. Certainly in our algorithm it demands each node know its approximate geographic position from GPS and we have to make an accurate map on 1st-phase codes distribution to be taken by each node. Also, it needs code synchronization when receiving from different user modulated with different codes. In the future work, we investigate the optimal cell structure and size. The number of the simulated cells in the performance evaluation is only limited to four and therefore the scenario will be expanded.

5. Acknowledgements

We kindly acknowledge Prof. Guan Yong Liang and Prof. Law Choi Look for their support and the anonymous reviewers for their helpful comments.

Reference

- [1] J. Gomez, A. T. Campbell, M. Naghshineh. Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification, 1997.
- [2] R. Garces and J. J. Garcia-Luna-Aceves. Floor acquisition multiple access with collision resolution. *Proc. ACM/IEEE Mobile Computing and Networking Conference*, pages 10-12, November 1996.
- [3] J. Deng and Z. J. Haas. Dual Busy Tone Multiple Access (DBTMA): A New Medium Access Control for Packet Radio Networks. In *IEEE ICUPC '98*, volume 2, pages 973-977, 1998.
- [4] V. Bharghavan, A. Demers, S. Shenker, and L. Zhang. MACAW: A Medium Access Protocol for Wireless LANs. *Proc. of ACM SIGCOMM'94*, pp. 211-225, London, UK, Oct. 1994.
- [5] F. Talucci, M. Gerla and L. Fratta. MACA-BI (MACA by invitation): A Wireless MAC protocol for High Speed Ad Hoc Networking. *Proc. of ICUPC'97*, San Diego, 1997.
- [6] L.Hu. Distributed Code Assignment for CDMA Packet Radio Networks. *IEEE/ACM Trans- on Networks*, 1(6):668--677, Dec 1993.
- [7] T. Makansi, Transmitter-Oriented Code Assignment for Multihop Radio Networks. *IEEE Trans, Commun*, COM-35(12) 1987.
- [8] R. Rozovsky, and P. R. Kuma. SEEDEx: A MAC Protocol for Ad hoc Networks. In *Proceedings of MobiHoc 2001*, Long Beach, October 2001.
- [9] Raymond Cunningham and Vinny Cahill. Time Bounded Medium Access Control for Ad Hoc Networks. *POMC'02* October 30-31, 2002, Toulouse, France.
- [10] Yu-chee Tseng, Chih-Min Chao...Dynamic channel allocation with location awareness for multi-hop mobile ad hoc networks In *computer communications* 2002.
- [11] Sheng-Hsuan Hsu, Ching-Chi Hsu..."a reliable multi-channel MAC protocol with efficient multicast support for ad hoc networks" 2002 IEEE.
- [12] Asis Nasipuri, J.Zhuang, and S.RDas. A Multichannel CSMA MAC Protocol for Multihop wireless Networks, in *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC'99)*, New Orleans, Sep, 1999.
- [13] Lichun Bao, J. J. Garcia-Luna-Aceves, Distributed Transmission Scheduling Using Code-Division Channelization, in *NETWORKING 2002*: 154-165

List of Figures

Figure 1	Near-far problem
Figure 2(a)	Hidden Terminal Problem
Figure 2(b)	Exposed Terminal Problem
Figure 3	The distribution of 1st-phase codes
Figure 4	Average throughput of 802.11 versus ideal two-phase coding algorithm
Figure 5	Aggregate throughput of 802.11 versus ideal two-phase coding algorithm
Figure 6	Average throughput under near-far interference versus the effect of power control
Figure 7	Aggregate throughput under near-far interference versus the effect of power control

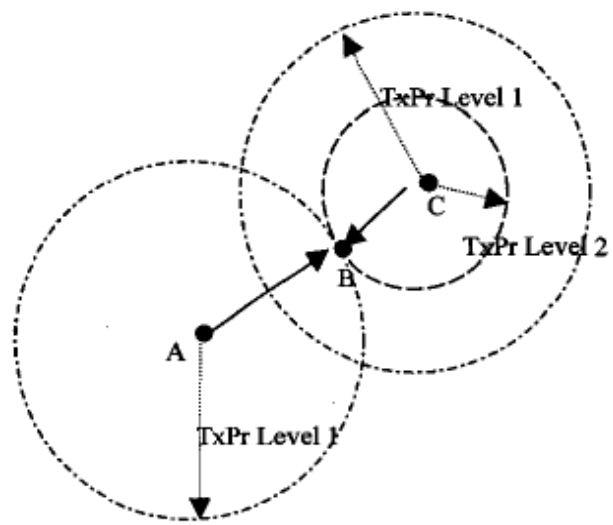


Figure 1

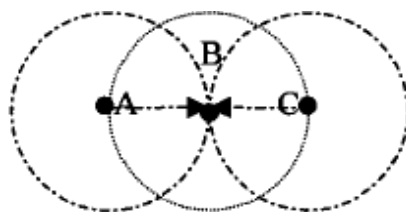


Figure 2(a)

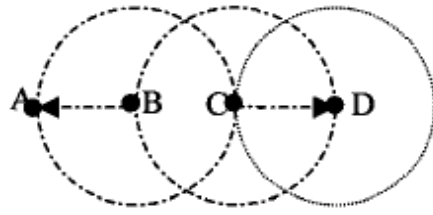


Figure 2(b)

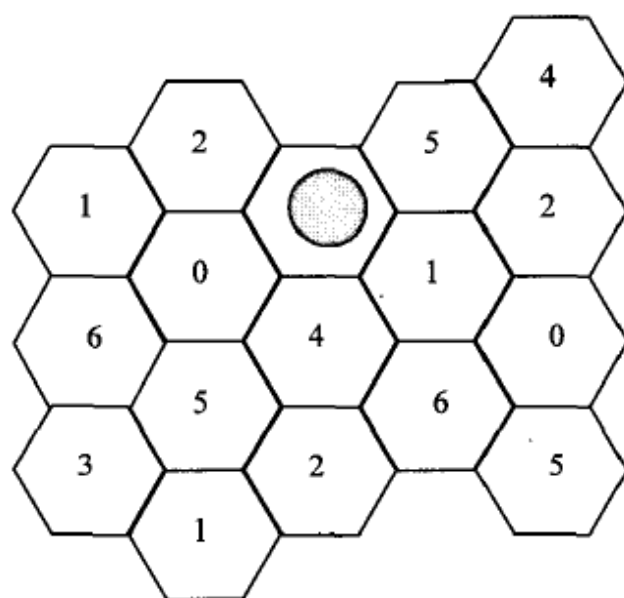


Figure 3

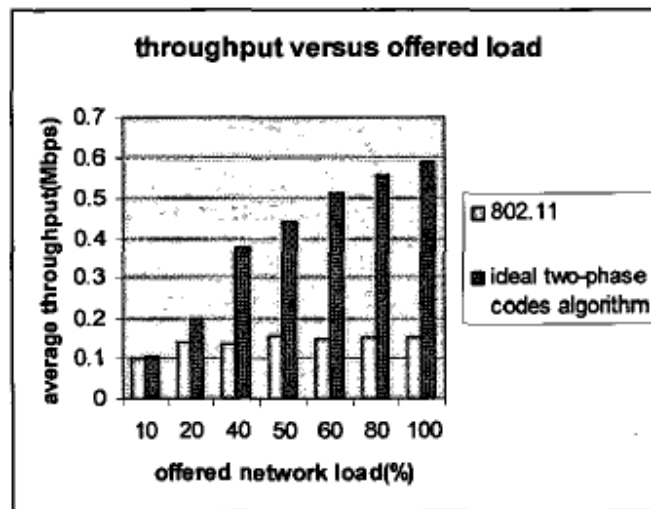


Figure 4

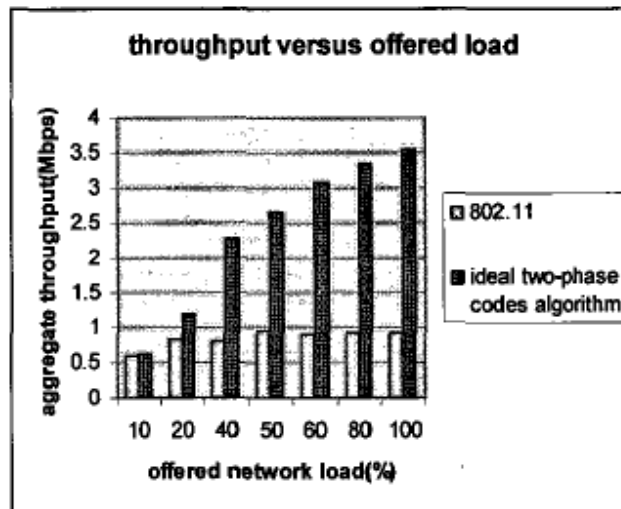


Figure 5

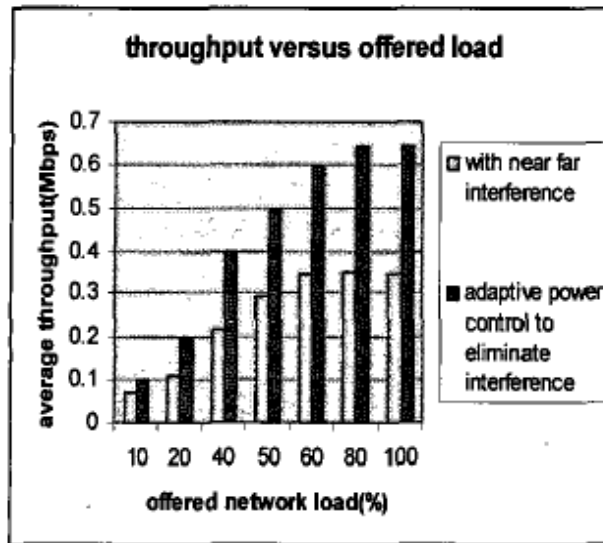


Figure 6

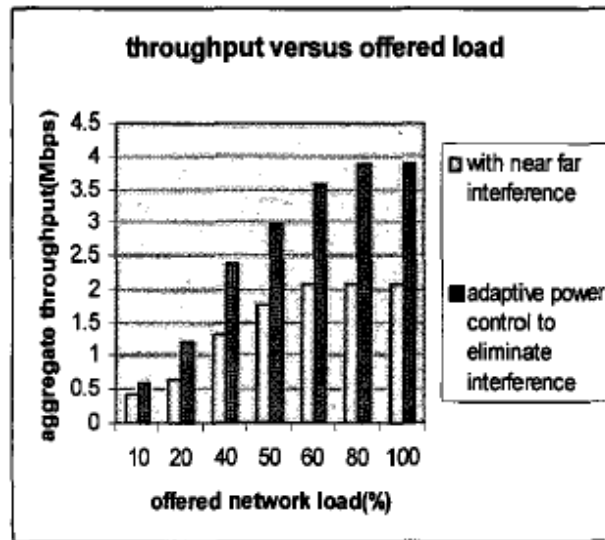


Figure 7