العنوان:	Performance Evaluation of Asynchronous Multi-Channel Mac Protocols for 802.11Wireless Networks
المؤلف الرئيسي:	Devendiran, Abd Allah
مؤلفين آخرين:	Sheltami, Tarek Rahil(Advisor)
التاريخ الميلادي:	2016
موقع:	الظهران
الصفحات:	1 - 75
رقم MD:	774856
نوع المحتوى:	رسائل جامعية
اللغة:	English
الدرجة العلمية:	رسالة ماجستير
الجامعة:	جامعة الملك فهد للبترول والمعادن
الكلية:	عمادة الدراسات العليا
الدولة:	السعودية
قواعد المعلومات:	Dissertations
مواضيع:	هندسة الحاسبات الإلكترونية، الشبكات اللاسلكية، الحاسب الآلى
رابط:	https://search.mandumah.com/Record/774856

PERFORMANCE EVALUATION OF ASYNCHRONOUS MULTI-CHANNEL MAC PROTOCOLS FOR 802.11 WIRELESS NETWORKS

BY

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A Thesis Presented to the
DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

COMPUTER NETWORKS

Mar 9, 2016

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS
DHAHRAN 31261, SAUDI ARABIA

DEANSHIP OF GRADUATE STUDIES

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ACKNOWLEDGMENTS

First and Foremost, all praises are due to Allah alone Who made this possible. I thank Him for His countless blessings and favours upon me. With His grace, all the good deeds are completed. And Peace and Blessings of Allah upon His chosen slave and Messenger, Muhammad, and those who follow him until the Last Day. And then, I am quite privileged to have Dr.Tarek Sheltami as my advisor. I thank him very much for his consistent support and guidance throughout this thesis. I thank my committee members Dr.Yahya Osais and Dr.Marwan Abu-Amara for their support and helpful inputs. I am highly indebted to Dr.Ashraf Mahmoud, for his basic DCF simulator code in Matlab and discussions related to it. I gratefully acknowledge that this work is a fundamental building block for my python simulator. Thanks to my wife, kids, and my family members who have been a constant source of support. I thank all of my friends -a quite a lot- who helped me in this challenging journey. Finally, Thanks to the Department of Computer Engineering, King Fahd University of Petroleum and Minerals for this great opportunity and also to the Kingdom of Saudi Arabia for the numerous endeavours they provide to students.

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THESIS ABSTRACT

NAME: ABDULLAH DEVENDIRAN

TITLE OF STUDY: PERFORMANCE EVALUATION OF ASYNCHRONOUS MULTI-CHANNEL MAC PROTOCOLS FOR 802.11 WIRELESS NETWORKS

MAJOR FIELD: COMPUTER NETWORKS

DATE OF DEGREE: Mar 9, 2016

Advances in physical layer techniques such as multi-rate transmission, smart antennas, etc., promise high data rate transmissions in wireless networks. However, the underlying MAC layer needs to improve in order to fully exploit these features, and to support high performance applications. By enabling concurrent transmissions over non-interfering channels, multi channel MAC protocols seek to maximize the network performance. Although the transceivers can switch between channels with ease, the available 802.11 protocol is designed only for a single channel. Some multi-channel MAC protocols are hard and impractical to implement in wireless networks, especially those based on tight global synchronization, and that lack broadcast support. In this work, we propose an asynchronous bidi-

rectional multi-channel MAC (ABMMAC), which is 802.11 compatible, low cost, and utilizes spectrum effectively, by using just a single half duplex transceiver. The proposed approach provides support for broadcast and is a logical extension of 802.11. A comparative evaluation against multi-channel protocols employing asynchronous mode of operation such as DCA, AMMAC, and BiMMAC is carried out. Simulation results show that the proposed MAC gives a better performance over its multi-channel variants and legacy 802.11 under small to big network sizes.

ملخص الرسالة

الاسم الكامل: عبد الله ديفيندران

عنوان الرسالة: تقييم أداء بروتوكولات MAC غير المتزامنة متعددة القنوات للشبكات اللاسلكية 802.11

التخصص: هندسة حاسب آلي

تاريخ الدرجة العلمية: 29 جمادي الأولى 1437هـ الموافق 9 مارس 2016

التقدم الكبير في تقنيات الطبقة الفيزيائية للشبكات اللاسلكية مثل الارسال بمعدلات متعددة و الهوائيات الذكية ... يبشر بسرعات عالية في الشبكات اللاسلكية. لكن بالرغم من ذلك لابد من تعديل طبقة ال MAC للاستفادة من تلك التقنيات في زيادة كفاءة الشبكات اللاسلكية و القدرة على دعم التطبيقات ذات الأداء العالي . بروتوكولات MAC متعددة القنوات تعمل على زيادة كفاءة الشبكة بتمكين الإرسال المتزامن في القنوات غير المتداخلة. بالرغم من توفر المبادلات التى تتيح التنقل بين القنوات بسهولة إلا أنه تم تصميم بروتوكول 802.11 للعمل على قناه واحدة فقط. الطرق المتاحة لتعدد القنوات التي تتطلب التزامن الصارم بين طرفي الاتصال و كذلك التي لا تدعم الإرسال الجماعي غير مناسبة للشبكات اللاسلكية. هذه الدراسة تقدم MAC بروتوكول غير متزامن ثنائي الإتجاة و متعدد القنوات متوافق مع 802.11 قليل التكلفة و مناسب للمبدلات التي ترسل باتجاه واحد و يستخدم نطاق التردد بكفاءة. وكذلك يدعم الإرسال الجماعي. تم إجراء تقييم شامل و مقارنة مع البروتوكولات متعددة النطاقات التى تدعم الإرسال غير المتزامن مثل DCA و AMMAC و BiMMAC. النتائج اظهرت الكفاءة العالية للبروتوكول مقارنة بالبروتوكولات المشابهة و البروتوكول التقليدي 802.11 في الشبكات الصغيرة والكبيرة

CHAPTER 1

INTRODUCTION

Medium Access Control (MAC) layer significantly impacts the network throughput, as it co-ordinates the channel access between wireless nodes. Advances in physical layer techniques such as multi-rate transmission, multiple coding and modulation, smart antennas making use of spatial multiplexing, transmit diversity, interference nulling, etc., promise high data rate transmissions in wireless networks [2]. However, the MAC layer needs to improve in order to exploit these features, and to support high performance applications. By enabling concurrent transmissions over non-interfering channels, multi channel MAC protocols seek to maximize the network performance.

The IEEE standard [3] defines multiple channels for communication at the physical layer. 802.11 b, g specifies 3 orthogonal or non-overlapping channels which are 22MHz wide. Every fifth channel can be used effectively without overlap, for example, channels 1, 6, and 11. 802.11a specify 12 non-overlapping channels: 4 channels of 20MHz each in the U-NII upper, lower, and middle bands.

When orthogonal channels are used, concurrent transmissions can co-exist on multiple channels without interference to each other. Although a transceiver is able to switch easily between various channels, the available 802.11 protocol is designed for a single channel.

Research efforts in multi-channel follow various paradigms: dedicated control channel, split phase, common hopping, and parallel-rendezvous. Each category has its specific advantages and weaknesses. Global network-wide synchronization is practically impossible for 802.11 networks unless with application of external devices like GPS. Also, support for broadcast is paramount to support routing and ARP messages. Our contribution includes:

- Proposal of Asynchronous Bidirectional Multi-channel MAC (ABMMAC) using a single half-duplex transceiver, backward compatible with 802.11, and with support for broadcast.

- Comparative evaluation with other multi-channel protocols namely: Dynamic Channel Assignment (DCA), Asynchronous Multi-Channel MAC (AMMAC), Bidirectional Multi-Channel MAC (BiMMAC), and the legacy single channel 802.11 with its RTS-CTS variant.

The proposed asynchronous bidirectional multi-channel MAC is low cost, with efficient spectrum utilization using a single half duplex transceiver, and an asynchronous mode of operation. Simulation results show that the proposed MAC gives a higher performance over 802.11 and its multi-channel variants in small to big network sizes.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

In designing a multi-channel MAC (medium access control), two challenges need to be addressed [4], [5]:

a) *Medium access mechanism:* How nodes negotiate to obtain a channel? For example, contending on a control channel [6] or Ad-hoc traffic Indication Message (ATIM) window [7].

b) *Channel selection algorithm:* How to choose from a pool of available data channels? Which algorithm will yield effective performance? For example, lowest numbered channel, random selection, soft reservation [8]. How long the channel will be used between the same pair of nodes? Such issues need to be addressed. Channel assignment can happen on a per packet basis as in [9] [10], link basis as in [7], flow basis as in [11], or component basis as in [12]. Also, channel assignment methods can be static, dynamic, or semi-dynamic

[13] [14].

Using multiple transceivers per node has been investigated in several works. In [15], the authors use two transceivers with one intended for transmission operating in fast mode, and other intended for reception working in slow mode. In [16], several continuous data frames are sent on the earlier agreed channel skipping channel negotiations, lessening overhead on the control channel and allow more transmissions. In [17], the authors use a single base channel by default, and switch to other channels as the load increases. In [18], the authors use several transceivers to increase performance. Using more than one transceiver increases cost, size, and energy consumption of a node.

Though multi-channel protocols perform significantly better than a single channel type, they introduce new kind of problems:

- **Multi-channel hidden terminal problem:** While two nodes involve in data transfer on a certain channel, they will miss the control packets exchange sent on other channels. Due to missing information on channels status, the two nodes may inadvertently choose a busy channel and start a data exchange, causing a collision.

- **Missing receiver problem:** Control packets sent on a certain channel to an intended node fail, as the node is busy in another channel either sending or receiving.

- **Global knowledge of topology, traffic requirements:** Synchronization based techniques need global information on topology and traffic such as global time slot synchronization as in TDMA, or pre-distribution of code as in CDMA. Synchronization can be achieved by exchange of timestamps and broadcast. Since broadcast messages are sent without any reservation of the channel, it is highly susceptible to collisions and heavy load situations make collisions even more. In synchronizing between different node clocks, due to driftness and other issues, achieving less than 1ms accuracy is extremely difficult. Unless using external devices like GPS, it is better to avoid systems using synchronization.

- **Other:** Other issues in multi-channel include: how to decide if the current receiver is on the control channel, when to start negotiations, how to compensate the missed control exchanges when the nodes were involved in data transfer, how to reduce channel status overhead, how to balance the load among the channels, etc.,[19]. Problems such as Information Asymmetry, Flow in the Middle [20] are also present.

Proposed solutions to encounter multi-channel hidden terminal include a dedicated control channel as in DCA [6], or scanning all the channels after the data transfer and update channel status table [21]. Wormsbecker et al., [8] note that, a careful channel selection strategy can avoid multi-channel hidden problem. Giving preference to a past-used-channel is a safe option than randomly selecting a channel or selecting a least numbered channel. In [22], neighbors can interrupt the control transmissions. If a data channel in use is selected inadvertently , the neighbors issue invalid signal to stop the on-going negotiation.

2.1 Classification of multi-channel MAC protocols

Existing wireless MAC protocols are classified on many aspects like single transceiver or multi-transceiver, synchronous or asynchronous, fixed assignment or dynamic assignment, contention based or schedule based, single channel or multi-channel, etc., Parameters like signaling technique, type of architecture, sharing mode, access mode are also considered. Research efforts in multi-channel follow various paradigms: dedicated control channel [16],[23],[24],[25],[22], split phase [7],[26],[27],[28],[29],[30],[31], common hopping [32],[33],[34], and parallel-rendezvous [19],[15],[35],[36],[37],[38],[39]. Each approach has its specific advantages and weaknesses.

2.1.1 Dedicated Control Channel:

Dedicated control channel approaches as in Dynamic Channel Assignment (DCA)[6], splits the bandwidth into one control channel and N data channels. Each node is equipped with two radio interfaces, one operating on the control channel and other on any data channel. Nodes exchange control information on a fixed control channel to gain access to any data channel. Due to a common control channel, multi-channel hidden terminal problem simply does not exist in DCA. Synchronization is not needed for this approach. Nodes are aware of the neighbor activities all the time. Broadcasting information can be sent on the control channel. But as the density of nodes increases, the control channel exchanges also rapidly surmounts resulting in a bottle neck on the control channel. The upper bounds on number of data channels that a control channel can support needs to be considered [20], [21]. The dedicated control channel causes resource wastage of precious bandwidth, especially when only a few channels are available, as that in 802.11b. Two transceivers per host increases cost of a node and makes it expensive. The energy consumption of the node is nearly doubled. Having additional transceiver also increases the size of the sensor and makes it less practical in some cases.

2.1.2 Split Phase:

Split phase approaches are commonly based on global time synchronization. The time axis is divided into periodic contention phase and data transfer phase. During contention phase, all nodes listen to an agreed upon common channel and contend with each other to reserve the data channels. Nodes that had successful negotiations can involve in data transfer during data transfer phase. Other nodes which cannot obtain a channel will have to wait until the next contention phase. After data transfer is complete, ACK may also be sent on the same data channel. At the end of data phase, or upon the completion of DATA/ACK, whichever is earlier, nodes switch to the control channel for the next control phase, and the cycle repeats. The control channel is also reused during data transfer. This kind of multi-channel operation is mainly based on a global temporal synchronization among the nodes. Beacons or in some cases, GPS can be used to provide synchronization, so that all nodes know the start of control phase. Nodes can have some internal timers to demarcate the end of control phase and the start of data transfer phase. A big challenge arises as to which node or set of nodes will co-ordinate the sending of beacons. In infrastructure mode of operation, the access point takes care of sending beacons and other such centralized operations. However, to achieve time synchronization in an ad-hoc network is extremely difficult. In this approach, multi-channel hidden terminal problem is eliminated since nodes are cognizant of channel reservations during contention phase. Since a single transceiver is enough, there is no additional cost or energy spending. All channels are used during the data transfer phase, so bandwidth is reused unlike dedicated control channel approach. However temporal synchronization among the nodes is needed, as all nodes have to enter contention phase or data transfer phase at the same time. During contention phase, the common channel is congested by the control signaling traffic and can get saturated as the network size increase. At the same time, the data channels are unused during contention phase. Nodes which failed to have channel access rights in the contention phase need to defer until the next contention phase.

2.1.3 Common Hopping:

In Common Hopping, nodes follow a common hopping pattern and periodically switch between the different channels. Nodes which want to communicate negotiate with each other, suspend hopping and stay on the channel to engage in data transfer. Once the data transfer is complete, they re-join the hopping sequence. In single rendezvous, only a single agreement can happen between a sender and receiver on a given channel at any time. Hopping approach spreads the control signaling overhead across all the available channels. This approach needs only a single radio. Congestion on a particular channel is avoided. However, this approach require tight time synchronization as a must, which is very difficult to achieve. In addition, broadcasting is a real issue, since nodes are on different channels at various points in time. As channel hopping is frequent, channel switching delay is also a significant overhead.

2.1.4 Parallel Rendezvous:

In another category of Parallel Rendezvous, multiple handshakes can happen simultaneously on all the available channels. As such the control overhead is spread across all the channels. The support for increasing number of channels is good. When channels are numerous and packets are short, parallel rendezvous perform better than dedicated control channel approaches due to the elimination of control channel bottleneck [40]. However, a tight global synchronization is needed and support for broadcast is not adequate.

CHAPTER 3

OVERVIEW OF SELECTED MAC PROTOCOLS

3.1 Single channel Protocols

The single channel protocols based on 802.11: simple 802.11 and RTS-CTS option, are discussed in brief.

3.1.1 Basic Distributed Co-ordination Function (DCF)

802.11 provides simplified access mechanism for nodes to access the channel in a distributed manner. A node looking to send data senses the channel for a small time called DCF Inter Frame Space (DIFS) and if the channel is free, it can send DATA immediately. The receiver sends an acknowledgement frame ACK. In case, the channel is not free, the sender waits until the channel is available, and then waits a random backoff plus a duration of DIFS and send DATA. At