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Review

Will MCCA revive wireless multihop networks?

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ABSTRACT

Wireless multihop networks (WMNs) are very favorable for many emerging applications, including those connected with public safety, Internet of Things or future Next Generation 60 GHz communication. However, the hidden station problem dramatically degrades efficiency of WMNs and impedes extensive usage of these networks. To eliminate the effect of hidden stations in Wi-Fi mesh networks, the latest version of the IEEE 802.11 standard proposes using deterministic channel access called MCCA. In the paper, we analyze this mechanism, focusing on both already achieved results and open issues.

1. Introduction

A decade ago WMNs attracted much attention of academia, military and industry. They would implement the dream of self-organized general purpose wireless network having impact on both economics and society [1]. WMNs should provide Internet access anytime and anywhere, connect sensors and also replace professional mobile radio. All these applications require high reliability, power efficiency and Quality of Service (QoS) support.

Nowadays, we have dozen of routing protocols (OLSR, AODV, DSR, etc.), thousands of papers studying various multihop issues (mostly, routing), mature technologies (e.g. Wi-Fi Mesh), several companies selling devices, and almost no interest of customers, no “wow-effect” [2]. Unreliability of wireless channel aggravated by typically used in WMNs Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) with its well-known hidden station problem [3] has almost killed WMN concept at the market of traditional networks, especially in the context of transmission reliability, QoS provisioning and energy consumption. While energy efficiency of multihop networks can be improved by using low power receive radio [4], such issues as transmission unreliability caused by the hidden station problem still remains open. This drawback cannot be overbalanced by such obvious WMN benefits as easy installation, easy maintenance, self-configuration, self-healing.

Nevertheless, in many emerging areas multihopping is at least important feature, which improves efficiency and scalability of new technologies. Thus, at the recent meeting of the IEEE 802.24 Smart Grid Technical Advisory Group, multihopping was named favorable in some Internet of Things (IoT) scenarios [5]. Apart from supporting by such core IoT technology as Zigbee, relaying is added in the novel Wi-Fi Halow technology aka IEEE 802.11ah [6], which was designed as a Wi-Fi answer to the IoT challenge. Deploying mains-powered relays close to battery-powered sensor stations (STAs) reduces energy consumed by STAs since the transmission can be done (i) at lower power and (ii) at higher MCS, which makes it shorter. Moreover multihop relaying can provide connectivity for devices installed in cellars, where the signal from the access point (AP) is too poor. Apart from that, WMNs are very attractive to deploy monitoring systems in rural areas, when we do not have infrastructure. Another promising area for multihop solutions is mmWave communication in license exempt bands. Here multihop transmission helps to overcome high attenuation and improves coverage. For example, recently formed IEEE 802.11ay Task Group which develops next generation 60 GHz Wi-Fi considers multihopping promising for such scenarios[7] as data center multi-rack connectivity, mobile fronthauling and wireless backhauling [8].

Many studies show that one of the most promising ways to overcome transmission unreliability and to provide QoS support in WMNs is deterministic channel access [9–12]. With deterministic channel access, a STA can reserve (negotiate with other STAs) time intervals in which it can transmit without contention. This allows (i) increasing transmission reliability, (ii) providing predictable delay, which are both needed for QoS support.

In many existing WMN standards (e.g., Zigbee, WiMAX Mesh, WiMedia), deterministic access is implemented via classical slotted Time Division Multiple Access (TDMA) scheme as follows. Channel

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time is divided into superframes, i.e., periodically repeated time intervals of equal duration. Each superframe consist of a fixed number of slots of equal duration. With some centralized or distributed algorithm, STAs reserve slots for transmission.

The efficiency of such a scheme significantly depends on the number of slots in each superframe and slot duration. Too long slots lead to underutilization of channel when STAs have few data to transmit. On the contrary, with too short slots, STAs can accurately reserve the needed amount of channel resources, but the control overhead is extremely high. For example, if the superframe duration is 100 ms and the slot duration is 100 us, i.e. a superframe has 1000 slots which can be reserved independently, we need a 1000-bit map just to describe the state of all slots (i.e. reserved/free), to say nothing of describing which STA can transmit in each slot. The problem of selecting superframe and slot duration is complicated by heterogeneity of traffic patterns and their QoS requirements. In particular, voice applications usually require short slots, while TCP streaming needs long ones. Many existing standards implementing slotted TDMA try to find something in the middle. But, both the superframe structure and slot duration are fixed and cannot be changed with time, which does not allow adapting the system for different usage scenarios.

The IEEE 802.11s amendment (the amendment was incorporated in the base IEEE 802.11 standard [13] in 2012) which defines Wi-Fi Mesh technology significantly revises the way of implementing deterministic access in WMNs. In particular, this amendment defines a novel deterministic channel access mechanism called Mesh coordination function Controlled Channel Access (MCCA), which can be used together with the mandatory random channel access called Enhanced Distributed Channel Access (EDCA). With MCCA, a STA can reserve sequences of periodic time intervals. It is important to note that (i) in comparison to aforementioned slotted TDMA schemes, a STA can adaptively choose duration and period of time intervals of each sequence based on its real traffic demands[1] and (ii) the amount of control overhead does not depend on the chosen values. So, MCCA provides a much more flexible way to organize deterministic access in WMNs. Moreover, inspired by MCCA, Wi-Fi developers used its main concept — periodic reservation of channel time — in many recent amendments to the Wi-Fi standard. In particular, IEEE 802.11aa uses a similar mechanism to negotiate contention-free transmissions of neighboring APs (so-called HCCA TXOP negotiation). The IEEE 802.11ah amendment contains a mechanism, called Restricted Access Window, which aims to reduce contention between thousands of autonomous devices in the Internet of Things scenarios. Periodic channel allocation is also used in millimeter wave Wi-Fi (IEEE 802.11ad and IEEE 802.11ay). Thus, the study of MCCA will help us to improve channel access in emerging Wi-Fi technologies related to the current hottest topics of wireless communication.

Nevertheless, being a framework, the IEEE 802.11 [13] standard leaves many issues crucial for implementation of MCCA out of consideration, e.g., how to manage reservations, how to use this mechanism for transmission of various categories of traffic, how to choose its parameters, which are discussed in this paper. At the same time, we have found only few of papers trying to address open issues of channel reservation in mesh network, e.g.[10–12,14–21]. Although other surveys on IEEE 802.11s are currently available in literature [22,23], this paper is the first one dealing with MCCA specifically. Thus, the contribution of the paper is a thorough analysis of MCCA operation, with focus on the issues left beyond the scope of the standard, including such important questions as how to choose parameters of MCCA reservations, how to use them for transmission, when to set up and to tear down reservations, which rate to use for transmission inside the reserved time intervals, how MCCA can be improved. We also raise a number of implementation-related issues. We describe possible solutions for the raised issues and analyze their impact on MCCA performance. We believe that our paper will give insight into MCCA — a novel and flexible framework to organize deterministic access in WMNs — and its implementation issues and inspire researchers for deeper investigation of this mechanism. This eventually will give us an opportunity to improve performance of WMNs and to address emerging challenges.

The rest on the paper is organized as follows. In Section 2, we describe both EDCA and MCCA, and the rules of their cooperative usage. Then we study MCCA open issues and provides some solutions to improve its efficiency. These issues are divided into three groups. The first group of issues — described in Section 3 — is related to the usage of MCCA functionality for data transmission. In Section 4, we go deeper and consider the second group of issues related to channel access. Specifically, we focus on MCCA low-level operation, filling the gaps in the standard and proposing some improvements of MCCA core functionality. Finally, Section 5 consider most important issues related to MCCA implementation in real devices. Section 6 concludes the paper.

[1] At the same time, time intervals of the same sequence are strictly periodic and of the same duration.

Table 1
EDCA access parameters.

AC	AC_VO	AC_VI	AC_BE	AC_BK
$AIFSN[AC]$	2	2	3	7
$CW_{min}[AC]$	3	7	15	15
$CW_{max}[AC]$	7	15	1023	1023

2. Channel access mechanisms in Wi-Fi mesh networks

To organize channel access in Wi-Fi Mesh networks, the IEEE 802.11 standard [13] introduces Mesh Coordination Function (MCF). With MCF, STAs can use two channel access mechanisms: random EDCA and deterministic MCCA. Let us describe them in detail.

2.1. EDCA description

EDCA is a CSMA/CA mechanism which provides differentiated QoS for various types of traffic. According to CSMA/CA, a STA senses the channel prior to data frame transmission and transmits the frame only if the channel is idle. Otherwise, it defers frame transmission. Since several STAs can defer transmission, the probability of a collision (simultaneous transmission of several STAs) right after a busy time interval becomes high. To decrease this probability, the truncated binary exponential backoff procedure is used.

To provide differentiated QoS, one of eight *user priorities* is assigned to each data frame. Based on user priority, data frames are divided into four access categories AC_VO, AC_VI, AC_BE, AC_BK destined for voice, video, best effort and background traffic, respectively, and listed in descending order of priority. For each access category (AC), a separate queue is maintained and frames from different queues are served with different channel access parameters. The values for these parameters depend on used PHY layer protocol. In particular, Table 1 shows the default EDCA access parameters for IEEE 802.11a/n/ac PHY.

To describe EDCA in detail, let us consider a non-empty queue of category AC.

After transmission of a data frame from the queue, the STA initializes the queue backoff counter with an integer value drawn from a uniform distribution over the interval $[0, CW[AC]]$, where