Real-Time Communication Support in IEEE 802.11-Based Wireless Mesh Networks

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INTRODUCTION

The IEEE 802.11 family of wireless standards became the dominant solution for Wireless Local Area Networks (WLANs) due to its performance, low cost and fast deployment characteristics (Hartmann & Meister, 2008; Sgora, Vergados, & Chatzimisios, 2009). Along its increasing popularity, there was a demand for interconnection of several different devices in the network, sharing common services. Thus, Wireless Mesh Networks (WMNs) appeared as a promising approach to deal with heterogeneity and diversity of those wireless networks (Farkas & Plattner, 2005).

WMNs provide greater flexibility, reliability and performance when compared to traditional wireless networks (Pinheiro, Sampaio, Vasques, & Souto, 2009), since they are able to extend the network coverage without any additional infrastructure by using multi-hop communication, where nodes can relay traffic by traversing multiple hops to reach a destination (Carrano et al., 2009).

There are several application domains where WMNs can be applied, such as home and enterprise networks, transportation and real-time systems, building automation and metropolitan area networks (Akyildiz, Wang, & Wang, 2005). However, despite the several application domains, in this article we are particularly interested in studying the support of real-time applications in WMNs.

Real-time applications are usually not resilient to delay and jitter constraints. The deployment of real-time services over WMNs requires the support of Quality of Service (QoS). To guarantee time-constrained communication in wireless multi-hop networks, real-time communication must be established according to specific traffic characteristics and QoS requirements.

Despite the benefits of WMNs, the main challenging task concerning QoS provisioning in WMNs is the communication channel that is a shared resource in a multi-hop relaying infrastructure. Also, it is important to consider some characteristics inherent to wireless mesh environments such as link instability, lack of central infrastructure, nodes mobility, channel access contention and hidden terminal problem (Farkas & Plattner, 2005).

This article discusses the aforementioned challenges related to QoS provisioning, targeting real-time communication support in IEEE 802.11 WMNs at Medium Access Control (MAC) sub-layer. A literature review of available techniques on the referred topic will be presented and discussed.

BACKGROUND

The IEEE 802.11 standard defines four MAC sub-layer functions to control medium access (IEEE Standard 802.11-2012, 2012):

1. Distributed Coordination Function (DCF) is the basic medium access mechanism based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA);
2. Point Coordination Function (PCF) is a polling scheme where stations are interrogated in order to determine which have the right to transmit;

DOI: 10.4018/978-1-4666-5888-2.ch713

3. Hybrid Coordination Function (HCF) introduces the concept of QoS and Transmission Opportunities by means of Enhanced Distributed Channel Access (EDCA) and HCF Controlled Access (HCCA) mechanisms;
4. Mesh Coordination Function (MCF) defines an optional medium control mechanism for IEEE 802.11s mesh networks called MCF Controlled Channel Access (MCCA).

However, regarding real-time communication support, these functions present some limitations. DCF only provides best effort services, where packets are simply discarded when queue is full. This leads to an undesirable behavior when considering real-time communication, since important messages may be discarded. In addition, there is no traffic differentiation mechanism to separate traffic according to its priorities (Ni, 2005).

PCF is not able to handle multiple QoS requirements of different traffic types, because it defines only a round-robin scheduling algorithm. In addition, the access point contends for the medium with the same priority of other stations in order to transmit the beacon frame, causing delays and decreasing network performance (Ni, 2005; Mangold, Choi, Hiertz, Klein, & Walke, 2003).

Regarding HCF, EDCA mechanism introduces access categories to traffic prioritization, but suffers from virtual collisions and priority inversion issues as the network load increases (Viegas, Sampaio, Vasques, Portugal, & Souto, 2012; Masri & Abdellatif, 2009).

Although HCCA significantly improves PCF, it has not been widely implemented. Also, if the hybrid coordinators of two access points are regularly attempting to gain channel access then there may be frequent collisions (Perahia & Stacey, 2008, p. 231).

On MCF, the optional MCCA, proposed to provide collision-free and guaranteed channel access by reserving time slots, fails to achieve the desired objective since its performance is highly affected by contention from non-MCCA mesh stations (once they are not aware of reservations). Also reservations are periodically broadcast among mesh stations which increase the network overhead (Krasilov, Lyakhov, & Safonov, 2011; Islam, Alam, Hong, & Lee, 2011).

Due to these limitations, novel proposals for supporting real-time communication over WMN emerged. The next section presents and discusses some of them, by describing its functionalities and characteristics.

REAL-TIME COMMUNICATION SUPPORT

To support real-time communication in multi-hop networks it is necessary to ensure network is properly dimensioned and enough resources are reserved in order to maintain QoS guarantees. For QoS provisioning, it may be required the reservation in advance of some resources, as the adequate reservations will help by maintaining delay, jitter and negotiated upper bound for packet loss rate requirements (Jha & Hassan, 2002).

The Internet Engineering Task Force (IETF) developed the Integrated Services (IntServ) and Differentiated Services (DiffServ) techniques aiming QoS provisioning in IP-based networks (Braden, Clark, & Shenker, 1994; Nichols, Blake, Baker, & Black, 1998). The IntServ technique aims to provide per-flow QoS guarantees to individual applications, where several services classes are defined. Those applications should be able to select a class based on their QoS requirements. It uses Resource reSerVation Protocol (RSVP) to allocate resources to links along a data path. However, IntServ scheme has scalability problems, where maintaining a large number of flows requires enormous amount of resources (Jha & Hassan, 2002, pp. 107-191).

DiffServ consists of the specification of a restricted communication domain with specific requirements, delimited by boundary routers that control the ingress and egress of network traffic. Ingress boundary routers are required to classify traffic according to a service level specification. DiffServ has a traffic conditioner, in which are included the traffic characteristics and the performance metrics (delay, throughput, etc.). At internal nodes, the traffic is processed at maximum available speed, once traffic classification has been previously done by boundary routers (Jha & Hassan, 2002; Sicker, McTasney, & Grunwald, 2009).

However, when considering the mobility of wireless mesh networks, neither IntServ nor DiffServ techniques are able to adequately deal with mobile nodes. This weakness is due to difficulties in reserving resources for mobile environments. As IntServ works with RSVP allocating resources to the links along data paths, with nodes mobility a path will change and consequently there will be no reserved resources in a future router where the mobile node may connect. Likewise, the main issue of DiffServ is the service level specification, i.e. when a mobile node moves to a new network and