Routing Protocols for IEEE 802.11-Based Mesh Networks

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INTRODUCTION

Wireless Mesh Networks (WMN) is a current attractive and "hot" topic due to its potential capability to support a myriad of wireless radio and access technologies such as IEEE 802.16 (WiMAX), IEEE 802.11 (WLAN) and IEEE 802.15 (WPAN), thus providing the required flexibility to integrate different radio access networks (Akyildiz & Wang, 2009). It allows creating large-scale hybrid networks, extending the connectivity and network services. Moreover, with the pervasive use of standard IEEE 802.11 devices, this standard is the most common wireless technology used in current WMN's deployments. For this reason this article is focused on the research challenges and new trends of IEEE 802.11-based WMNs only.

Traditionally, mesh networking research works has mostly been carried out using routing protocols for ad-hoc networks which do not scale well on wireless mesh settings (Baumann et al., 2008). In other words, the use of just current 802.11 ad-hoc technologies is not sufficient for multi-hop wireless mesh networks, as it is the case of IEEE 802.11s wireless mesh networks. The lack of specific routing protocols designed for wireless mesh networks, that take the mesh properties into consideration is one of the major concerns.

Although the hop count is still the traditional routing metric used in most of the common routing protocols designed for multi-hop wireless networks, the minimum hop-count metric may lead to poor performance making it unsuitable for WMNs (Draves, Padhye, & Zill, 2005; Liu et al., 2008; Borges, Curado, & Monteiro, 2011). Thus, much research work has been conducted to propose more efficient routing metrics for wireless multi-hop networks, in order to replace the traditional hop-count as the routing metric. At the same time, new routing protocols have been proposed to make use of these new metrics in order to improve the overall routing performance in WMNs. This article also aims to give an overview of the most representative works related to routing metrics and protocols that have been proposed for WMNs and new trends in this field.

The IEEE 802.11s standard is relatively new, released in September 2011, and now part of the IEEE 802.11 set of standards (LAN/MAN standards Committee, 2012). Briefly, the IEEE 802.11s aims to create a framework to enable wireless mesh networking for standard IEEE 802.11 devices. However, there are still few proposals/implementations in full compliance with the specifications of the standard. Therefore, this article covers a broad set of IEEE 802-11 based routing solutions instead of being constrained to the IEEE 802.11s WMNs.

BACKGROUND

Routing in 802.11-Based Wireless Mesh Networks: Research Challenges

The most relevant challenges for IEEE 802.11-based routing protocols arise from the fact that WLANs operate in unlicensed bands, hence sharing the medium with other communication technologies. As a result, interference is a common issue. Devices that also use these unlicensed bands include different types of sensors, cordless telephones, low power devices, microwave ovens, security cameras, baby monitors, and many others. Even some licensed services may operate in these bands, such as amateur radio, and some satellites (Akyildiz & Wang, 2009). This means

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that the assumption of a crowded and noisy frequency spectrum must be a concern when designing new routing protocols for wireless environments.

The instability of wireless links (topological instability) and the consequent path breakage (path instability) is potentially one of the most complex challenges for WMNs and are directly related with the inherited hidden and exposed node problems of wireless communication, which become even more serious in WMNs environment due their multi-hop nature. Although some work has been done to overcome this problem, the effects of the hidden (Vutukuru et al., 2008) and exposed nodes (Mittal & Belding, 2006) may be minimized but not avoided.

Another important challenge for WMN's routing protocol design is: how to detect and characterize external interferences? It is well-known that multi-hop paths cause more collisions for single channel than for multiple channels. The same idea applies to the number of radios (Jain et al., 2003; Padhye et al., 2005; Subramanian et al., 2006; Kyasanur & Vaidya, 2006). However, does this means that a multi-channel and multi-radio technology is enough to overcome the aforementioned challenge? In other words, with a sufficient number of radios and channels, interference can be completely eliminated? The right answer might be "*probably not*" because no matter how many channels or radios you have, you must bear in mind that at any moment, any external device may start transmitting on the same channel, potentially creating interference. Therefore, channel assignment becomes crucial, influencing the topology and hence the network capacity.

Routing Metrics

A good routing metric accurately captures the quality1 of the network links and allows the computation of the best quality paths. So far there is not any standard routing metric to be used in WMNs. In fact, it is unlikely that a single metric will become suitable for all WMN's settings. Thus, the development and use of different routing metrics on WMNs are necessary to cope with the myriad of characteristics from distinct scenarios. For example, a multi-channel and multi-radio setup will require a special routing metric different from that used in traditional WMNs, where the nodes use only one wireless card and communicate on the same channel (Draves et al., 2004b; Draves et al., 2004b). Therefore, a multiplicity of routing metrics has been proposed for WMNs (Draves et al., 2004b ; Liu et al., 2008).

Many link and node characteristics can be taken into account to provide a good metric for the link/node/path quality. Besides basic measures such as delay, path length, transmission rate, and loss rate, there is a set of other important characteristics of the WMN environment that must be taken into account.

One important characteristic is its measuring method, i.e. the method used to gather all information required for its calculation. Regarding the measuring method, a routing metric can be classified as active (if it uses probe frames to measure) or passive (otherwise). Although active probing can provide much more updated and useful information, it suffers from its associated overhead.

Kotz et al. (2003) observed that wireless links often exhibit quite different propagation conditions in one direction than in the other. Frames may be successfully sent from one node to another but not in the opposite direction. This phenomenon is known as link asymmetry and may also affect the accuracy of some routing metrics.

Finally, the isotonicity property of a routing metric ensures that the order of weights of two paths or links is preserved if they are appended or prefixed by a common third path or link. Isotonicity is a necessary condition for a routing metric in order to allow the routing protocol to apply well-known algorithms to find minimal weight paths, such as Bellman-Ford or Dijkstra's algorithm. A non-isotonic metric will force the routing protocol to apply complex algorithms to find the best quality paths. A comparison of the routing metrics based on these characteristics is shown in Table 1.

Moreover, the impact of interference on the capacity of wireless networks has been broadly studied (e.g. Gupta & Kumar, 2000; Jain et al., 2003; Padhye et al., 2005). The interference includes the inter-flow interference and intra-flow interference. In wireless routing, the intra-flow interference is the interference caused by intermediate nodes sharing the same flow path. Inter-flow interference refers to the interference caused by neighboring nodes of distinct flow paths but competing for the same busy channel.

From the aforementioned discussion, it becomes clear that there is no "*one size fits all*" solution for routing in Wireless Mesh networking, in what concerns routing metrics. It becomes also clear that a good routing metric for WMNs tends to capture all