Wireless Mesh Networks: Network Architecture, Routing Protocols and Research Challenges

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Abstract—Wireless mesh networks (WMNs) have the potential to revolutionize the way we use the Internet. These networks have a low power requirement and therefore could be potentially fuelled by a low cost renewable energy source. Numerous spaced out meshed nodes route the data in a multi-hop manner in the WMNs. The WMN can be designed using three different network architectures. The key benefits of using a wireless mesh network are that they are easily adaptable, expandable and have low cost compared to conventional networks. Also WMNs support high demand, which is a must in today's world. In this paper, we study the network architectures, routing protocols, and the research challenges of WMNs.

Keywords— Mesh Networks, wireless, multi-hop, routing, network architecture, research challenges.

I. INTRODUCTION

Definition: When a large number of radio nodes are organized in a mesh formation, the communication network that is formed is termed as a Wireless Mesh Network (WMN).

Wireless mesh networks are rapidly becoming the most preferred mode to deliver voice, video and data in outdoor environments. In a mesh network, there are nodes called mesh nodes that relay data over the network [6]. Mesh Cloud is the coverage area of all the nodes in a single network. Wireless Mesh Network (WMN) is a wireless network that has either a partial or full mesh topology. WMNs are a form of wireless ad-hoc network. WMNs comprise of mesh clients, mesh routers and gateways [10]. Mobile computers, smart phones, other wireless devices etc are the mesh clients. Mesh routers direct traffic to and from the gateways which may or may not have Internet connectivity [4].

A distinct advantage that WMNs enjoy over other mobile networks is that they are highly reliable and fault tolerant as opposed to conventional mobile networks wherein the failure of even a single base node terminates the communication [2]. WMNs can self form and self heal [9][10]. Wireless mesh networks can be implemented with various wireless technologies namely 802.11, 802.15, 802.16 among others [7]. WMNs are undergoing rapid progress and in turn inspiring numerous applications.

II. NETWORK ARCHITECTURE

On the basis of network topologies, WMNs can be designed in 3 different network architectures. Each of the three architectures can be briefly summarized as follows:

A. Flat Wireless Mesh Network

This type of architecture is the simplest case among the three WMN architectures [2]. The client machines which act as both hosts and routers, form the network [1]. The nodes interact with each other to serve routing, network configuration, service provisioning, and other application provisioning. The issues in constructing a flat WMN are addressing schemes, routing and service discovery schemes. The advantage of this architecture is that it is relatively easy to implement and understand. The shortcomings include being unable to scale and accommodate high resource constraints.

B. Hierarchical Wireless Mesh Network

In accordance to the meaning of the word hierarchical, a hierarchical WMN has multiple tiers or levels. A client WMN is actually same as a conventional ad hoc network [2]. Client nodes (occupying the lowest position in the hierarchy) interact with the main base network via WMN routers [5]. Often the base network is formed by the dedicated WMN nodes, meaning that the backbone nodes may not originate or terminate data traffic like the WMN client nodes [1]. The responsibility to self-organize and maintain the backbone network is provided to the WMN routers.

C. Hybrid Wireless Mesh Network

A unique case of the hierarchical WMNs yields the Hybrid Wireless Mesh Network. When the WMN makes use of other wireless networks for communication along with hierarchical WMN, that particular architecture is termed as a hybrid wireless mesh network. The hierarchical WMN ensures connectivity to Internet, Wi-Fi, cellular and sensor

networks etc. whereas the other wireless networks provide better interconnectivity in

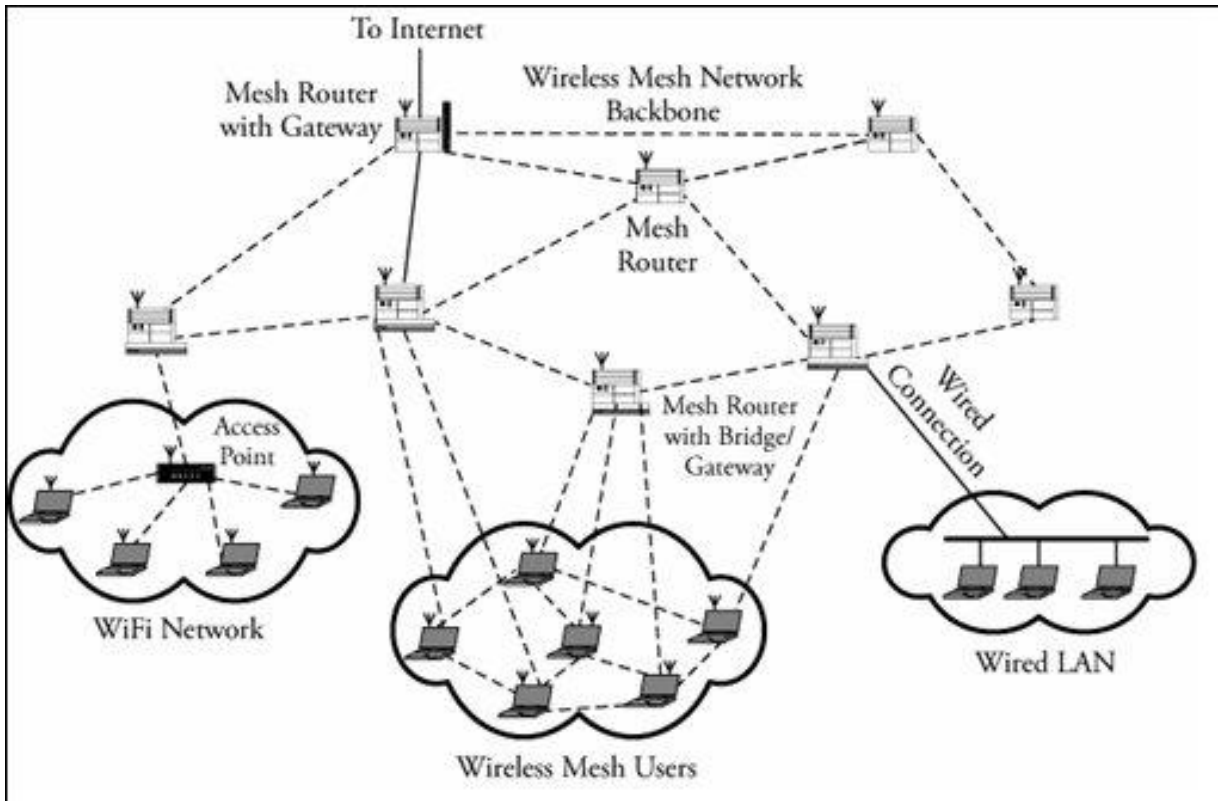

Figure 1: Wireless Mesh Networks [8].

WMNs [1]. The growth of WMNs depend heavily on how it works with other existing wireless networking solutions, therefore this architecture is of prime importance in development of WMNs [2].

III. ROUTING IN WIRELESS MESH NETWORKS

The primary function of any wired/wireless network is to have an efficient routing capability. Routing protocols provide the necessary paths to the mesh nodes through a WMN, so that they can communicate on good or optimal paths over multiple hops. The protocols should be robust enough to consider the variations of the radio environment the varying weather conditions. The newness of WMNs makes design of routing protocols for WMNs an active research area. The next section of this paper will discuss the various routing metrics in brief.

A. Routing Metrics

The goal of any routing protocol is to find out the minimum weight –path (weight cost) between the source and target node. The routing metric defines the cost [12]. The path cost is the sum of all the link metrics on the path from source to destination.
In a wireless mesh network, the routing metric must:

- Maintain stability in the route. Ensuring route stability, i.e., no frequent route changes.
- Ensure that the selected paths have minimum path cost.
- Use efficient algorithms to calculate minimum path cost.
- Ensure loop free forwarding.

B. Routing Protocols

There are more than 70 schemes for routing data packets over the wireless mesh networks [7]. Some of the commonly used routing protocols include:

- AODV (Ad hoc On-Demand Distance Vector)
- DSDV (Destination-Sequenced Distance-Vector Routing)
- OLSR (Optimized Link State Routing protocol)

- OSPF (Open Shortest Path First Routing)
- PWRP (Predictive Wireless Routing Protocol)

IV. RESEARCH CHALLENGES

Here, we will list out the research challenges in the field of WMNs one by one.

A. Physical Layer

Several factors can impact a performance of a WMN. They include:

- Mobility: To accustom to change in frequency of the network users.
- Link Adaptation: Robust codes to restore reliability [3].
- Variable Transmission Power: Variable power gives freedom in link adaptation algorithm [2].
- Multiple Transceivers: If multiple communication channels are available, then send/receive simultaneously on different channels [1].
- Link Quality Feedback: The availability of link quality information this can significantly improve the efficiency.
- Transceiver Performance: Quick synchronization between sender and receiver.

B. Data Link Layer

- To appropriate make use of multiple physical channels.
- Proposed MAC protocols promise ability to handle multiple channels, however at the cost of an expensive physical layer [1] .
- To develop Smart Antenna for MAC Layer with wider coverage that is more energy efficient.

C. Network Layer

- The objective of any network layer is the delivery of packets from source router to destination router. WMNs require the network layer especially because they use multiple-hops to reach from the source to destination [2].
- Efficient routing necessary as it separates success from failure.
- Routing protocol must be scalable
- Support of multiple gateways makes a protocol reliable.
- A good routing protocol easily adapts to different network topologies.
- Quality of Service: Selecting routes according to the traffic class is important.
- Routing is primarily responsible for the performance of a WMN.

D. Transport Layer

- To modify the TCP to suit the needs of a multiple hop environment of WMN [3].

V. CONCLUSION

Wireless Mesh Networks is a rapidly developing field of study. All types of companies – ranging from small start-ups to multi-national companies are investing attention towards research on WMNs [3]. In order to estimate their future impact, a large number of research challenges need to be met.

WMNs are a challenging and complex network, particularly because of their multi-hop structure, the mobility of network nodes, and the unreliable nature of the wireless channel. The success of WMNs in the future will depend not only on how well the research challenges are achieved, but also on the methods that enable a high level quality of service, low jittering and very low loss of data packets.

A very noticeable characteristic of WMNs is that they have a very low power requirement [11]. This low power requirement could potentially be met by a low cost renewable energy source. Hence, WMNs have a very promising future.

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