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A SURVEY ON WIRELESS MESH NETWORK AND ITS CHALLENGES AT THE TRANSPORT LAYER

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ABSTRACT

Wireless mesh network is a very promising and novel communication technology. The scope of wireless mesh networks is significantly wide both in terms of architecture and applicability. But as the technology is new and has a rather complex set of architectures, it possesses quite a few challenges in every layer of the network model. In this paper, we have studied the architecture of wireless mesh network (WMN) and a comparison of existing wireless technologies with WMN. Then we focus our interest on the challenges of wireless mesh networks at the transport layer. Up to this date, no novel transport layer protocol has been designed specifically for wireless mesh networks and active research is in progress in different parts of the world. Upon delineating the challenges, we have also assembled the findings of some of the congeneric research activities at the end of this paper.

Keywords: Hybrid Wireless Mesh Networks; Infrastructure Wireless Mesh Networks; Performance of TCP in Wireless Mesh Networks; Wireless Mesh Networks; Wi-Fi; Wi-Max.

1. INTRODUCTION

A Wireless Mesh Network (WMN) is a network which consists of mesh nodes unionized in mesh topology. 'Mesh node' is a generic term which can refer either to mesh clients or mesh routers. Here mesh routers in a wireless mesh network is significantly different from traditional wireless routers in that mesh routers provide additional gateway/bridge facilities which enables it to accommodate other members of the wireless family (i.e. Wi-Fi, Wi-Max, cellular networks, wireless sensor networks etc) under a wireless mesh network architecture. Mesh routers also supply a wired interface to support clients having traditional Ethernet, thus making it backward compatible. A wireless mesh network maintains a continuous connection. If a node in the path fails for a particular transmission then the other nodes dynamically selects another route to transmit the data to the appropriate destination. Wireless mesh network uses multi-hop communication. The nodes maintain a routing table which is updated in real time to provide dynamic self-configuration. A device can connect to a wireless mesh network if it is in a set range.

A wireless mesh network can be created using the elements of existing network technologies with some modification. Up-front cost of building a wireless mesh network is relatively low, as the price of the radios has plumped down over the last few years, and the fact that we can place one node at a time as per requirement. The scope of wireless mesh networks is excitingly extensive. But because of its wide scope and versatile architecture, amendments to the available protocols in almost every layer is a necessity for a wireless mesh network to perform at it's peak [1]. Numerous working groups in different parts of the world are putting up a continuous effort to set the right standards for wireless mesh networks. IEEE 802.11 [2], 802.15 [3], 802.16 [4] have started separate working groups for wireless mesh networks, where IEEE 802.11 working group has 802.11s dedicated solely for wireless mesh networks. The rest of the paper is orchestrated as follows. In Section 2, we put together the findings of some of the relative research works conducted recently. Section 3 depicts the network architecture of WMNs, while in section 4 an overview of existing wireless network technologies is provided. Section 5 is based on the advantages of wireless mesh network over its counterparts. Section 6 gives an overview of Transmission Control Protocol (TCP). In section 7, we focus our interest on the transport layer challenges of wireless mesh network. We bring the paper to a close in section 8.

2. RELATED WORKS

Many researchers have been done on wireless mesh networks already, and a number of researches in similar fields are in progress. ([1], [8], [9], [10], [11], [12], [13], [14], [15], [16]). Ian F. Akyildiz and Wang [1] provided a general overview on wireless mesh network. In this paper, the researchers have compiled the architectures, protocols, applications, and challenges of wireless mesh networks. Omar Villavicencio [8] analyzed the performance of 802.11n in Multi-Channel Multi-Radio (MCMR) wireless ad-hoc networks. The researcher proposed a redesigned MAC to support MCMR and packet aggregation technique to improve throughput. Ashish Raniwala and Tzi-cker Chiueh [9] designed a multi-channel wireless mesh architecture which supports multiple 802.11 interface cards in each node. Using proper channel assignment the throughput of this network can be increased as a factor of 6/7. Dimitrios Koutsonikolas, Jagadeesh Dyaberi, Prashant Garimella, Sonia Fahmy [10] studied the performance of a 32- node wireless mesh network testbed which was deployed in the Purdue University. The study showed that as the number of hops increases, TCP window size lessens the throughput of the network. Claudio Cicconetti, Ian F. Akyildiz, and Luciano Lenzini [11] introduced a fair end-to-end bandwidth algorithm (FEBA) for the MAC layer of an 802.16 node with Single Radio Multiple Channel (SRMC). This algorithm showed that by using multiple channels the network capacity can be improved due to frequency reuse and channel sharing. The researchers of [12], [13] analyzed the impact of MAC layer on the performance of TCP. They showed how the problems of Floor Acquisition Multiple Access (FAMA) and Code Division Multiple Access (CDMA) can be solved using link layer acknowledgment and less aggressive backoff timer policy. They extended the Multiple Access Collision Avoidance (MACA) for this purpose. Gavin Holland and Nitin Vaidya [14] investigated the performance of mobile ad-hoc network using a new performance metric called expected throughput. They also showed how Explicit link failure notification (ELFN) could be used to help TCP distinguish between congestion and non-congestion losses and thus improve the performance. The researchers of [15] studied the capacity of mesh network using three different technologies- Single Channel Single Radio (SCSR), Single Channel Dual Radio (SCDR) and Multiple Channel Multiple Radio (MCMR). Here it is shown that

MCMR performs the best amongst the three techniques. A cross layer design for limiting the multiple access interference and increasing the throughput is proposed in [16].

3. NETWORK ARCHITECTURE OF WMN

The building blocks of wireless mesh networks are "mesh nodes" (Figure 1). Mesh nodes are classified into two groups, namely mesh routers and mesh clients [1]. Mesh routers are different than traditional wireless routers in terms of functionality in that they have additional gateway/bridge facilities, which enable a mesh router to connect to other existing wireless technologies like Wi-Fi, Wi-Max, cellular, wireless sensor networks, etc through multiple interfaces, thus making it more potent and versatile. Because of the enhanced capability of mesh routers, mesh clients have a wide domain. A client having a wireless interface compatible to the mesh router can directly connect to it. This client may also function as a router, but unlike the mesh routers here a client has only one wireless interface. Clients using traditional Ethernet as network interface card can also connect directly to the mesh routers.

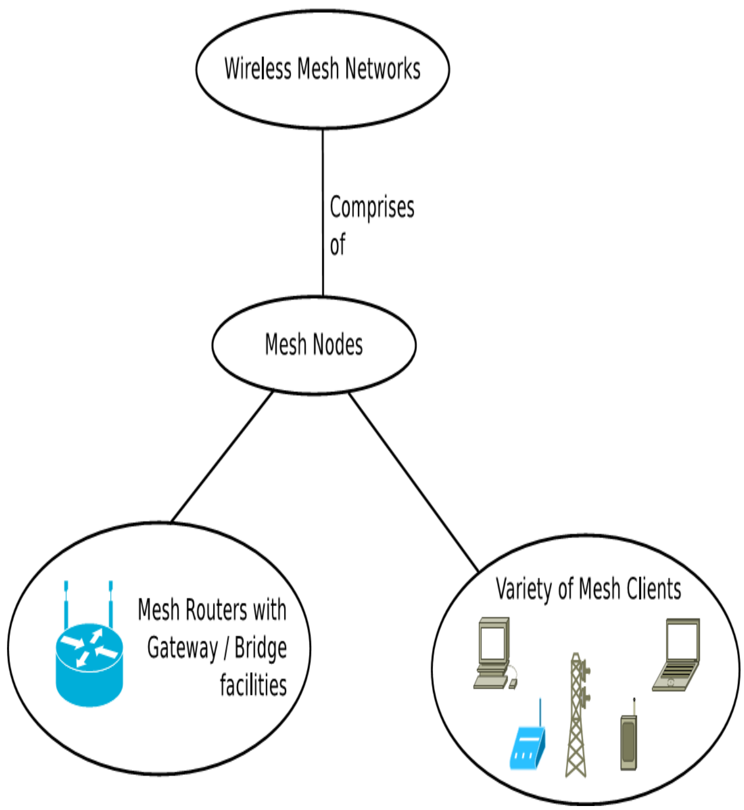

Fig 1: Building block of Wireless Mesh Network

In [1], the authors classified the architecture of wireless mesh networks into three main groups, namely:

1. Infrastructure Wireless Mesh Networks
2. Client WMNs
3. Hybrid WMNs

3.1 Infrastructure Wireless Mesh Networks

We can refer it as three tier architecture. At the topmost tier there is the Internet. The second tier consists of a mesh backbone formed by mesh routers. Finally in the third tier we have mesh clients. Figure 2 depicts the components of an Infrastructure Wireless Mesh Networks. Client either have a direct connection to the mesh routers or they could come from different wireless technologies like Wi-Fi, Wi-Max etc where the corresponding access points/base stations have a wired connection to the mesh routers. Two different types of radios are used by the mesh routers for communication: one is to maintain backbone communication and the other is used for communicating with the client no

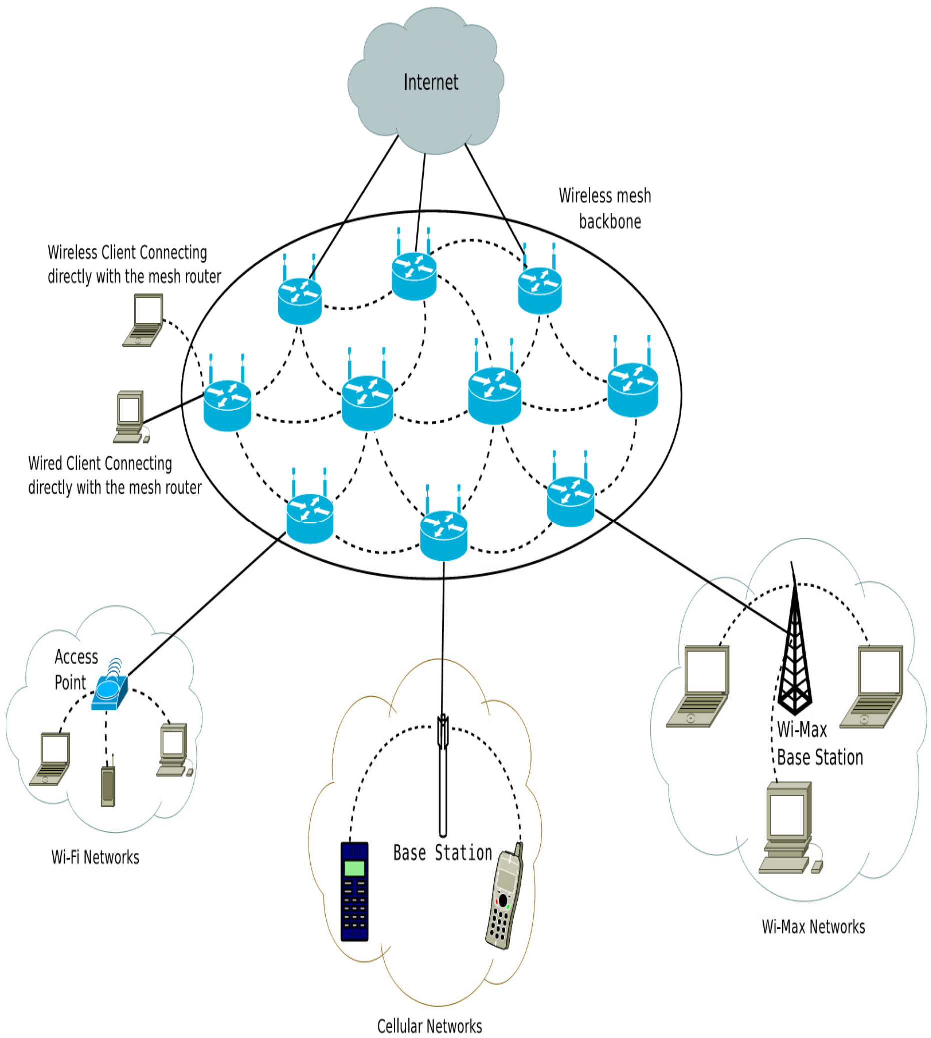

Fig 2: Infrastructure Wireless Mesh Network

3.2 Client WMNs

In this architecture, there is no backbone of mesh routers, but only mesh clients (Figure 3). Here the functionalities of mesh routers are provided by the mesh clients, and a peer to peer network is formed. Packets travel from source to destination by hopping through nodes. Client WMNs as a single unit don't have Internet access, as it is not connected to any infrastructure backbone, but it has the capability to do so. Any node of a client WMN can connect to a mesh router backbone and form a hybrid architecture, which we will discuss shortly afterwards.

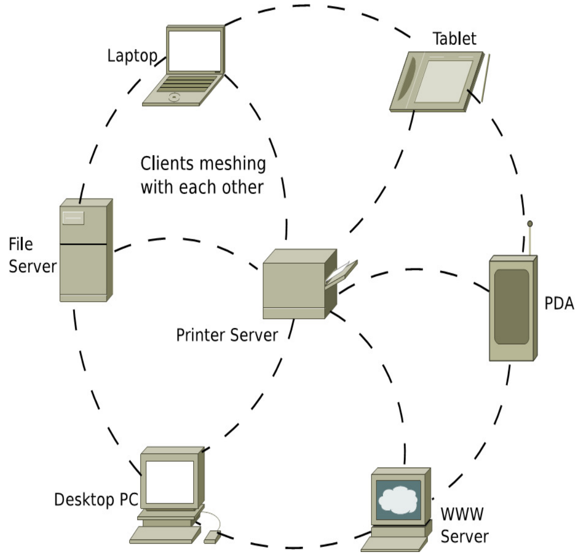

Fig 3: Client Wireless Mesh Network

3.3 Hybrid WMNs

A hybrid wireless mesh network is formed when a client WMN gets connected to an infrastructure mesh. Figure 4 shows the architecture of a Hybrid WMN. If any node/a few nodes of a client WMN connects to the mesh router backbone of an infrastructure WMN, then we get a hybrid wireless mesh network. Among all the three architectures, hybrid WMNs is the best in terms of functionalities.

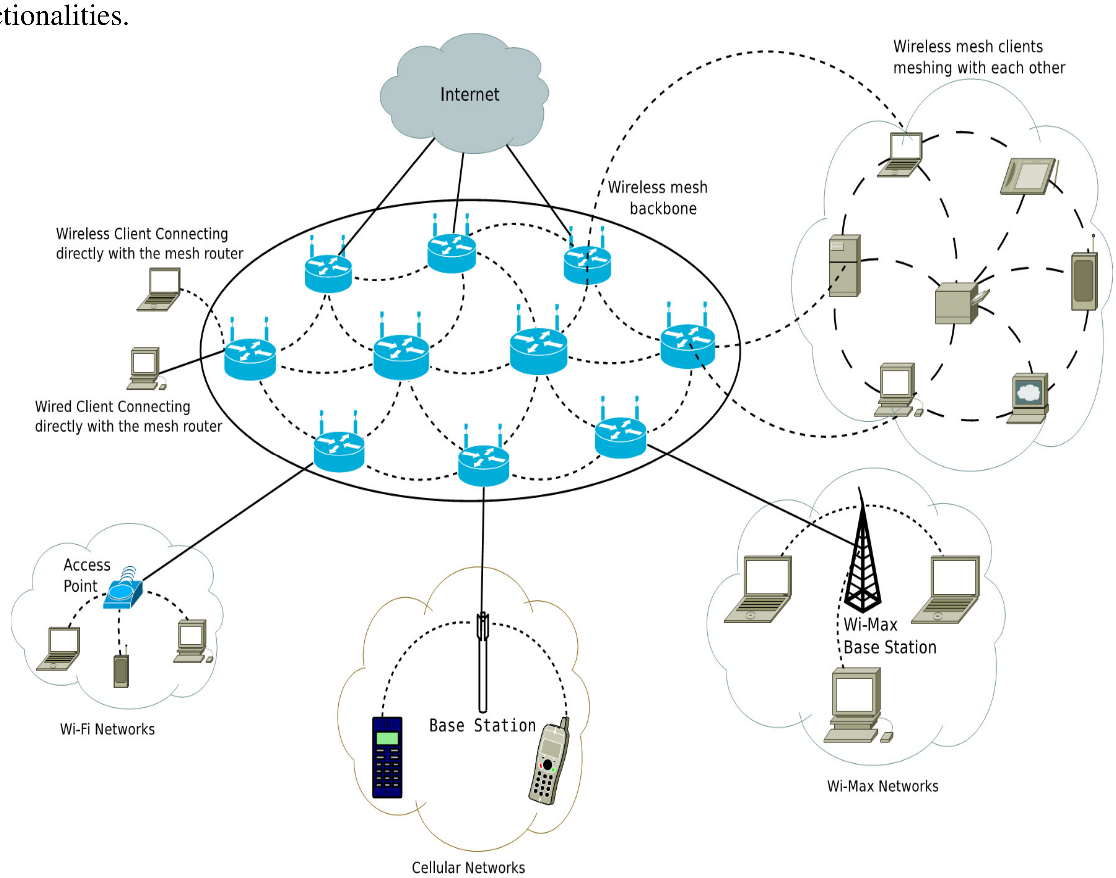

Fig 4: Hybrid Wireless Mesh Network

4. AN OVERVIEW OF EXISTING WIRELESS NETWORK TECHNOLOGIES

We will mainly discuss about Wi-Fi (as defined in 802.11), Wi-Max (as defined in 802.16), cellular networks and mobile ad-hoc networks. TABLE I, II and III point out the advantages and shortcomings of Wi-Fi, Wi-max and Cellular networks technologies respectively.

TABLE I
Advantages and Shortcomings of Wi-Fi

	Pros	Cons
Wi-Fi (defined in 802.11)	Offer High Data Rates (11 Mbps for IEEE 802.11a and 802.11g)	Limited coverage
		Multiple access points connected to wired backbones results in high up-front cost.

While the Wi-Fi technology is popular it has a few shortcomings. The ranges of the access points (AP) are fairly limited, and multiple access points connected to wired backbones results in high up-front cost. Bandwidth is also relatively low in Wi-Fi networks. Besides common 802.11 Wi-Fi uses unlicensed frequency bands (2.4-2.485GHz for 802.11b/g), hence channel interference with other devices using the same frequency band (Microwave oven, 2.4GHz phones, etc) is common and degrades quality of service and overall performance of Wi-Fi networks.

TABLE II
Advantages and Shortcomings of Wi-Max

	Pros	Cons
Wi-Max (IEEE 802.16 Family)	Offer higher data rates than Wi-Fi. (70 Mbps for IEEE 802.16d and 100 Mbps for proprietary solutions.)	
	Wide area coverage	Line of sight (LOS) requirement: A client not having a clear LOS to the WMAN base station may not receive service.
	Guaranteed quality of service over a large area (up to tens of miles from the base station)	Base stations are complex and expensive to build

Wi-Max networks (802.16 family) overcomes few of the shortcomings of Wi-Fi networks in that Wi-Max uses licensed frequency bands, thus ensures quality of service for its clients. Wi-Max provides higher bandwidth, and its base stations are more powerful and provide wide area coverage. Several Wi-Max base stations can easily cover a whole city. The most recent addition to the Wi-Max family is mobile Wi-Max (defined by 802.16e working group), which adds mobility support and promises to be a popular technology. This technology is not commercially available yet though.

TABLE III
Advantages and Shortcomings of Cellular Networks

	Pros	Cons
Cellular Networks	Offers wide area coverage	Service is relatively expensive
		Fairly low data rates (Even the third generation of cellular networks (3G) offer 2Mbps at best).

The shortcomings of Wi-Max are the high up-front cost of the base stations and line-of sight requirement. Then there are ad-hoc networks. Unlike Wi-Fi or Wi-Max, an ad hoc network has no infrastructure. As defined in 802.11, an ad hoc network is a network having a BSS (Basic Service Set) without an AP (Access Point). A BSS consists of wireless stations acting as client nodes. As ad-hoc networks don't have any infrastructure, it is the added responsibility of the client nodes to play the role of a router and provide services like routing, addressing, etc. Mobile ad hoc networks (MANET) are an extension of the idea of ad hoc networks which supports mobility of the client nodes.

6. ADVANTAGES OF WIRELESS MESH NETWORKS OVER ITS COUNTERPARTS

The upfront cost of building a WMN is significantly lower than that of a Wi-Fi or Wi-Max network. That's because the price of radios has plumped down over the last few years, thus price of wireless mesh routers is fairly low. Besides, a mesh router can be placed upon existing cell phone towers or such, thus the cost of setting up additional towers (like base stations in Wi-Max) is cut.

The scope of a wireless mesh network is one of the many striking features it possesses, perhaps the most significant one. A wireless mesh network not only supports anonymous client nodes connecting directly to mesh routers via both wired and wireless interfaces, but it has the capacity to accommodate all the existing wireless technologies stated above as well. An AP of a Wi-Fi network or a base station of a Wi-Max network could connect to a wireless mesh network easily by having a wired connection to one of the mesh routers of mesh backbone. Same is true for ad hoc networks like MANET, which itself is a special case of WMN.

Any node or two in a MANET can connect to a mesh router and be a part of a WMN. All these features of WMN make it applicable to many scenarios.

In [1], authors showed that wireless mesh networks is a good choice in many cases like broadband home networking, community and neighborhood networking, enterprise networking, metropolitan area networks, transport systems, health and medical systems, security surveillance systems etc.

6. OVERVIEW OF TCP

Transmission Control Protocol (TCP) is a process-to-process reliable protocol under the TCP/IP protocol suite. TCP creates a virtual/logical connection between two ends to transmit data segments. To ensure reliable transfer of data segments, TCP provides services like Flow Control, Error Control and Congestion control. Flow control ensures that the receiver end is not overwhelmed with data. Error control mechanism checks segments for errors. Congestion Control is used to control the sending rate of segments. Congestion occurs in a network when network load exceeds in Routers/ Switch buffers which directs to loss of packets. Congestion control mechanism maintains a window named Congestion Window to dynamically adjust the sending rate of packets for minimizing the loss rate [5] [6]. TCP has several policies to deal with congestion such as slow-start-exponential increase, additive increase and multiple decrease. Slow start is a policy where congestion window size increases exponentially until it reaches a threshold value. Additive Increase is a policy inclined to avoid congestion where congestion window size increases linearly until network congestion is detected. Upon detecting an event of congestion, the policy Multiple Decrease is used to reduce congestion window size [5] [7].

7. CHALLENGES OF WIRELESS MESH NETWORKS AT THE TRANSPORT LAYER

The versatility of wireless mesh networks in terms of architecture imposes a number of problems in using TCP at transport layer. Nodes in a wireless mesh network could be either stationary or mobile, and could come from different sets of wireless technologies within the same architecture of a WMN. Nodes can move, new nodes can be added on the fly and existing nodes might leave the network as well. As a consequence, factors like dynamic changes in routing paths, different kinds of packet losses are common and frequent in a WMN. Classical TCP was not designed to handle such wide range of scenarios. For example, classical TCPs can't distinguish congestion losses from non-congestion losses like link failures [1]. Hence in the event of a non-congestion loss, network throughput drops rapidly. And when the wireless channels are freed of congestion, classical TCPs cannot recover quickly enough. To make TCP perform better for WMNs, it needs to be ensured that TCP is able to differentiate between congestion losses and link failures. Because of its ad-hoc nature, dynamic changes of routing path are common in wireless mesh networks. And because of the wide scope of its architecture, factors like mobility, variable link quality, traffic load etc should be taken under consideration which could cause large variations in RTT (Round Trip Time, the total time a packet takes to travel from a source end system to a destination end system and then back again to source). As classical TCP was designed to rely on a smooth measurement of RTT, its performance is bound to fall in a wireless mesh network.

Another problem with classical TCPs in wireless mesh networks is the significant drop of performance in occurrence of a network asymmetry. Network asymmetry is an event where the bandwidth, loss rate and delay of a network in forward direction is fairly different from reverse direction. As TCP relies heavily on ACK, its performance could plummet in the event of a network asymmetry where TCP data and TCP ACK packets may take different paths, resulting in different packet loss rate, latency or bandwidth. Besides, as the channel condition and bandwidth of the path changes frequently, TCP data and ACK packets might face network asymmetry problem even if they take the same path [1].

8. CONCLUSION

Wireless mesh network is a technology with exciting prospects and fairly wide scope. But there lies numerous challenges at different layers to make WMNs perform optimally. There are open research issues to make WMNs robust, scalable, secure, self-organized and self-configured. Our quest was to get a basic understanding of the technology and then move on and focus our interest on the performance of wireless mesh network at the transport layer. To get the best out of wireless mesh network in terms of performance a novel transport layer protocol is required that will take many different scenarios prevalent in wireless mesh networks under consideration which classical TCPs do not. Although dedicated groups in different parts of the world are working on it relentlessly, many such researches are required for the betterment of wireless mesh networks.

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