

Wireless Mesh Networks in IoT Networks

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Abstract—Internet of Things is one of the hottest topics in both industry and academia of the communication engineering world. On the other hand, wireless mesh networks, a network topology that has been discussed for decades that haven't been put into use in large scale, can make a difference when it comes to the network in the IoT world today. This paper is a brief introduction of how these technologies have the possibility to come together and how to integrate the mesh network into existing IoT networks to potentially make a difference in the new era.

Keywords—IoT; Wireless Mesh Networks; sensors; wireless; network topology;

I. INTRODUCTION

With the significant growth of the semiconductor industry, creating small devices with powerful processing ability and network capabilities are no longer a dream for engineers. Currently, Internet of Things (IoT) has become one of the hottest topics in both industry and academia of wireless communication field. Today, most of the research of the IoT-enabled devices is mainly of the data collecting and processing units namely creating new sensors. However, the network that integrating the IoT devices to the Internet is usually left untouched by simply using existing computer network solutions such as WLAN or Bluetooth. These computer networks are not designed for low-powered devices such as remote sensors even these IoT devices are considered to be mini computers. The single point of failure nature of these Network makes the entire system extremely vulnerable when it comes to disasters or even difficult environment as the sensors may need to be deployed into some hardly reachable locations. Besides, the capacity of the central hub/router of the network can also limit the coverage of the service provided by IoT devices, and the range is also constrained by the same factors. As most of these remote IoT devices are small, and the devices are usually battery powered, so the power-hungry network options such as using cellular network or satellite are also not ideal for most of the remote scenarios in the IoT networks.

A wireless mesh network (WMN) is a communications network made up of radio nodes organized in a mesh topology instead of star topology used in most of the networks, according to Akyildiz, X. Wang in the book of Wireless Mesh Networks. [1] It is not a new concept at all, as it had emerged from the Multiple Ad Hoc Networks in the 70s from Packet Radio Network (PRNET) created by The Defense Advanced Research Projects Agency (DARPA) of the U.S. Department of Defense. [2]. Later in the 90s, many other civil solutions had also been proposed and created for different uses such as

expanding the coverage of broadband services. The distributed network nature of the wireless mesh network with its simple configuration is ideal for be implement in the IoT networks to take advantage of its expanded range as well as keep the hardware design minimal using smaller network module. Such networks also are more robust in the harsh environment as the network are distributed with no single central point of failure. In this paper, the authors will discuss all of these features of WMNs in detail and why these features make WMNs ideal for the IoT networks over the traditional star networks as well as discussing the way of integrating the WMN into the existing IoT networks or design the IoT network with new feature from the beginning.

II. WIRELESS MESH NETWORKS

A. Wireless Mesh Networks Introduction

The main difference between WMNs and star networks WMNs are wireless networks, which have the ability of dynamically self-organizing and self-configuration, and with mesh connectivity automatically establishing among nodes in the network while the conventional star network has a star topology which means all the terminal nodes are connected to a single central point which connects to the upper level of the network. The Fig. 1 illustrated the topology of two networks.

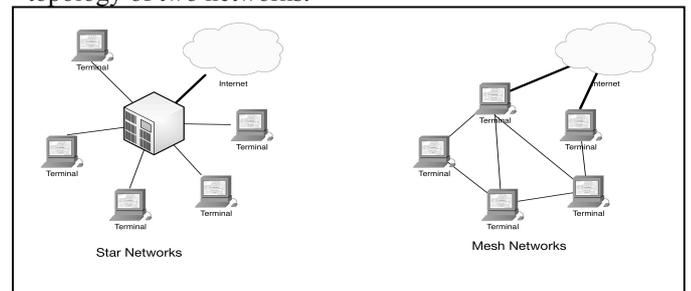
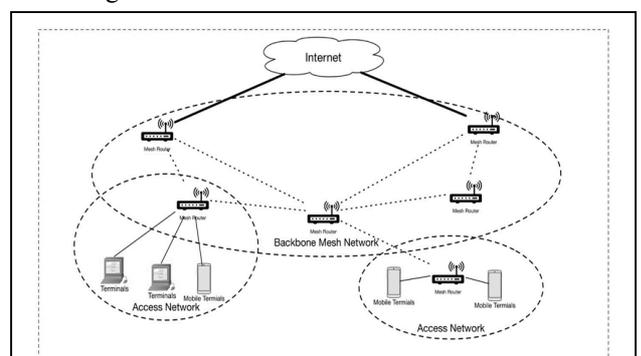


Fig. 1 Star Networks and Mesh networks

Currently, WMNs are adapted in several places, majorly in three different forms as follows:

1) Infrastructure/Backbone WMNs:

As shown in fig.2 this type of WMN includes mesh routers that form an infrastructure for clients that connect to them. The devices in the mesh router coverage areas still form a star network while the



mesh routers form a mesh of self-configuring, self-healing links among themselves. With gateway functionality, mesh routers can be connected to the Internet. Infrastructure/Backbone WMNs are the most commonly used WMN as its simple and easy to integrate with the existing devices as only the routers need to be fitted to the mesh networks.

2) Client WMNs:

Client meshing provides peer-to-peer networks among client devices like a big ad-hoc network. In this type of architecture, client nodes constitute the actual network to perform routing and configuration functionalities as well as providing end-user applications to customers. Hence, a mesh router is not required for this type of network. This type of network is usually not accessible to the Internet.

3) Hybrid WMNs:

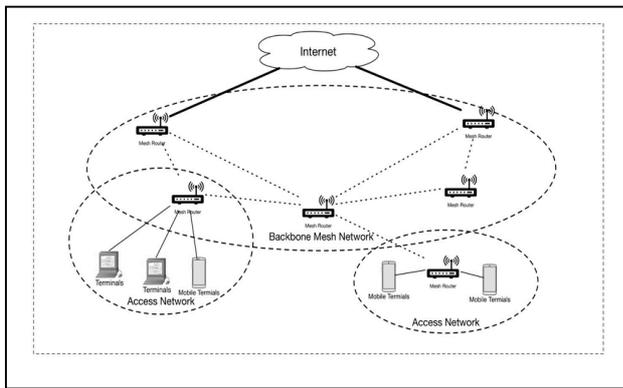


Fig. 3 Hybrid WMN structure

As shown in fig. 3 the hybrid mesh network architecture is the combination of infrastructure and client meshing as shown in the figure below. Mesh clients can access the network through mesh routers as well as directly meshing with other mesh clients. While the infrastructure provides connectivity to other networks such as the Internet, the routing capabilities of clients provide improved connectivity and coverage inside the WMN.

Only the infrastructure WMN and the hybrid WMN are suited for the network according to the requirement of different scenarios. Therefore, the discussion in the later part of this paper is mainly focus on these two kinds of WMNs.

B. Advantage of Mesh Network in IoT Networks

WMNs can bring many advantages to the IoT networks, and the most prominent one is the versatility of the network. When using the infrastructure WMN structure, adding a new router requires only simply putting the new device straightly into the field within the range of the existing network. The capacity and range of the network expand without introducing more cables and connections. For the hybrid network, this process is even simpler. Placing the new IoT devices in the field where the old mesh network is covered, the new sensor just works. It is because of the auto-configuration feature of the network will expand the network automatically. Hence, the

network structure would be simpler, and the price of covering a larger area, especially in the rural area without reliable network everywhere could be much lower. Power consumption can also be significantly reduced when connecting remote IoT sensors or other devices to the network. The devices can only connect to closest mesh device instead of a distant central network hub, in the Hybrid case, it can even be a neighbouring node. This connects may make a chain of IoT devices, reducing the cost of power of the central hub to cover the most distant device.

Apart from the scaling and cost advantages when setting up new networks, WMNs also provide a more robust network for all kinds of applications in the IoT-world when it comes to unlikely events such as nature disasters. Even when some part of the link is destroyed and several devices are out of the connection. The rest of the network is still self-connected and self-configured with a new network and works the same. So long as one of the new network component connected to the internet, the entire sub-network will stay connected, only losing the connection from the node that is disconnected, whereas, in the conventional networks, this means the coverage of the entire area is lost, cutting off the IoT service totally.

C. Disadvantage of Mesh Networks in IoT network

Certainly, the WMN has some disadvantages. The unconventional network structure requires new network protocol support and the protocol should be compatible with the existing network as the IoT devices will eventually connect to the Internet. Besides, the repair of the network when a larger scale black-out is happening could be harder, as the cut-off the connection can hardly be detected when a larger network is disconnected. However, this can be solved by introducing error-checking report in the network packets, but at an expense of slower network. Lastly, the delay and the scalability of the network also limited by the nature of the mesh network. As proven by Belding-Royer EM et. al [3] in the famous paper, the delay and the data rate of the network also need to be limited. This may not be a problem in the IoT-devices, but needs to be considered when it comes to selecting the appropriate tool for the work required.

III. INTEGRATION OF MESH NETWORKS IN IOT NETWORKS

This section is to show how to have mesh network enabled IoT network by integrating new network components into the existing networks using both infrastructure and hybrid network structures. Designing an IoT with mesh network in mind for the new development will also be introduced in the third part of this section to show the way to maximize the power of the mesh networks.

A. Infrastructure/Backbone Mesh networks

This is the simplest way of integrating WMN capabilities into the IoT networks. Illustrated in the fig. 2, the infrastructure/backbone WMN network works at the router level. The IoT networks using the traditional star network can easily migrate to WMN ready by simply switching the existing

routers/base stations on the edge of the network with mesh routers. This switch can introduce interconnectivity between the routers themselves instead of using an uplink which depends on the individual Internet connection from each router. After such migration, adding new routers into the current range of the network will simply scale up the network. However, as described in the disadvantage section, the network will suffer more delay and eventually, the network will be unusable when the hop number reach the magic number of six. [3]

This integration of the mesh networking into the existing IoT networks has already increased the scalability of the network without introducing significant investment.

B. Hybrid Mesh Networks

To integrate hybrid mesh network structure into the existing networks is more complicated but more rewarding. Instead of switching the routers/base stations, to take advantage of the versatility of the hybrid WMN, the network module of the individual IoT devices must be changed as well. The functionality of interconnectivity must be added to the modules. This can be done by reprogramming the module's controller. Some additional storage space is also preferable as the modules does not only store its own data, but the transferred data from the other modules is also required before the data gets forwarded. Broadcasting capabilities and timed network observation function are also essential to support the self-configuration feature of the WMN as every node is able to connect to the optimized node nearby when new node is introduced in the network. This can be done by adjust the RF module more promptly looking for available nodes when not connected. Integrating such capability will introduce more power consumption in each node, and this may cause the downgrade of service of certain IoT devices.

C. Designing the Meshed IoT Network from Ground Up

Apparently, the best way of integrating WMN into the IoT network is from very beginning. This means when designing the IoT devices, the integration with WMNs are considered. This includes two aspects, the end nodes and the network devices. Firstly, the end nodes, which are the IoT devices themselves. To design a WMN ready end node, the limitations of WMNs, especially Hybrid WMN, since the device itself will involve in forming the network, needs to be considered. The data package the device transmits each time shouldn't be too big as the speed limitation and the unpredictable of the WMN nature. Besides, the synchronize timing is also crucial to minimize collisions. Additionally, since most of the wireless

IoT devices are battery powered, the dynamic network to provide mesh routing are more power hungry than conventional network modules, the optimization of the microcontroller is very important. The balance between the network and data processing is the key when designing a successful meshed IoT end node. Secondly, the network devices, since the network should be a hybrid network, which means each incoming connection to the mesh routes may not be only one devices. The MAC protocol is very important here to control the access of network both in bound and out bound. At the same time, it also needs to be compatible with the Internet as its the border device between the Internet and the meshed IoT network. When both network as well as end nodes are designed with such WMN consideration in mind, the mesh ready IoT devices are just around the corner.

IV. CONCLUSION

As described in this paper, WMNs have all these great features using for the communication in the IoT networks. It is still under-developed as the industry advancing today. With the much more powerful MCU and processors today, the dynamic network topology can be achieved even in the tiny IoT devices. The mesh network topology has its unique advantage and disadvantage in the world of the IoT networks that can leverage the scale, distributed nature and low require of data-rate of the IoT devices. The advantage certainly outweighs the disadvantages of using the WMNs in such environment. Newer hybrid WMNs can be a solid choice when it comes to design the structure of the network, especially in the remote areas with its the robustness and scalability. This paper is simply discussing the possibility and the basic way of integrating such under-utilized network topology into the current and future IoT networks in the background of the advanced technology we have today. WMNs will certainly make a difference in the industry once being deployed on large scale in the IoT world and make the IoT more accessible to a wider audience.

REFERENCES

- [1] X. W. Ian Akyildiz, *Wireless Mesh Networks*, London: John Wiley & Sons, 2009.
- [2] J. Okin, *The Internet Revolution: The Not-for-Dummies Guide to the History, Technology, and Use of the Internet*, 1 ed., Winter Harbor, ME: Ironbound Press, 2005.
- [3] P. M. M.-S. , a. L. E. M. Elizabeth M. Royer, "An Analysis of the Optimum Node Density for Ad hoc Mobile Networks," 2001