Mesh Router Family

White-Paper

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I. History

Rev.	Date	Author(s)	Remarks
1.0	17.11.18	SZE	Initial version of the document.

1 Introduction

There are situations where it is wanted to temporarily deploy a greenfield networking infrastructure, for instance to

- provide connectivity to a huge number of people at major events,
- ensure communication for security forces at major events, or
- provide network coverage in disaster areas.

These are just a few examples, others can easily be found.

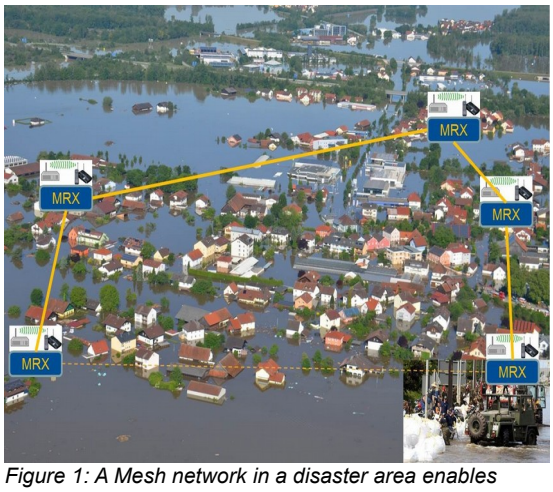

Figure 1: A Mesh network in a disaster area enables voice, video, messaging and other forms of communication if everything else has failed. Battery-powered mesh nodes can be installed on rescue vehicles, or be placed by rescue forces or drones.

IEEE 802.11s Mesh Networking is a technology that allows to build a local Ethernet “backbone” without a single cable or fibre. Based on the well-established IEEE 802.11 WLAN, it provides wireless communication between a number of mobile stations (mesh nodes) almost without any prior configuration. Given only a WLAN channel, a network name and a password, the nodes are able to identify each other and form an ad-hoc mesh network where each node can communicate with every other node, even across multiple “hops”. The network dynamically adjusts itself to changes in the topology and to nodes going in or out of reach.

The Mesh Router family of devices uses Mesh Networking as a basis for creating on-demand IP networks. It adds various features on top of the core mesh backbone that make it suitable for almost any use case of spontaneous networks:

- support for manual or various forms of automatic IP configuration
- LTE internet gateway nodes
- 802.11 WLAN or Ethernet cable based client access
- easy management with state-of-the-art Web Interface
- live graphical WLAN signal quality monitor for optimum antenna alignment
- live graphical mesh topology monitor

2 Features of Mesh Networks

The IEEE 802.11s standard describes how different mesh nodes can interconnect to form a distributed, ad-hoc network for the exchange of Ethernet frames. These mesh networks feature the following properties.

2.1 Automatic Operation

A minimum of configuration is required to establish a working mesh network. Each mesh node only

needs to know the WLAN channel, the network name (mesh ID) and the access password (mesh key). Whenever two or more mesh nodes with similar configuration “see” each other, they automatically interconnect and become members of the mesh network. The mesh network resolves communication paths automatically and is able to direct Ethernet frames to the new nodes without further configuration.

2.2 Scalability and Extensibility

Eliminating dead spots and providing better or larger coverage is as easy as adding additional mesh nodes to the mesh network all the way between the covered and the uncovered areas. The new nodes automatically integrate themselves into the existing mesh, provided they are appropriately configured (channel, mesh ID, mesh key), and extend the reach of the mesh network.

2.3 Mobility

The word mobility has several meanings for mesh networks:

- Since IEEE 802.11s mesh networks use WLAN to build the Ethernet backbone, they do not need any cables or fibres to work. Therefore, battery-powered mesh routers can be used anywhere to create ad-hoc networks, even on the green field (in the literal sense).
- The mesh nodes are not required to maintain fixed positions. The IEEE 802.11s mesh technology is designed to gracefully handle topological changes and dynamically reconfigures itself as individual mesh nodes loose contact with their neighbours and establish new links.

Figure 2: Mesh network to provide internet access in undeveloped areas.

2.4 Reliability and Resiliency

Each mesh node can associate with several neighbouring nodes that are in reach of the WLAN transmission, which creates a multitude of possible paths through the mesh network for Ethernet frames transferred from node A to node B. Usually, the shortest and fastest path between A and B is chosen. If one of the mesh links (or even a whole mesh node) fails for some reason, the mesh network reconfigures itself after a short transitional period and chooses a different path henceforth.

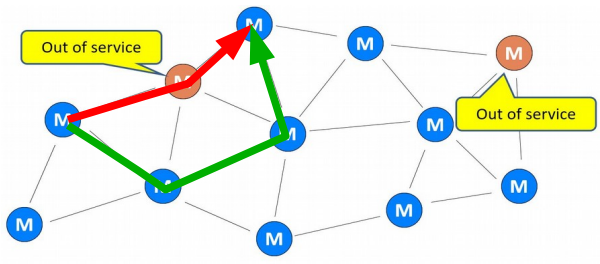

Figure 3: Mesh network using an alternative path (green arrow) routed around a defective mesh node to replace the broken path (red arrow).

The only thing this resiliency mechanism requires is that the mesh network consists of slightly more nodes than strictly required, so that each node can associate with more than two neighbours and alternative paths are always available.

3 Mesh Networks Explained

3.1 Mesh Peer Links

Each mesh node sends out periodic “beacon” frames containing the Mesh ID on the selected channel. When any two mesh nodes with the same Mesh ID see themselves, they try to establish a peer link with each other and negotiate cryptographic session keys based on a pre-shared key, the Mesh Key. If that succeeds, they declare the link open and allow the transmission of encrypted Ethernet frames.

The peer link remains open until one of the nodes requests the link to be closed or the WLAN connection between both nodes fails.

Each mesh node can handle multiple peer links simultaneously. The exact limit depends on WLAN hardware constraints, but 8 – 16 links are quite common.

3.2 Mesh Routing

From a high-level perspective, a mesh network looks almost like an ordinary, albeit variable Ethernet switch. It accepts standard Ethernet frames from some source and forwards it to the destination, both of which are identified by MAC addresses.

On their way through the mesh network, but invisible for the end-to-end user, the Ethernet frames have to be augmented with additional routing information. They carry up to 6 MAC addresses simultaneously:

1. the MAC addresses of the current and the next transit mesh node (hop),
2. the MAC addresses of the ingress mesh node and the egress mesh node, and
3. the original end-to-end source and destination MAC addresses.

When an unicast frame enters the mesh network, the ingress mesh node

1. determines the corresponding egress mesh node,
2. determines the path to the egress mesh node, and
3. finds the required next hop on this path.

The frame is dropped if any of the information cannot be resolved, otherwise the frame is transmitted to the first hop using this information. Each subsequent hop looks up the next hop on the way to the egress mesh node until the frame finally finds the destination.

Non-unicast Ethernet frames are always transmitted as broadcasts across the mesh network.

Two MAC tables are required on each mesh node for a proper operation of this routing scheme: the mesh path table and the mesh proxy table. The mesh proxy table contains entries for end-to-end destination addresses and stores the egress mesh node to which that destination is connected. The mesh path table contains entries for the mesh nodes themselves and stores the next-hop MAC address on the way to that destination.

3.3 Mesh Path Resolution

When an unicast frame to an unknown destination is to be transmitted, the ingress mesh node starts a path discovery for the given destination MAC address by broadcasting a corresponding path request frame into the mesh network. As the broadcast frame travels through the mesh, each mesh node that receives it inspects the MAC addresses of the requester and the previous hop as well as the current path length, and learns this information in the mesh path table. This means an eventual path reply can be returned to the requester without having to start another path discovery first. Existing entries in the mesh path table are only overwritten if the stored entry is either outdated or holds a longer path.

If the processing node does not host the requested MAC address, it adjusts the path length information in the frame and re-transmits the request. Otherwise it prepares an unicast path reply frame and sends that back to the requester.

Failed or closed peer links anywhere in the mesh network may have an impact on established paths through the mesh. If a mesh node detects a failed or closed peer link, it looks up all paths in its mesh path table that were using this link and declares the path broken by broadcasting a path error notification through the mesh. This will trigger new path discoveries for frames that were using the broken paths.

4 Mesh Router Family of Devices

The Mesh Router family of devices makes use of the IEEE 802.11s Mesh Networking standard to provide an easy-to-use solution for ad-hoc Ethernet and IP networks. The Mesh Routers automatically build the mesh backbone and allow arbitrary devices (clients) access to the mesh network via standard 10/100/1000 Mbit LAN ports and an integrated IEEE 802.11 WI-FI Access Point. They also support everything required to operate an IPv4 network, like DHCP, DNS and routing.

Figure 4: Robust, DC powered Mesh Router with 3 Mesh antennas and 3 WIFI-AP antennas.

4.1 Applications for Mesh Router Devices

With a simple profile selection, the Mesh Routers can be configured for the most common use cases. All configuration can be done using the provided, state-of-the-art Web interface that supports user management and different access levels. The same profile must be selected on all Mesh Routers that become members of the same mesh network. All configuration is remembered across power cycles.

4.1.1 Ad-hoc Internet Access solution

This profile is suitable for providing easy Internet access to a number of clients. The Mesh Routers form a LAN and manage the network resources (IP addresses, routes, DNS servers) automatically. One or more Mesh Routers with an integrated LTE gateway should be present in the mesh network to provide an uplink into the Internet, any operational LTE gateway is automatically detected and used if appropriate. Each of the Mesh Routers has a fixed, individual IP address for accessing the Web interface.

The application works in a plug-and-play style once the LTE access parameters are set up: the Mesh Routers are powered up, find themselves, clients can connect and surf the internet.

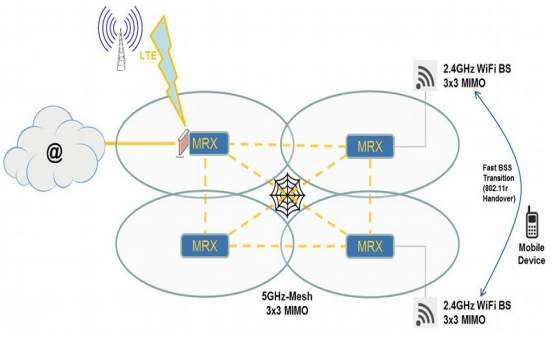

Figure 5: Example Mesh network for mobile clients with LTE uplink for Internet Access.

4.1.2 Intranet Connection solution

This profile is suitable for the case that an existing network infrastructure (the Intranet) must be made

available in an off-site location and that an adequate external gateway (e.g. VPN tunnel) provides the connection to the Intranet.

The Mesh Routers assume that the Intranet gateway is connected to one of the mesh nodes and that the Intranet manages all network resources. When this profile is selected, the Mesh Routers appear like the port of an Ethernet switch to the clients. IP routing, DHCP and DNS servers are disabled. The mesh nodes request an IP address via DHCP from the Intranet so that their Web interface is accessible.

Again, the application works in a plug-and-play style: the Mesh Routers are powered up, find themselves and once the Intranet gateway is connected, the clients can use the Intranet resources.

4.1.3 Other use cases

As an alternative to the mostly automatic configurations described so far, the Mesh Routers support a manual configuration where most of the parameters can be tuned as needed to allow the Mesh Routers to operate satisfactorily in unforeseen conditions.

4.2 Proprietary Mesh Networking Extensions

The IEEE 802.11s Mesh Networking standard provides a good foundation for the ad-hoc formation of an Ethernet backbone, but it is missing features to gather a global view of the mesh network. The Mesh Routers implement proprietary extensions to the standard that fill this gap and enable interesting features like

- detection and identification of member Mesh Routers, including serial number and IP address
- tracking of Mesh Router failures
- detection of LTE uplinks and automatic routing set-up
- live analysis and visualization of the current mesh topology

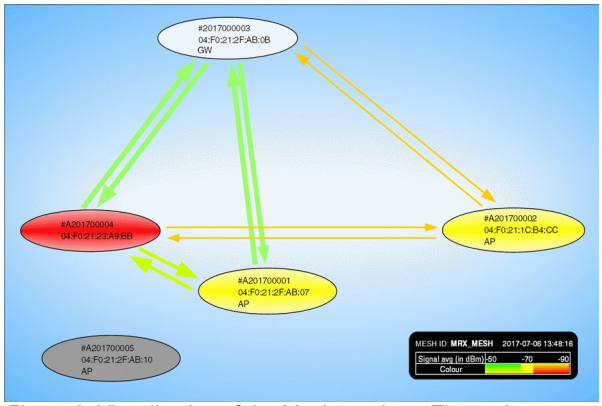

Figure 6: Visualization of the Mesh topology. The nodes contain device name, MAC address and capabilities, node colours indicate alarm/warning states. Arrow colours indicate signal quality.

5 Summary

The IEEE 802.11 Mesh Networking standard provides a good foundation for the ad-hoc creation of Ethernet networks. With a minimum of configuration it is self-finding, self-healing, mobile, extensible and dynamic.

The Mesh Router family of devices is built on this foundation and adds numerous features to create a full, easy-to-use networking solution. Some of these features are:

- easy configuration with state-of-the-art Web interface
- simple configuration for the most common applications with ready-to-use profiles
- built-in management of IPv4 network resources
- clients can access the network via LAN cable or WI-FI Access Point
- Mesh Routers with integrated LTE Gateway, automatically detected and used for internet access
- visualization of the mesh topology
- mesh health monitoring, detection of Mesh Router failures

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