Whitepaper

Introduction to Mesh Networks

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Mesh networks have been around for more than forty years. Originally a mobile wireless solution for military applications in the US, they have been used since 2000 mainly as civil network solutions for whole streets to connect private households to broadband Internet via WLAN, gaining rapidly in popularity. Today, mesh networks are frequently found in industry applications (for example to network measuring devices and meters), in company and city networks, in mobile applications between vehicles, and based on other technologies, such as Zigbee, to be used in sensor networks. These mesh networks always serve as flexible solutions to increase the range of individual radio users through their radio range and supply a simple, high-performance redundant network.

Along with a number of radio technologies, there have been a range of different approaches in industry and research to routing algorithms and features of mesh networks. This whitepaper includes an introduction to WLAN mesh networks, with a focus on the mesh node's mesh technology.

1 Area of application

Applications which have enjoyed a lot of attention in recent years have been city networks which were set up in major cities by volunteers, such as the Freifunk Netz in Berlin or the Funkfeuer project in Vienna, where a number of mesh technologies have been connected by 1,000 different nodes to provide broadband Internet access, gather experience with this technology and set up a network which is independent of providers. Even larger networks which use mesh networks for specific areas and also apply various other routing technologies have been set up, for example, in Catalonia (guifi.net; 15,000 participants at the end of 2011) and Athens (awmn.gr; 3,000 users in mid-2010).

Along with these free applications, which require a strong media exposure due to their reliance on voluntary supporters, there are a number of less extensive and popular mesh networks, for example in hotels, office buildings, campsites, building sites, industrial installations, mines etc., where cabled networks would be too complex, uneconomical or simply impossible. Internet providers also use mesh networks as backbone connections to offer their customers Internet access.

Along with these static applications, there are also mobile application scenarios. WLAN mesh networks are used between vehicles to enable fast communication, for example for fire brigade and disaster control. Some hand-held devices also use mesh technology to ensure a more extensive redundant radio coverage between emergency units.

2 Classification of WLAN mesh networks

The mesh node's mesh technology is a Layer 2 technology in accordance with the ISO/OSI model. Unlike other mesh protocols and dynamic routing protocols, an Ethernet-compatible interface is provided so that the user may consider mesh as a big switch featuring dynamic size and ports which are distributed across a number of different devices. The mesh itself is based on Ethernet-compatible interfaces, allowing WLAN devices to be integrated in the mesh in the infrastructure and ad-hoc modes, Ethernet interfaces, and LWL interfaces.

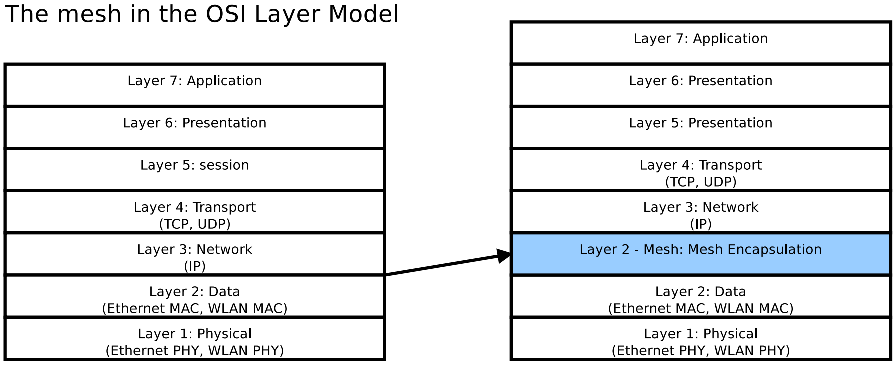

Figure 1: The mesh node's Layer 2 mesh in the ISO/OSI layer model

In most instances, WLAN ad-hoc networks are used for mesh networks, allowing communication between all devices logged into the radio cell in direct radio range. Occasionally, mesh networks are also developed in the infrastructure mode, although their flexibility is limited due to their being point-to-multipoint (as opposed to multipoint-to-multipoint). To protect the mesh network, the relevant mechanisms of the underlying technology, e.g. encryption with WPA-NONE or IBSS/RSN in the WLAN ad-hoc mode, are used.

3 Functionalities of mesh networks

Mesh networks develop dynamic networks. To achieve this, each participant initially explores its neighbourhood by transmitting its own identity and features via broadcasts (message to all users) – in routing protocols, these data packets are frequently referred to as "HELLO packets". As each participant performs this process, the participant detects which devices operate within its radio range or neighbourhood.

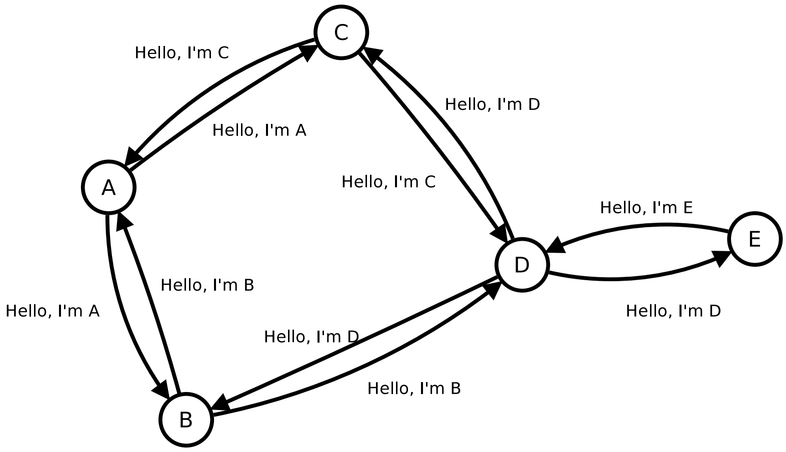

Figure 2: Neighbourhood detection

In step two, the signal quality of these devices is established, for example through the packet loss rate, signal-to-noise ratio or selected bit rate of the WLAN's rate control algorithm. This signal quality is incorporated into the metrics used to evaluate and compare routes.

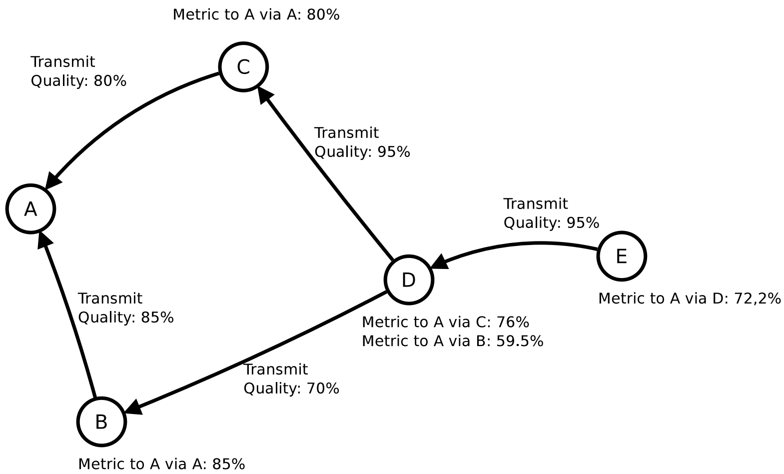

Figure 3: Neighbourhood detection

Finally, information about the routes is transmitted from device to device. The mesh node's mesh algorithm does not rely on complex pathfinding algorithms; instead, the optimum route is detected implicitly through the packets sent, each participant transmitting route packets featuring metrics of 100

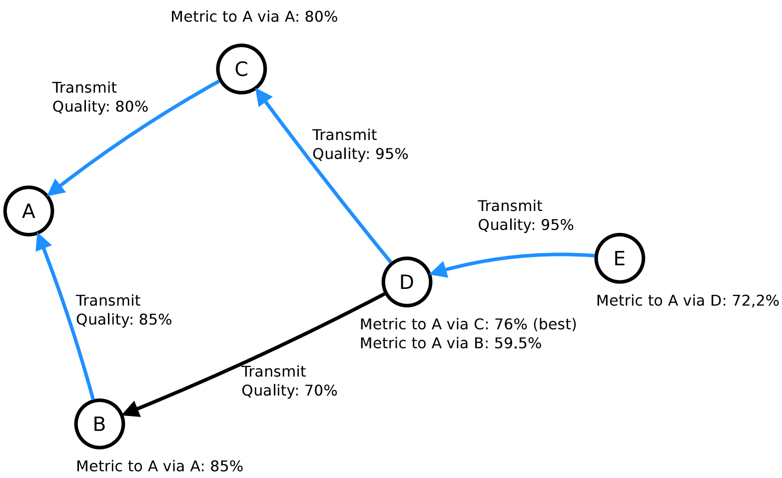

Figure 4: Flooding and route development

The mesh network properties resulting from these mechanisms make it attractive for a number of different applications: as the routing packets are flooded across the whole network, there is a wide range of possible routes, ensuring redundancy. Periodic transmission automatically adapts the metrics to changes in signal quality or loss of individual connections, allowing the network to adapt dynamically to the conditions. The third significant property is its self-healing capacity. Disruptions generally only affect a part of the network, and it does not take long to find alternatives to bypass the disrupted device or disrupted connection.

The description above is a simplified summary of the mesh node's mesh algorithm. Additional factors, such as signal quality in both directions (different antennae may mean that signal quality is better in one direction than in the other) and the number of hops also have an impact. Other influences also contribute to route selection, but to go into further detail would go beyond the scope of this whitepaper.

This architecture holds challenges for a number of scenarios. For example the use of the same radio channel by all users would limit the bandwidth – only one device per radio neighbourhood may transmit at any one time to prevent a loss of packets through collision. This lowers the effective bandwidth, especially across several hops, which may be acceptable for applications with low requirements, such as small hotel WLANs, but has proved problematic for bigger networks with a lot of data traffic such as video data. This problem may be solved by using a number of WLAN modules, as described in the following section.

4 Using several network devices and cables

A lot of mesh WLAN devices provide the AP functionality through the same WLAN module as the mesh functionality. Since clients as well as mesh participants transmit on the same channel in these cases, the available bandwidth is strongly affected. For this reason, the mesh node stipulates the operation of access point and mesh on different WLAN modules, enabling the use of different WLAN channels which do not negatively affect each other.

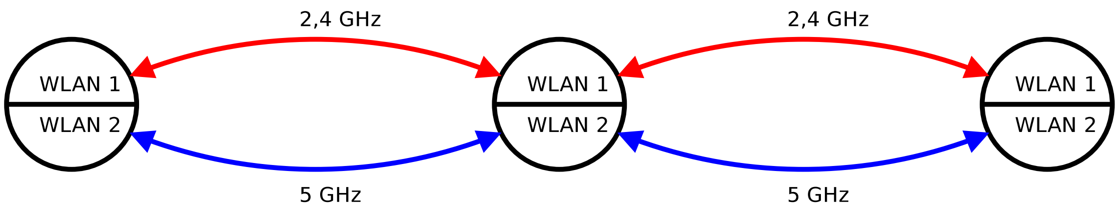

Figure 5: Redundancy through use of several WLAN modules

In addition, the mesh may be configured on any number of devices. For example two WLAN modules may be configured on different channels and operated in the mesh mode, achieving redundancy and expanding the mesh network across several radio channels while maintaining the properties of a large, interconnected mesh network with all its advantages. If two devices have a connection on both radio frequencies, this allows the maintenance of the connection, even if one of the two frequencies is disrupted.

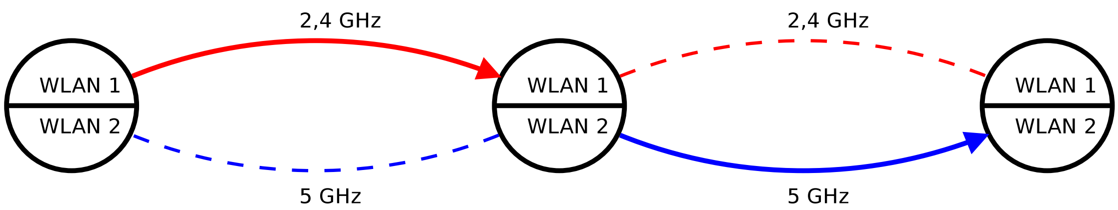

Figure 6: Alternate use of WLAN modules

As several radio modules are used, additional functions may also be supplied, such as the use of different modules for transmission and reception. If a data packet is transmitted and reaches the device on the one module, it will be transmitted to the subsequent neighbour on the second WLAN module, provided that a good connection is available on this module. This allows simultaneous transmission and reception, considerably increasing the effective bandwidth even across several hops.

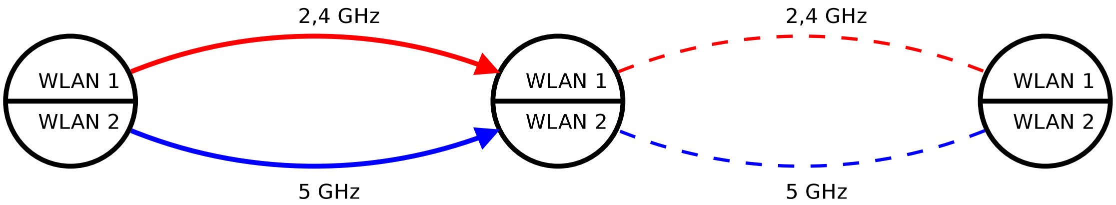

Figure 7: Bonding of WLAN connections

Another option which may be used if several WLAN modules are available in the mesh is to bond these modules, allowing, if two connections of similar quality are available, an equal distribution of the packets to be transmitted. Throughput can be optimised significantly better with this method than using a single connection.

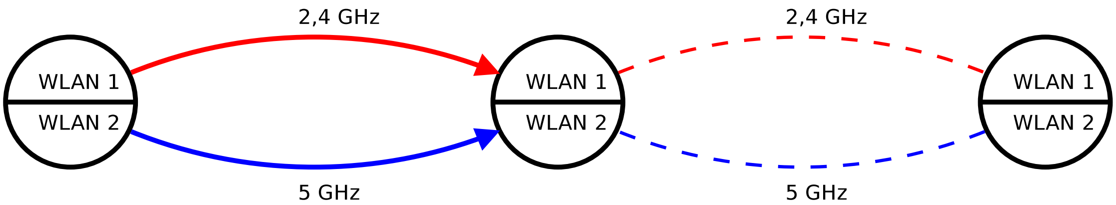

Figure 8: Mesh connected by cables

As the mesh algorithm may be applied to all Ethernet-compatible technologies, Ethernet modules may be integrated into the mesh accordaning to the same principle. A typical example would be a tower on which mesh nodes for the relevant directions are mounted, scanning those directions. The mesh nodes are cable-connected by Ethernet and do not require a separate radio connection.

5 Connection of LANs

In most scenarios, additional LANs are connected to the mesh. In a simple scenario, this may be a WLAN/BSS provided as access point through the second WLAN module, but may also be Ethernet LANs into which the mesh node is integrated

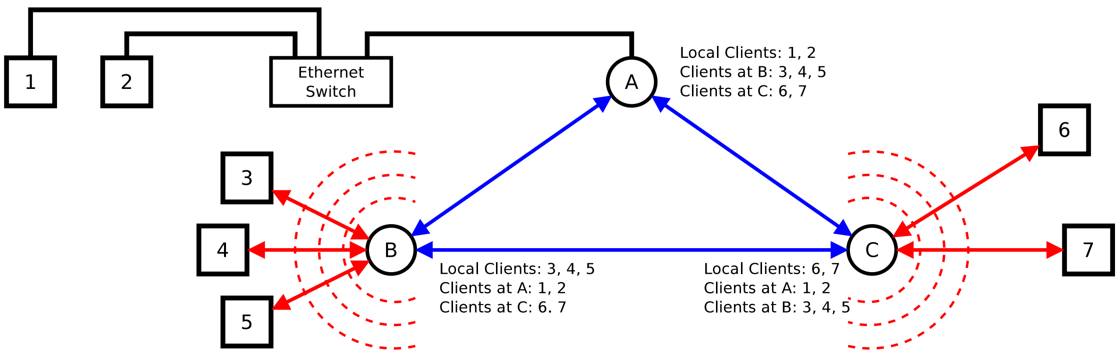

Figure 9: Publication of network devices in the mesh

The mesh in the mesh nodes operates like a switch which registers the hardware addresses (MAC addresses) of the connected participants and issues them (exclusively) at the destination port to which the target device is connected. The MAC addresses of the incoming data packets are registered and stored in a local database. These local databases are exchanged among mesh participants by attaching them to routing packets. By flooding them within the network, each participant is informed as to who has connected which end devices, enabling them to compose the global translation table. This table allows participants to check each incoming data packet, using the destination MAC address, as to which mesh participant the data packet is to be transmitted to. The mesh recipient will then transmit it to their connected LAN or WLAN and consequently to the target device.

This mechanism is a very straightforward, transparent and configuration-free way of connecting several networks. The mesh nodes may be operated as easily as a switch – the local networks are merely connected to the mesh node, everything else is taken care of by the mesh network.