

ITRAINONLINE MESH NETWORKS

Developed by: Sebastian Büttrich, wire.less.dk

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1. About this document

These materials are part of the ItrainOnline Multimedia Training Kit (MMTK). The MMTK provides an integrated set of multimedia training materials and resources to support community media, community multimedia centres, telecentres, and other initiatives using information and communications technologies (ICTs) to empower communities and support development work.

1.1 Copyright information

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1.2 Prerequisites

It is recommended to read all basic units about wireless networking first, especially the one on “Infrastructure and Topology”. A good understanding of wireless standards, basic radio physics and antennas will be helping you in understanding this unit.

1.3 Degree of Difficulty

The degree of difficulty of this unit is Advanced.

2. Introduction

Mesh networks, very briefly explained, are networks in which information is passed on between *nodes* in a many-to-many fashion and in a flat hierarchy, in contrast to centralized networks.

Mesh networks have over the last few years (from the start of the 2000s) attracted more and more interest in the wireless networking world, from hardware vendors to software engineers, from commercial companies to community activists.

The reasons for this range from technical robustness and ease of implementation to promises of low costs and low energy consumption, to the vision to ubiquitous networks covering whole cities and countries.

Without doubt, the ad-hoc, decentral and non-hierarchic nature of mesh networks has attracted many technology workers interested in community networks, due to the implicit values they seem to carry.

3. Defining mesh networks

The following is the basic definition of a mesh network:

“A mesh network is a network that employs one of two connection arrangements, full mesh topology or partial mesh topology. In the full mesh topology, each node is connected directly to each of the others. In the partial mesh topology, nodes are connected to only some, not all, of the other nodes.”

This is best illustrated by a picture of a simple full mesh, in which all nodes (computers) are connected to all the others:

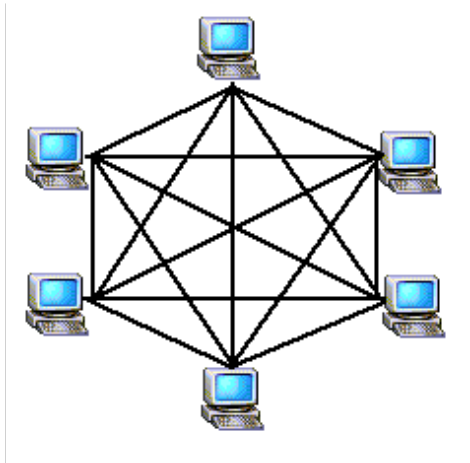


Image 1: Schematic of a full mesh topology

Secondly, a network diagram of a partial mesh, closer to a realistic wireless mesh implementation: nodes have a varying degree of connection, with some nodes connected to many and others on the edges having only a few or one connection(s).

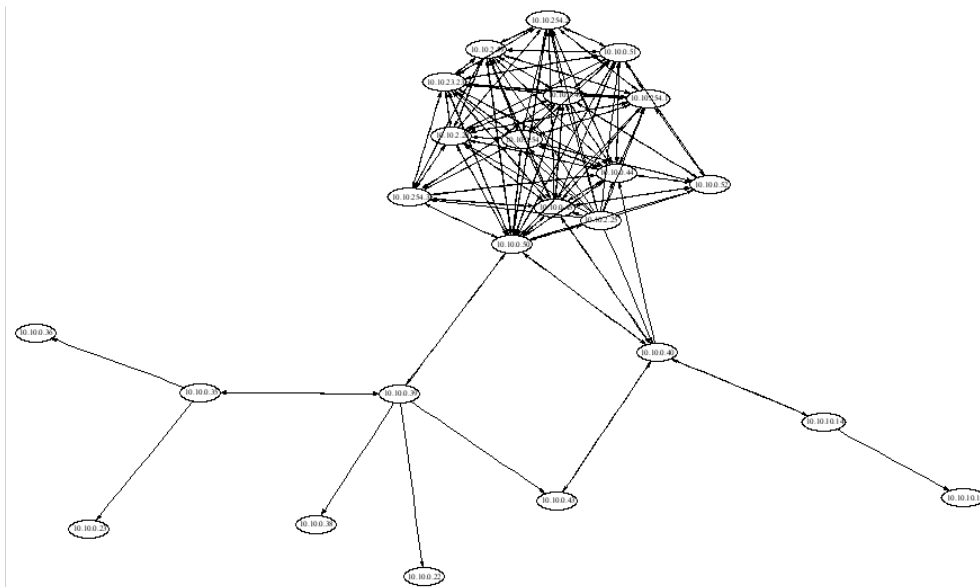


Image 2: A realistic mesh diagram

3.1.1 Mesh topology and dynamics

As you can see from the definition, nothing is necessarily dynamic in a mesh. However, in recent years, and in connection with wireless networks, the term "mesh" is often used as a synonym for "ad hoc" or "mobile" network. Obviously, combining the two characteristics of a mesh topology and ad hoc capabilities is a very attractive proposition.

While some see the biggest advantages of mesh network in dynamic environments, most of the successful and relevant implementations that have emerged so far, are quite static, for example with nodes / antennas based on rooftops.

See the mesh case stories for a better understanding of this.

3.1.2 Mesh topology in common understanding

Despite the differences in understanding and implementation, it is useful to remember a common understanding of mesh networks as

networks that handle many-to-many connections and are capable of dynamically updating and optimizing these connections.

3.1.3 Mesh topology – a typical scenario

A typical mesh scenario in an urban environment may look like this, connecting mostly rooftops - but potentially including many other locations for nodes, like antenna towers, other towers, trees, mobile nodes (like cars, people with computers, ...):

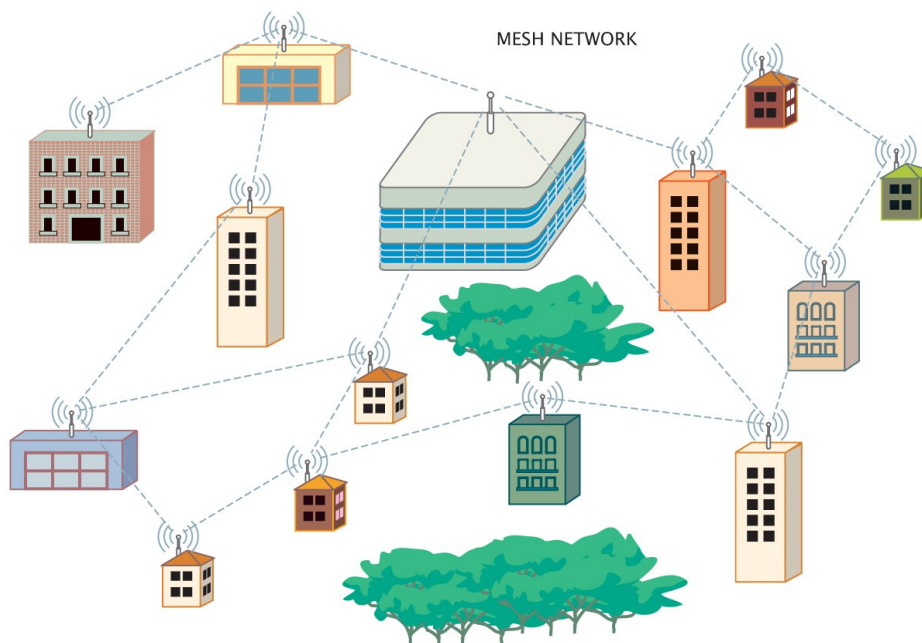


Image 3: A typical mesh scenario

3.1.4 Mesh topology - related terms

When reading about mesh networks, you might come across many related terms that are sometimes (and not always correctly) used as synonyms for mesh networks:

MANET (mobile ad hoc network) – combining the two aspects of mobility and dynamics (that are not necessarily present in a mesh network)

Ad-Hoc network – focussing on the spontaneous, dynamic nature of a network

Multi-Hop-Networks – focussing on the fact that information is travelling through many nodes

4. Motivations, expectations and limitations

Mesh networking technology is gradually maturing to a point where it cannot be ignored when considering wireless networking technologies for deployment. The first large-scale community mesh deployments (for example, up to some hundred nodes) have demonstrated enough advantages to motivate further experimenting.

These are some of the reasons why mesh networks are seen as an attractive option:

4.1.1 Reality fit

Reality rarely comes as a star, ring, or a straight line. In difficult terrain - be that urban or remote - where not every user can see one or few central points, chances are she can see one or more neighbouring users.

4.1.2 Price

The fact that each mesh node runs both as a client and as a repeater potentially means saving on the number of radios needed and thus the total budget. While this point loses relevance with dropping radio prices, more importantly, mesh approaches can reduce the need for (expensive and vulnerable) central towers and other centralized infrastructure.

4.1.3 Organization and business models

The decentralized nature of mesh networks lends itself well to a decentralized ownership model wherein each participant in the network owns and maintains their own hardware, which can greatly simplify the financial and community aspects of the system.

4.1.4 Ease and simplicity

For a device that is pre-installed with wireless mesh software and uses standard wireless protocols such as 802.11b/g, the setup is extremely simple. Since routes are configured dynamically, it is often enough to simply drop the box into the network, and attach whatever antennas are required for it to reach one or more existing neighbouring nodes (assuming that we can solve the issue of IP address allocation).

4.1.5 Network robustness

The character of mesh topology and ad-hoc routing promises greater stability in the face of changing conditions or failure at single nodes, which will quite likely be under rough and experimental conditions.

4.1.6 Power

The substrate nodes of a mesh network - possibly excepting those nodes that maintain an up-link to the Internet - can be built with extremely low power requirements, meaning that they can be deployed as completely autonomous units with solar, wind, hydro, fuel cell or human generated power.

Piggybacking mesh networks on projects that primarily aim at energy production might be a very feasible strategy - with every panel or windmill, a node. Power generating units are typically connected to points of infrastructure and human presence. This makes them valid locations for network nodes. As a secondary benefit, the presence of integrated network nodes within power networks may allow for better monitoring and management.

4.1.7 Integration

Mesh hardware has all advantages of embedded technology: it is typically small, noiseless, and easily encapsulated in weatherproof boxes. This means it also integrates nicely outdoors as well as in human housing.

4.1.8 Urban and remote environments

Until now, mesh networks have most often been proposed for urban networks and municipality networks. However, there is a big potential for mesh networks in rural and remote connectivity scenarios.

4.1.9 Issues and limitations

As for any technology, there are issues and limitations for mesh networks, most of these based around the limits in bandwidth, scalability and the difficulties to guarantee Quality-of-Service (QoS). These issues will be discussed in detail in their own chapter.

It is important to be aware of the fact that organizational and communicational structures of a project – e.g. its hierarchic structure or level of internal democracy – are not necessarily reflected one to one by the technical structure of a network. They belong to different domains.

5. Mesh routing protocol types and metrics

A mesh routing protocol is a piece of software that has to handle the (dynamic) routing and connection of nodes in a mesh.

5.1.1 Elements of mesh routing

Among the main elements of mesh routing protocols are:

Node discovery – to find out about nodes as they appear and disappear

Border discovery – to find out about the limits/edges of a network

Link metrics – to measure the quality of the links between the nodes

Route calculation – to find the best routes, based on the quality of the links

IP address management – to assign and control the IP addresses on the network

Uplink/backhaul management – to take care of connections to external networks, for example uplinks to the general internet

5.1.2 Mesh routing protocols: Types

Depending on the way in which the protocol controls the links and their states, we distinguish two main types of mesh routing protocols:

Pro-active (Table-driven)

These are characterized by proactive checking of link state and updating of routing tables, which leads to high complexity and CPU load, but also to high performance.

Reactive (On-demand)

Passive reacting on detection problems (non-working routes) tends to be less performant, but is also less demanding on CPU.

The lines between those two types are not strict - many mixed and different approaches exist.

In what follows, we list the most important examples of mesh routing protocols:

Mesh routing protocols: Pro-active (Table-driven)

OLSR (Optimized Link State Routing Protocol), OLSR-EXT, QOLSR
TBRPF (Topology Broadcast based on Reverse-Path Forwarding routing protocol)
HSL (Hazy Sighted Link State routing protocol)
MMRP (Mobile Mesh Routing Protocol), short: MobileMesh
OSPF (Open Shortest Path First)

Mesh routing protocols: Reactive (On-demand)

AODV

5.1.3 Metrics

Metric calculation deals with the quality of links and routes – we often speak of the *cost* assigned to a certain route. This must not be misunderstood as a financial cost, rather in the way: “How much does my data suffer when taking this route (for example, because the route is slow or lossy)?”

In principle, the routing protocol is independent from the metrics calculation - it just needs to know how “good” the route is, not where that value comes from.

Yet sensible metrics are the core of wireless mesh networking.

To illustrate this:

In the wired world, a minimum of hops usually assures the best connection because all wires are supposed to be next-to-perfect connections.

In the wireless world, many short hops might in the end be better than a few long hops.

6. Mesh routing protocols: Examples

The following is an overview of some of the mesh routing protocols relevant in wireless networking.

6.1.1 MMRP (MobileMesh)

- Mobile Mesh protocol contains three separate protocols, each addressing a specific function
- Link Discovery - a Simple 'Hello- Protocol
- Routing - Link State Packet Protocol
- Border Discovery - Enables external tunnels

Developed by Mitre.

The Mobile Mesh software is covered by the GNU General Public License (Version 2)

Comment: MobileMesh is a good starting point for educational experiments with Linux laptops.

Some instructions can be found here: <http://www.oreillynet.com/pub/a/wireless/2004/01/22/wirelessmesh.html>

6.1.2 OSPF

Open Shortest Path First (OSPF) developed by the Interior Gateway Protocol (IGP) working group of the IETF, is based on the SPF algorithm.

The OSPF specification is in the public domain, published as RFC1247.

OSPF sends calls for the sending of link-state advertisements (LSAs) to all other routers within the same hierarchical area. Information on attached interfaces, metrics used, and other variables are included in these LSAs.

OSPF routers accumulate link-state information, using the SPF algorithm to calculate shortest paths.

As a link-state routing protocol, OSPF contrasts (and competes) with RIP and IGRP, which are distance-vector routing protocols. Routers running the distance-vector algorithm send all or a portion of their routing tables in routing-update messages to their neighbours.

6.1.3 OLSR

OLSR is short for *Optimized Link State Routing* protocol, and described in RFC3626.

OLSR is a routing protocol for mobile ad-hoc networks. The protocol is pro-active, table driven and utilizes a technique called multipoint relaying (MPR) for message flooding. Currently the implementation compiles on GNU/Linux, Windows, OS X, FreeBSD and NetBSD systems.

OLSRD is meant to be a well structured and well coded implementation that should be easy to maintain, expand and port to other platforms. The implementation is RFC3626 compliant with respect to both core and auxiliary functioning.

OLSR is currently seen as one of the most promising and stable protocols.

6.1.4 OLSR with ETX Metrics

The Expected Transmission Count (ETX) path metric was developed at MIT (Massachusetts Institute of Technology).

The Expected Transmission Count (ETX) path metric is a simple, proven routing path metric that favours high-capacity, reliable links. The ETX metric is found from the proportion of beacons sent but not received in both directions on a wireless link, this means: it is simply counting losses.

In practical wireless mesh experiments, the (in)stability of routing tables (how often do we change? how often do we change our preferred gateway?) proves to be most critical.

Most metrics calculation concepts are based on 'minimization of hop counts', a wired concept which is inappropriate for wireless networks. ETX adds more 'reasonable' behaviour under real life conditions, by basing metrics on packet loss and thus number of packets sent, and not on hop count.

As most other protocols, link metrics are in principle independent of routing protocol and vice versa (transparency). Thus, ETX may be used in combination with various routing protocols.

6.1.5 AODV

The Ad hoc On Demand Distance Vector (AODV) protocol is a routing protocol designed for mobile ad hoc networks. It enables dynamic, self-starting, multi-hop routing between computers.

The protocol is in the process of being standardized at the IETF and currently is an experimental RFC

The AODV@IETF project is made possible through the joint collaboration of the MOMENT and NMSL laboratories at UC Santa Barbara and Intel R&D.

7. Mesh Hardware

Mesh nodes can be almost any piece of computing equipment,

from laptops over (almost no-cost) refurbished computers over modified home access points (in the \$50 range) to mid-price embedded boards to expensive carrier grade equipment for several thousand dollars.

The future will see more and more mobile devices like PDAs, cell phones and mixes of the two which are in principle capable of becoming mesh nodes.

The mesh hardware market is in dynamic development, and, often outside classical markets, open platforms and standards enable open development.

In what follows we give a few examples of mesh hardware suitable for wireless community networks.

Examples:

4G AccessCube

While this model has disappeared from the scene by the time of writing (November 2005), it was used in many successful mesh experiments and is still a good example of what a mesh node might look like:

dimensions: small cube (7x5x7cm)
low power consumption (ca. 4-6W)
100Mbps Ethernet
power over Ethernet (802.3af standard)
up to 2 (4,6) WLAN (802.11a/b/g) interfaces (RP-SMA connectors)
400MHz MIPS processor
32MB flash, 64MB RAM
USB
Price (2004) Approx. EUR 200-400



Image 4: 4G AccessCube

MeshNode



Image 5: MeshNode

<http://www.meshnode.org/>

The MeshNode is an outdoor-ready, waterproof box containing a Debian/GNU-Linux based system, with two radio cards in dual band (2.4 GHz & 5.8 GHz).

Price: from approximately EUR 500

Linksys WRT54G, GS, GL

While this home use access point was not originally meant as a mesh or outdoor device, it has, due to low price and open source (GPL) firmware, become one of the most interesting and versatile low budget options

Many firmware distributions for the Linksys WRT series are available:
OpenWRT, EWRT, Batbox, Sveasoft, FreifunkFirmware, and many more.

Hardware specs: RAM / Flash / CPU speed

WRT54G v2	16	4	200 MHz	
WRT54GS	32	8	200 MHz	Processor: BCM4712KPB

Price (Status 2005): circa EUR 60 (WRT54G) / EUR 70 (WRT54GS)



Image 6: Linksys WRT54G

Locustworld MeshAP

The UK based company Locustworld produces the MeshAP system, and is active in many development and community projects.

The hardware has a 500 MHz processor, 128 MB ram, on board radio cards, 32 MP compact flash drive, and no moving parts.

The Locustworld MeshAP software is based on MobileMesh, one of the most popular platforms in community mesh networking.

Price (Status 2005): £250 each or £220 in orders of 10+



Image 7: Locustworld MeshAP

Mesh hardware: customized laptops

Any laptop or stationary PC with a wireless card or inbuilt radio can serve as a mesh node.

The possible setups are too numerous to mention, however a few targeted software packages for this should be named, e.g. Pebble Linux, MeshLinux.

8. Mesh related software packages

In what follows we present in short form a mix of customized Linux distributions, packages, software collections of different kinds, aiming at or suitable for mesh networking.

All represent good starting points for educational experiments as well as real life implementations.

The focus here is put on free/open source software.

8.1.1 MeshLinux

By Elektra, Berlin/Germany

Based on Slackware Linux, circa 50 MB ISO

Targeted at reuse of (older) laptops.

Mesh protocols included: MobileMesh, OLSR, BGP, OSPF, RIP, AODV

8.1.2 Zebra/Quagga

By Kunihiro Ishiguro

GNU Zebra is free software that manages TCP/IP based routing protocols. Part of the GNU Project, distributed under the GNU GPL

Mesh protocols included: BGP-4 (RFC1771, A Border Gateway Protocol 4), RIPv1, RIPv2, OSPFv2, IPv6 ready.

Fork: Quagga adds RIPv3, OSPFv3

8.1.3 CUWin

By the Champaign Urbana community project, USA.

“The software the Champaign-Urbana Community Wireless Network (CUWiN) project releases is a complete operating system for wireless, meshing nodes. We start with a stock NetBSD distribution and add wireless drivers, routing code, and specialized systems which allow the nodes to work in harmony to route traffic for each other.”

Uses HSLs, OSPF, ETX

8.1.4 Pebble

By NYCWireless community.

“Pebble Linux is a smallish (smaller than 64 megs, larger than 8 megs) distro image designed for embedded style devices such as the Soekris boards, or a Stylistic 1000. It is based off of Debian GNU/Linux. It runs on many different types of systems, such as old 486 machines, mini-itx boards, etc.”

Mesh protocols included: OSPF, (OLSR in Metrix version)

8.1.5 OpenWRT

OpenWrt is a Linux distribution for the Linksys WRT54G, a minimal firmware with support for add-on packages, custom tunable.

Two filesystems, a small readonly squashfs partition and a larger writable jffs2 partition.

Readonly core provides: network initialization (Ethernet and wireless), firewalling, DHCP client / server, caching dns server, telnet server and busybox environment

ssh and web interfaces available via ipkg

Many more packages, e.g. php, ncat, spash, asterisk

Mesh protocols: OLSR, AODV,

Based off OpenWRT:

FreifunkFirmware, by the Freifunk group, Berlin/Germany.

The Freifunk Firmware can be installed on either a Linksys WRT54g (version 1.0 to 2.2), a WRT54gs (version 1.0 and 1.1), a WAP54g (version 2.0 only) or a compatible device to set up a typical OLSR node quickly and easily.

-

9. Mesh case stories

Not aiming at completeness or listing of 'most famous' cases, this is instead a subjective representation of different approaches in different settings – encouraging further reading.

9.1.1 Germany: Freifunk OLSR Mesh, Berlin, Germany

This experimental urban community network currently consists of around 200 nodes, based on OLSR FreifunkFirmware. This software has found a lot of use in community and development projects.

Source: <http://www.freifunk.net>



Image 8: Freifunk OLSR Mesh Berlin

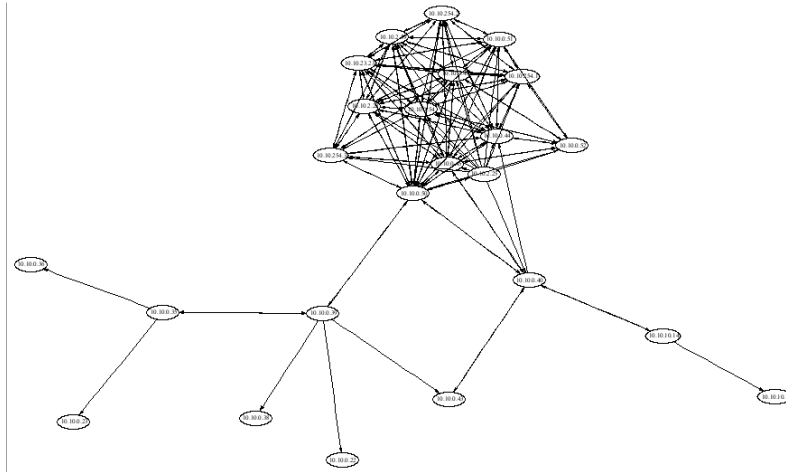


Image 9: OLSR mesh diagram

9.1.2 USA: The Champaign-Urbana Community Wireless Network (CUWiN)



Image 10: CuWin network

Source:

<http://cuwireless.net/whatiscuwin>

CUWiN is a research and development initiative, developing an open source implementation of Hazy Sighted Link State routing protocol, aiming at highly robust, scalable ad-hoc wireless networks.

9.1.3 India: Dharamsala Wireless-Mesh Community Network

Since 1959 the former government of Tibet, led by the 14th Dalai Lama, has maintained a government in exile at Dharamsala, in northern India.

“The Dharamsala Wireless-Mesh community network came to life in February 2005, following the deregulation for outdoor use of WiFi in India (28, January 2005). By the end of February 2005, the mesh had already connected 8 campuses. Extensive tests during February showed that the hard mountainous terrain is most suitable for Mesh networking, as conventional point-to-multipoint networks, cannot overcome the line-of sight limitations presented by the mountains. Mesh topology also offered much larger area coverage, while the “self healing” nature of Mesh routing, proved to be essential in places where electricity supply is very erratic at best.

At present day (October 2005), the Mesh backbone includes over 30 nodes, all sharing a single radio channel. From October 2nd, broadband Internet services are provided to all mesh members. The total upstream Internet bandwidth available is 6Mbps. There are over 2000 computers connected to the Mesh, and about 500 have Internet access. “



Image 11: Dharamsala mesh



Image 12: Dharamsala mesh, equipment

Source:

<http://www.tibtec.org>

9.1.4 South Africa: Mpumalanga Mesh Network, Meraka Institute, CSIR



Image 13: Mpumalanga mesh

Source:

<http://wirelessafrica.meraka.org.za/>

“The Meraka Institute's first Cantenna installed in a rural setting was successfully mounted onto the house of Agnes Mdluli, a health worker from Peebles valley, near White River in Mpumalanga, on July 6 2005. This cantenna is made from a metal can, such as a coffee tin, and a section of bicycle spoke soldered into a special connector which can connect to another point with a similar antenna up to 5km away. The project in Peebles Valley is one of 10 sub-projects in the First Mile First Inch (FMFI) project being funded by the International Development Research Centre (IDRC). The Meraka Institute is in charge of the technical development as part of its Community Owned Information Network (COIN) initiative under the Wireless Africa project banner. “

Mesh networking - more than technology ... the PicoPeering agreement

The PicoPeering Agreement is an attempt to connect community network islands by providing the minimum baseline template for a peering agreement between owners of individual network nodes.

Its principles include:

- Free Transit
- Open Communication
- No Warranty
- Terms of Use
- Local Amendments

<http://picopeer.net>



Image 14: PicoPeer logo

10. Issues and limitations in mesh networking

As for any technology, there are issues and limitations for mesh networks, most of these based around the limits in bandwidth, scalability and the difficulties to guarantee Quality-of-Service (QoS). The discussion is often controversial and sometimes very biased, based on personal agendas and interests.

It is important to remember that expectations and requirements may be very different depending on where and who one is.

While any bandwidth under a few MB/s would be unacceptable in a highly developed urban scenario, some kB/s might be a major achievement elsewhere -

Enterprise level QoS implies other challenges than basic rural connectivity.

10.1.1 Latency

Latency (the delay of packages along their path) obviously has to grow with the number of hops.

The effects of latency are dependent on the application using the net: email for example will not suffer even from great latencies, while voice services allow us to feel latency very direct:

Latency can be felt from 170ms on ... but then sometimes walkie talkie with 5 s delay is better than no voice connection at all.

10.1.2 Throughput

The issue of throughput/bandwidth exists in all multihop networks.

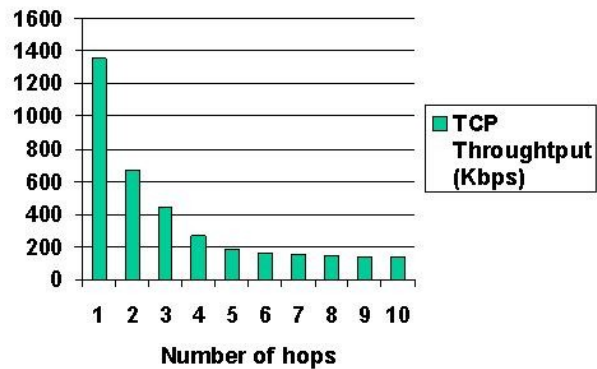
The maximum throughput scales with $1/n$ or $1/n^2$ or $1/n^{1/2}$, depending on model (n is the number of hops).

For 802.11 based wireless, the throughput limits are mainly determined by the half duplex quality of the radios. In that case, we have

throughput $\sim c/n^a$ with $a = 1..2$

However, the mesh idea is not tied to 802.11 in principle, and future wireless standards, preferably full duplex, might remove this limitation.

Impact of Multi-Hop Wireless Paths [Holland99]



TCP Throughput using 2 Mbps 802.11 MAC

527

Image 15: TCP throughput for 802.11 MAC

10.1.3 Scalability

Mesh has not been tested sustainably in real life with more than a few dozen to the lower hundred nodes:

MIT roofnet: 40-50
Berlin OLSR: circa 200?
CUWin: circa 50
Dharamsala: > 30

Commercial implementations (200 nodes? 10,000 nodes?) often do not share (true) experience openly, and their results are therefore hard to evaluate.

10.1.4 Security

Simply speaking, ad hoc networks per definition need to recognize and talk to clients before they know them. This constitutes an inherent security challenge.

Mesh networks are by design vulnerable to Denial-of-Service (DoS) attacks.

10.1.5 IP Distribution

IP distribution in mesh networks is far from trivial - while automatic assignment of IP addresses via DHCP in private IP ranges is unproblematic, mesh networks might in principle meet neighbouring networks at any time, and the danger of duplicate addresses and network conflicts is obvious.

IPv6 could bring a solution to this, but is still some years from any large scale implementation.

11. Conclusions

This unit presents the basics of mesh networks, with focus on community networks and free/open source implementations.

The main things you should remember from this unit are:

An understanding of what mesh networks are,

networks that handle many-to-many connections and are capable of dynamically updating and optimizing these connections.

an idea of the main advantages and limitations of mesh networks,

a basic understanding of mesh routing elements,

and an idea of what hardware may be used to build mesh networks.

From there on, we hope that the keywords and starting points in this document help you to find further information and get in touch with helpful people.