Mesh Networks

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Session overview

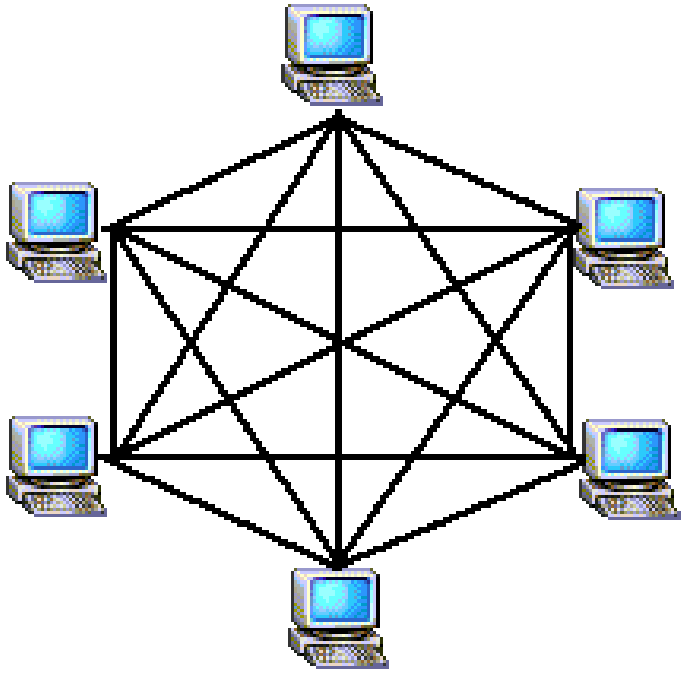
- Mesh topology
- Motivations, expectations and limitations
- Mesh routing protocols
- Mesh hardware
- Mesh oriented software
- Mesh case stories
- Issues in mesh networking

Mesh topology - definition

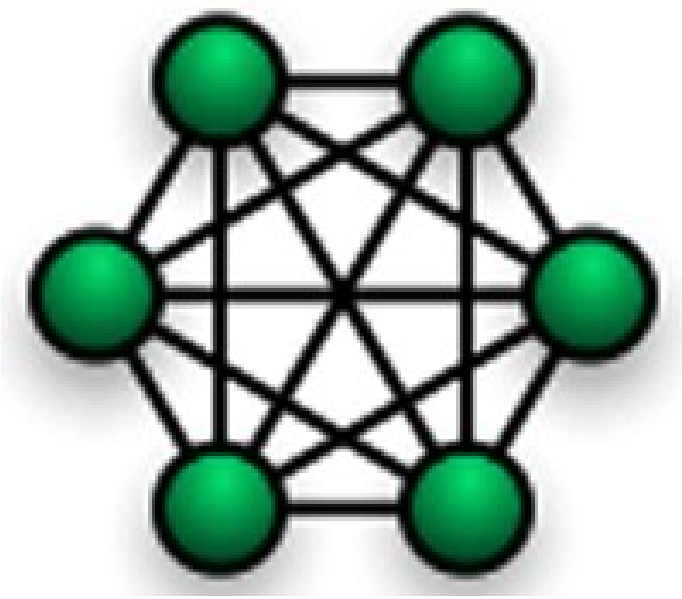
- A mesh network is a network that employs one of two connection arrangements,
  full mesh topology or partial mesh topology.
  In the **full mesh topology, each node is connected directly to each of the others**. In the **partial mesh topology**, nodes are **connected to only some**, not all, of the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

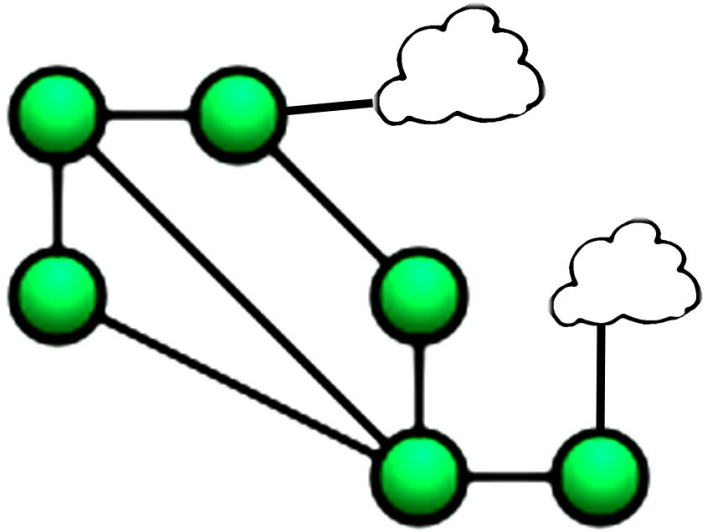
Mesh topology - definition

- Mesh, the simple way:



Mesh topology - definition: full & partial mesh





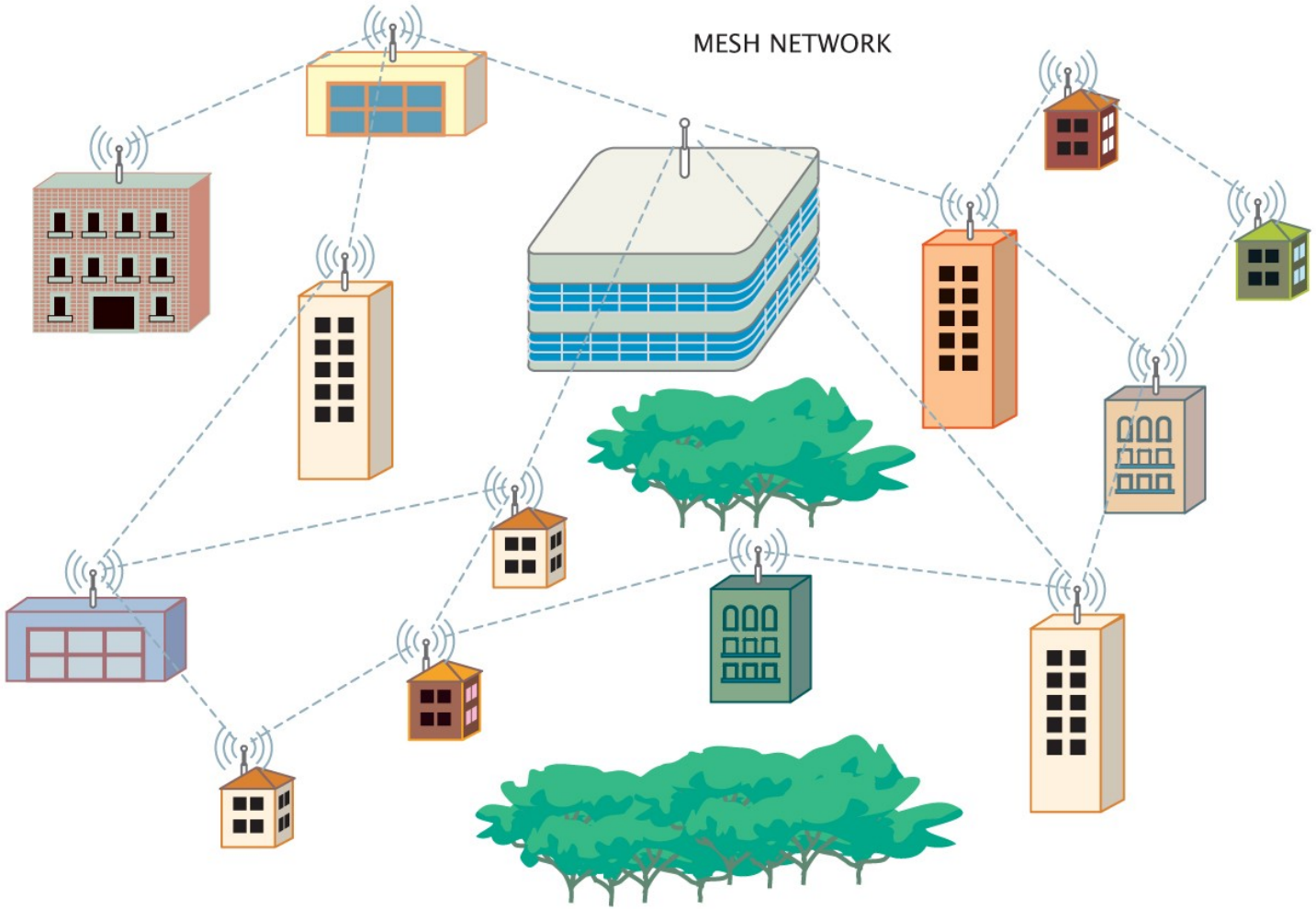
Mesh topology – what it is not (necessarily): dynamic

- 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.

Mesh topology – a common understanding

- Mesh network - a network that handles many-to-many connections and is capable of dynamically updating and optimizing these connections.

Mesh topology – a typical scenario



Mesh topology – related terms

- MANET (mobile ad hoc network)
- Ad hoc network
- Multi-Hop-Networks

Mesh networks – Motivations & expectations: why Mesh?

- Reality is not regular
- Low-cost (potentially)
- Distributed ownership models
- Gradual deployment of infrastructure
- Simplicity
- Robustness
- Low power requirements per unit

Mesh networks – motivations & expectations

- **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.

Mesh networks – motivations & expectations

- **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.

Mesh networks – motivations & expectations

- **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.

Mesh networks – motivations & expectations

- **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 neighboring nodes (assuming that we can solve the issue of IP address allocation).

Mesh networks – motivations & expectations

- **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.

Mesh networks – motivations & expectations

- **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.

Mesh networks – motivations & expectations

- **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.

Mesh networks – motivations & expectations

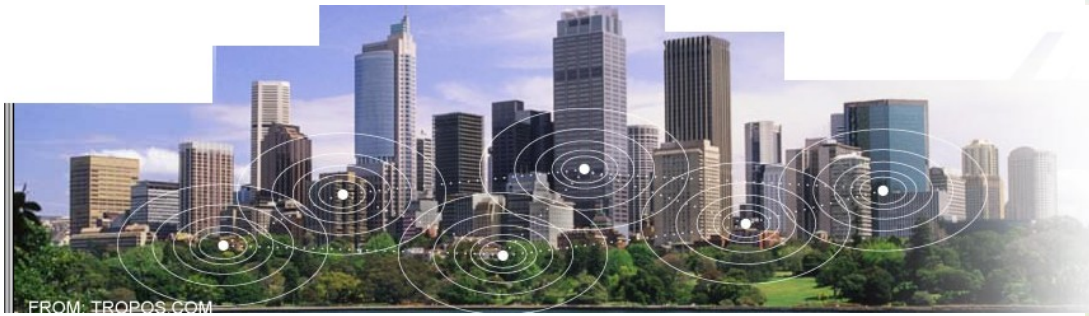
- **Integration**

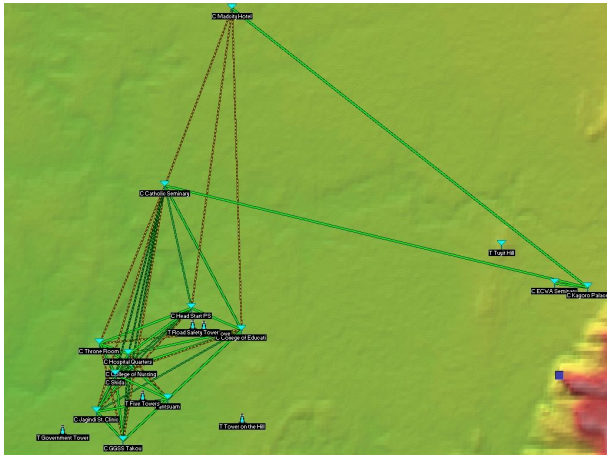
  Mesh hardware has all advantages of embedded technology: it is typically small, noiseless, and easily encapsulated in weatherproof boxes. This means it also integrates nicely outdoors as well as in human housing.

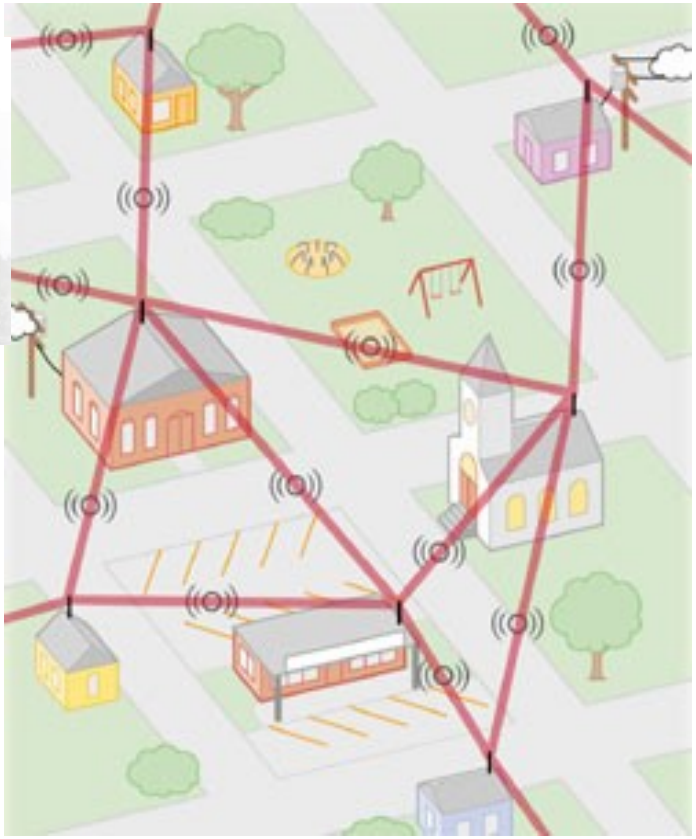
Mesh networks – motivations & expectations

- Until now, mesh networks have most often proposed for **urban scenarios and unicipality networks**
- But there is big potential for **rural and remote connectivity** scenarios

Mesh networks – motivations & expectations

- 





Mesh routing protocols: elements of mesh routing

- Node discovery
- Border discovery
- Link metrics
- Route calculation
- IP address management
- Uplink/backhaul management

Mesh routing protocols: Types

- **Pro-active (Table-driven)**
  Proactive checking of Link state and updating of routing tables – high complexity and CPU load, high performance
- **Reactive (On-demand)**
  Reacting on detection problems (non-working routes) – less demanding on CPU
- Lines between types are not strict
- More and mixed types exist

Mesh routing protocols: Metrics

- Metric calculation deals with the *cost* assigned to a certain route
- 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 ad hoc networking

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)
- HSLS (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

Mesh routing protocols: MMRP (MobileMesh)

- Mobile Mesh protocol contains three separate protocols, each addressing a specific function
    1. Link Discovery – a Simple “Hello” Protocol
    2. Routing - Link State Packet Protocol
    3. Border Discovery - Enables external tunnels
- Developed by Mitre (with military interest involved)
- The Mobile Mesh software is covered by the GNU General Public License (Version 2)
- *Comment: MobileMesh is a ood starting point for educational experiments, e.g. With Linux laptops*

Mesh routing protocols: OSPF

- Open Shortest Path First (OSPF) developed by the Interior Gateway Protocol (IGP) working group of the IETF , based on the SPF algorithm
- OSPF specification is in the public domain, published as RFC1247.
- 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 included in LSAs.
- OSPF routers accumulate link-state information, use 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 neighbors.

Mesh routing protocols: OLSR

- Optimized Link State Routing protocol. 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 ment 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.
- One of the most promising and stable prorocols
-

Mesh routing protocols: OLSR with ETX

- ETX developed at MIT
- 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.
- In practical experiments, the (in)stability of routing tables (how often do we change? How often do we change 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*.
- 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.

Mesh routing protocols: AODV

- The **Ad hoc On Demand Distance Vector (AODV) protocol** is a routing protocol designed for mobile ad hoc networks. ...enables dynamic, self-starting, multihop 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.

Mesh routing protocols: proprietary extensions

- Based on protocols described, many commercial players develop their (proprietary or open) versions
- Combinations with extended management software, aiming at higher Quality of Service

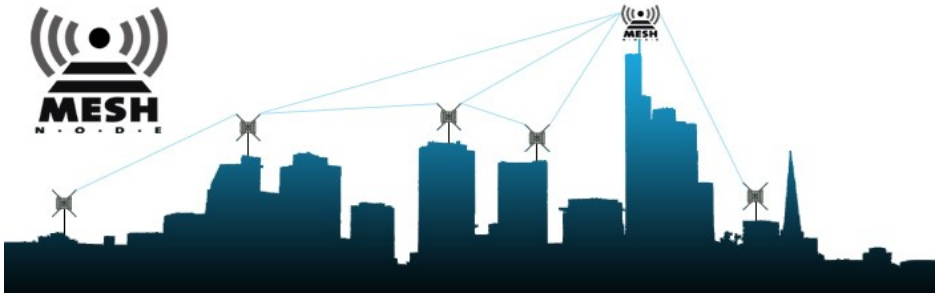
Mesh hardware

- Ranges from (almost no-cost) refurbished computers over modified home user Access points for USD 50 to mid-price embedded boards to carrier grade equipment for several thousand USD
- Challenge: to balance TCO (total cost of ownership), quality, requirements – as with all other network hardware.
- Market is in dynamic development
- Open platforms and standards enable open development

Mesh hardware: 4G AccessCube

- 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
- Circa EUR 200 **(out of production by 2006!)**

Mesh hardware: Meshnode



- Standard model comes with a
  266mhz,
  128mb ram,
  64mb cf card,
  POE powered board.
- It includes
  2 minipci cards
  (Senao 2,4GHz(b/g) and Atheros 5GHz(a/b/g)),
  four antennas
- Built into a waterproof outdoor enclosure.

Mesh hardware: Linksys WRT54G

- Not originally meant as a mesh device
- Due to low price and GPL firmware, one of the most interesting and versatile low budget options
- Many firmware distributions 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
BCM4712KPB			

- Price: circa EUR 60 (WRT54G) / 70 (WRT54GS)

Mesh hardware: Locustworld MeshAP

- 500mhz processor, 128mb ram, on board WiFi, 32mb compact flash drive.
- No moving parts!
- £250 each or £220 in orders of 10+

Mesh hardware: any old laptop will do!

- Any old laptop or stationary PC can serve as a mesh node
- Targetted software packages for this exist: Pebble Linux, MeshLinux, ..
- Basically any Linux system can be a basis
- Arguments pro/contra using refurbished hardware

Mesh software packages

- Presenting a mix of distributions, packages, software collections of different kinds
- All represent good starting points for mesh experiments/implementations
- Focus on Free Software

Mesh software packages: MeshLinux

- By Elektra, Berlin/Germany
- Based on Slackware, circa 50 MB ISO
- Targetted at reuse of (older) laptops
- Mesh protocols included: MobileMesh, OLSR, BGP, OSPF, RIP, AODV

Mesh software packages: 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

Mesh software packages: CuWin

- By 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

Mesh software packages: Pebble

- By NYCWireless community
- Pebble Linux is a smallish (smaller than 64megs, 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)

Mesh software packages: 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 initalization (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,nocat spalsh, asterisk
- Mesh protocols: OLSR, AODV, ...

Mesh software packages: FreifunkFirmware

- By Freifunk group, Berlin/Germany
- Based off OpenWRT
- 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.

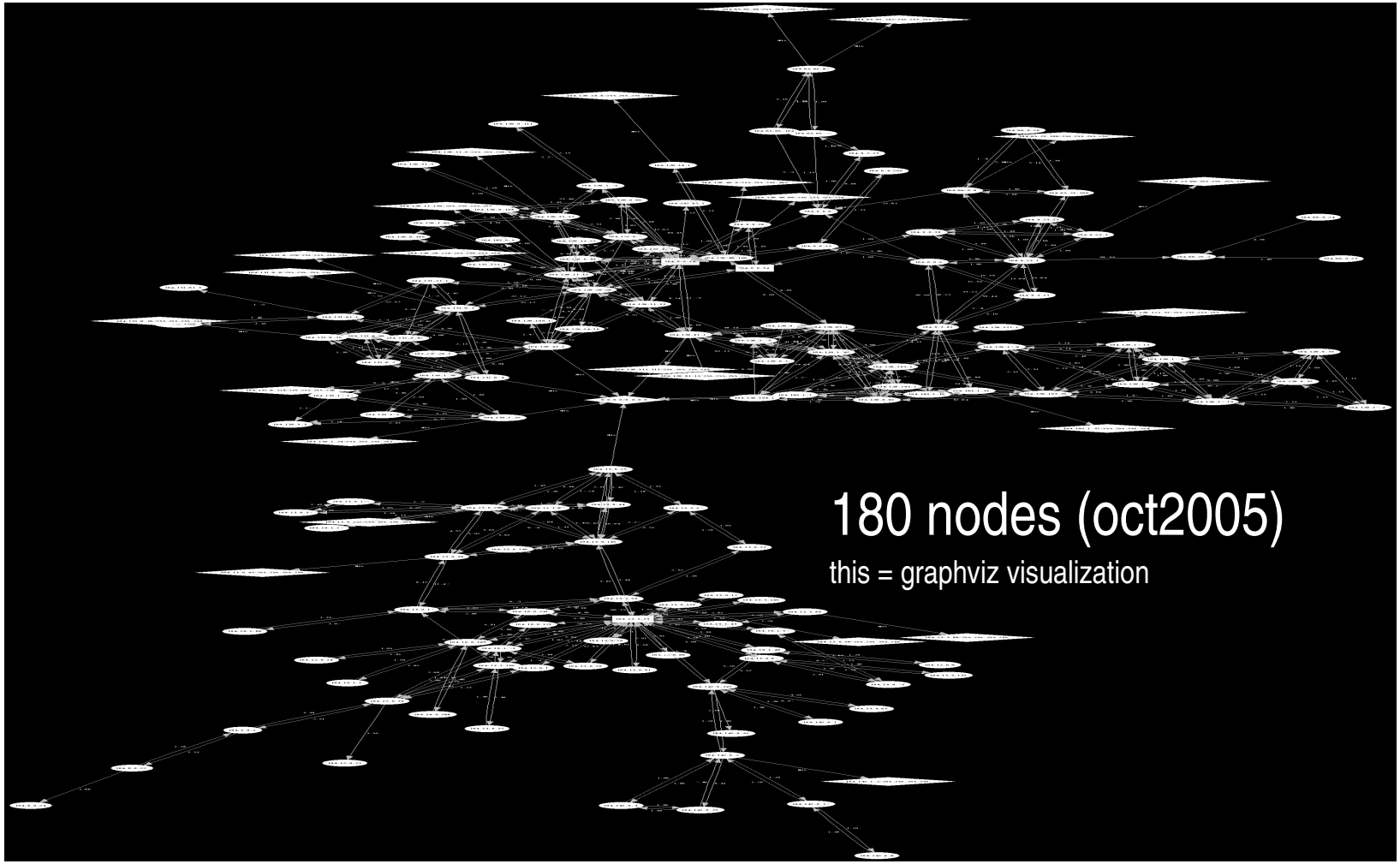
Mesh cases

- Not aiming at completeness or listing of “most famous” cases
- A representation of different approaches

Mesh cases: OLSRFreifunk, Berlin, Germany

Mesh cases: OLSR Freifunk

Berlin, Germany



Mesh cases: MIT Rooftop

Mesh cases: CUWin

Mesh cases: Dharamsala

- Using Linksys WRT54G with OpenWRT firmware
- Using OLSR with ETX
- Connecting non-profit organizations
- Developed by
  Dharamsala Information Technology Group / TibTec

Mesh cases: Mpumalanga / White River (Peeble's Valley), SA

- Meraka Institute, CSIR Pretoria
- Using FreifunkFirmware
- < 10 nodes right now, but growing
- First node was the Aids care training and support (ACTS) clinic

Commercial & proprietary

- Tropos
- BelAir
- Nortel
- Strix
- Nokia
- Cisco
- & & &

Mesh cases: Tropos.com Chaska, Minnesota

- Quoting their website:
  .... delivering metro-scale Wi-Fi mesh network products and services, with more than 125 customers and 40 resellers in eight countries around the world at the end of 2004. .... fastest, lowest cost and simplest way to deliver true wireless broadband (>1 Mbps) over large geographic areas using low-cost standard Wi-Fi clients ..
- Proprietary MetroMeshTM routing software &
  Predictive Wireless Routing Protocol PWRP TM
- Chaska, Minnesota: Municipal network claims:
  circa 250 nodes
  covering 16 sqm
  with 36 backhaul points

The Tropos 5110 outdoor MetroMesh router.

Mesh cases: Taipei/Taiwan

- Example for bigger municipal network
- From Nortel press release: *“ The city of Taipei, Taiwan selected Nortel Networks for huge wireless mesh network that is expected to encompass 10,000 wireless access points in service by year-end 2005 and serve an area of 272 square kilometers, where 90% of Taipei's 2.65 million people live. “*
- Nortel/Qware

Mesh - more than technology ... the PicoPeering agreement

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

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

http://www.picopeer.net/

Issues in mesh networking

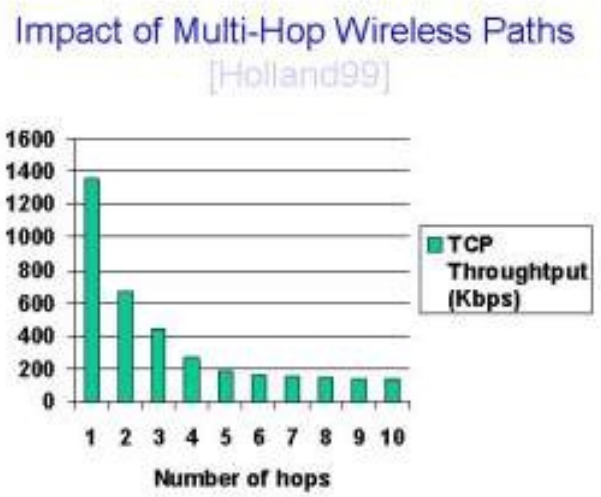
- Throughput
- Latency
- Scalability
- Security
- IP distribution

Issues in mesh networking

- As for any technology, there are limits and issues – often subject to biased and heated discussion
- Expectations and requirements depend on where and who one is: *Enterprise level QoS* implies other challenges than *basic rural connectivity*
- Simply: many things have not been tried yet (scale, stability, ...) and can not be answered in laboratory test beds

Issues in mesh networking: Throughput

- Issue of throughput in all multihop networks (discuss!)
- Scales: with $1/n$ or $1/n^2$ or $1/n^{1/2}$?
- For 802.11 MAC, determined by half duplex quality of radios ... in that case: throughput ~ c/n^a with a = 1...2
- Mesh idea not tied to 802.11 MAC in principle



TCP Throughput using 2 Mbps 802.11 MAC

527

Issues in mesh networking: Latency

- Latency obviously has to grow with number of hops
- Effects of latency dependent on application
- Example VoIP: latency can be felt from 170ms on, but sometimes *walkie talkie* with 5 s delay is better than nothing

Issues in mesh networking: Scalability

- Mesh has not been tested in real life with more than a few dozen nodes:
  MIT roofnet: 40-50
  Berlin OLSR: circa 180
  CuWin: circa 50
  Dharamsala > 30
- Commercial implementations (200 nodes? 10,000 nodes?) often do not share (true) experience – and are therefore hard to evaluate
- Lab is not real life!

Issues in mesh networking: Security

- Ad hoc networks per definition need to *talk to clients before they know them -*
  this imposes an inherent security challenge!
- Vulnerability to Denial of Service attacks

Issues in mesh networking: IP distribution

- IP distribution in mesh networks is far from trivial
- DHCP in private IP ranges is unproblematic, but what happens
  when a mesh meets a neighbour mesh?
- Ipv6 might solve many issues, but is not implemented widely yet

Conclusions

- 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

Mesh networks: URLs

- See *Additional Resources document*