Wireless Mesh Networking

Training materials for wireless trainers

The Abdus Salam
International Centre
for Theoretical Physics

Goals

The goal of this lecture is to introduce

- The main concepts behind mesh networking
- The motivation and expectations from mesh networking
- The routing protocols used in mesh networking
- The hardware and software used in its deployment
- Some case studies of mesh networking

WiFi Networking

The WiFi has been specified by the IEEE in the family of 802.11x standards to define services at the physical and data link layers. These two layers allow only a link-local management of traffic using three different types of network topologies:

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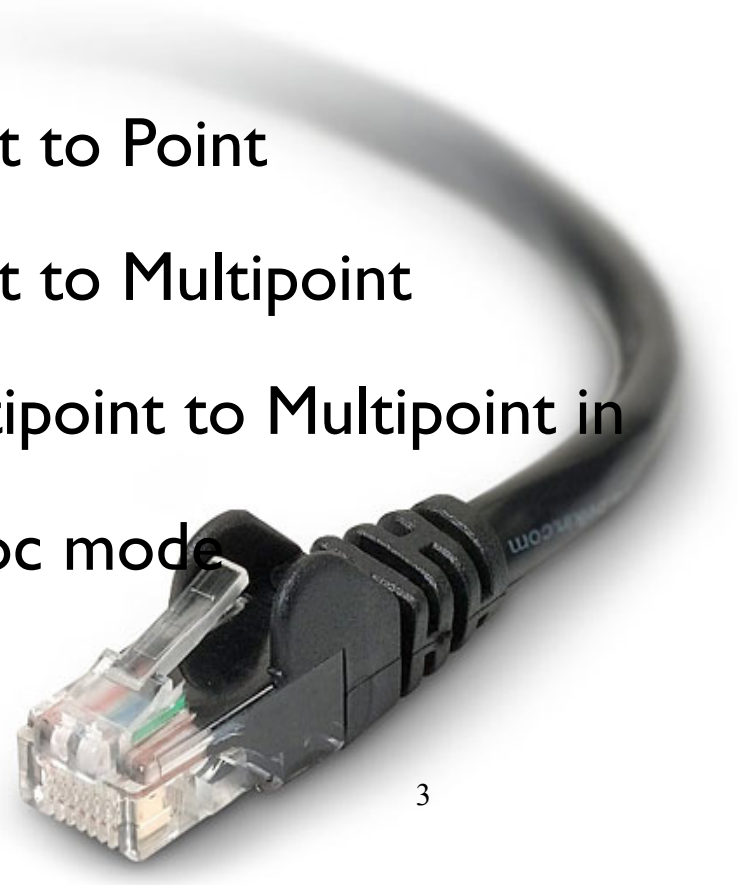
TCP/IP Protocol Stack	
5	Application
4	Transport
3	Internet
2	Data Link
1	Physical

- Point to Point
- Point to Multipoint
- Multipoint to Multipoint in Ad-hoc mode

} WiFi



Mesh networking = Ad-hoc + Routing

•802.11 WiFi provides a **link-local connection**. It does *not* provide any routing functionality!

• In ad-hoc mode, all radios can communicate with each other as long as they are in range. They will not relay traffic for other nodes without an additional **routing protocol implemented by higher level layers**.

TCP/IP Protocol Stack	
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Mesh

WiFi

Routed wireless networks

As the network grows, it becomes necessary to use some sort of routing scheme to maintain traffic efficiency.

Advantages

- Broadcast domains are limited, making more efficient use of radio bandwidth
- Arbitrarily large networks can be made when a variety of routing protocols and bandwidth management tools are available

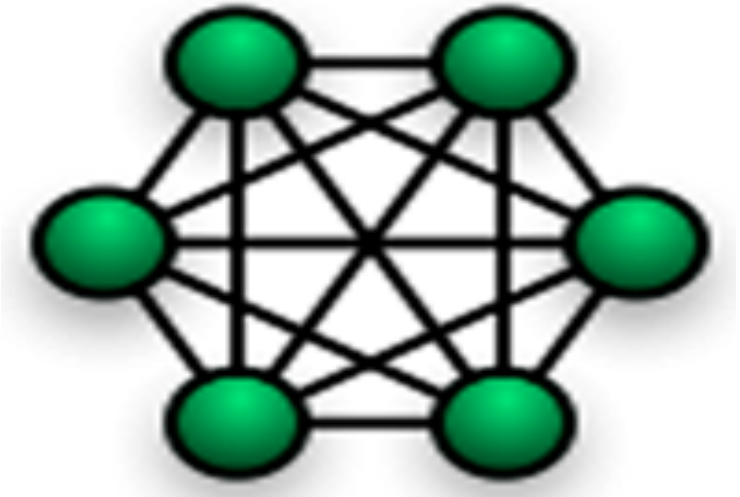
Disadvantages

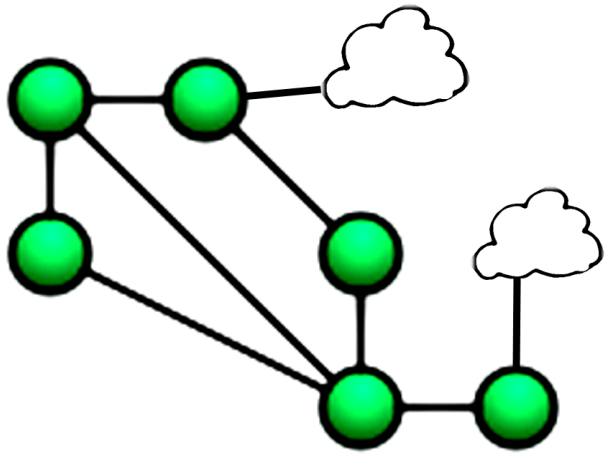
- More complex configuration.
- Roaming between APs is not supported

Mesh Networking Topologies

In a ***mesh network,*** any node of a network may communicate with any other using either

- A **full mesh topology** where each node is connected directly to each of the others or
- **A partial mesh topology** where nodes are connected to only some, not all, of the other nodes."





Mesh networks: motivations & expectations

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

Mesh networks: Reality is not regular

- Reality rarely comes as a star, ring, or a straight line. Long WiFi links for example are more easily deployed when a clear line-of-sight (LOS) may be found.
- In **difficult terrain** – urban or rural - where not every user can see one or few central points, the probability of seeing one or more neighbouring users is more increased.

Mesh networks: price

- **Savings in Radio costs:** 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.
- **Savings in tower costs:** 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: 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: 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: 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: power

- **Low power requirements:** 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. They can be deployed as completely autonomous units with solar, wind, hydro, fuel cell or human generated power.
- **Integration in power generating units:** 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.
- **Integration in power networks:** As a secondary benefit, the presence of integrated network nodes within power networks may allow for better monitoring and management.

Mesh networks: indoor/outdoor 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 indoor** environments.

Mesh networks: rural and remote connectivity

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

Mesh networks: urban and rural deployments

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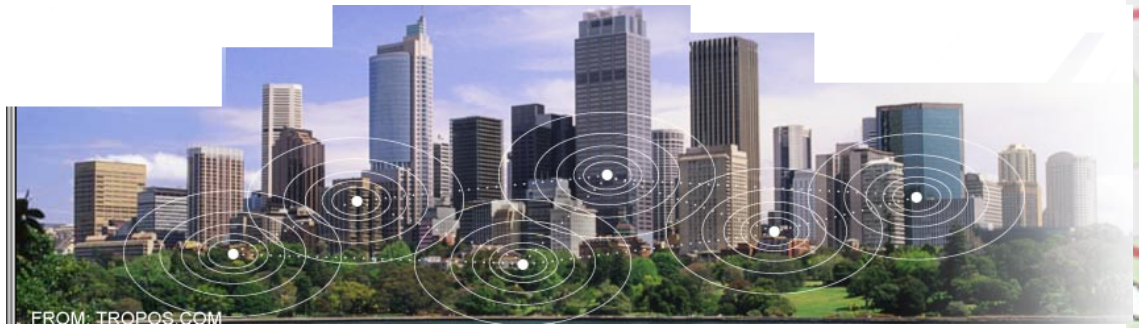
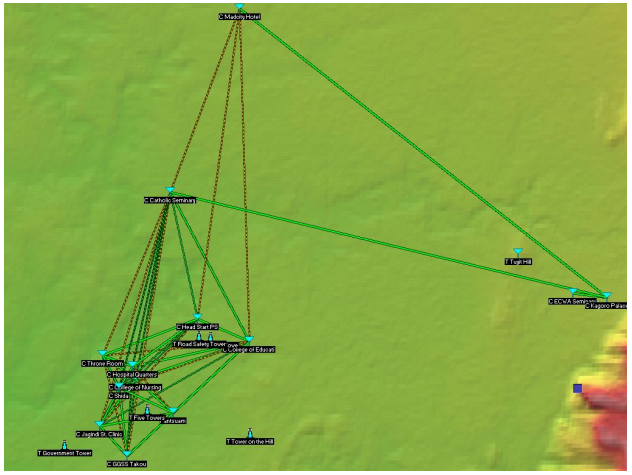
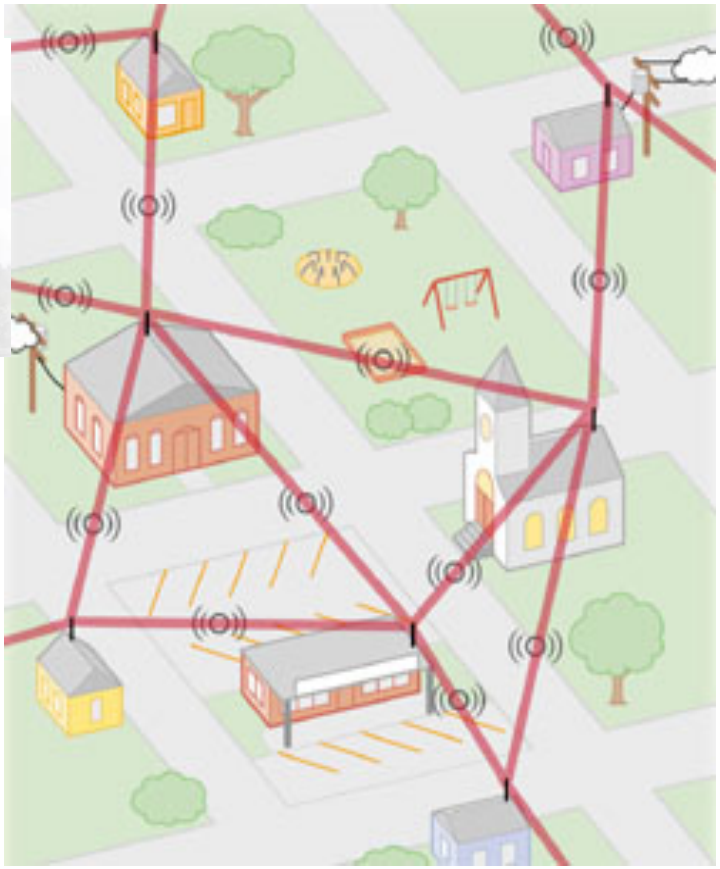






Mesh routing protocols: elements of mesh routing

- 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
- **Hybrid Pro-Reactive**
  - 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)

- **MMRP** (Mobile Mesh Routing Protocol), short: MobileMesh
- **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)

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:OLSR

- Optimized Link State Routing protocol uses an implementation which is **RFC3626 compliant** with respect to both core and auxiliary functioning.
- 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.
- It is one of the **most promising and stable** protocols.

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. 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.

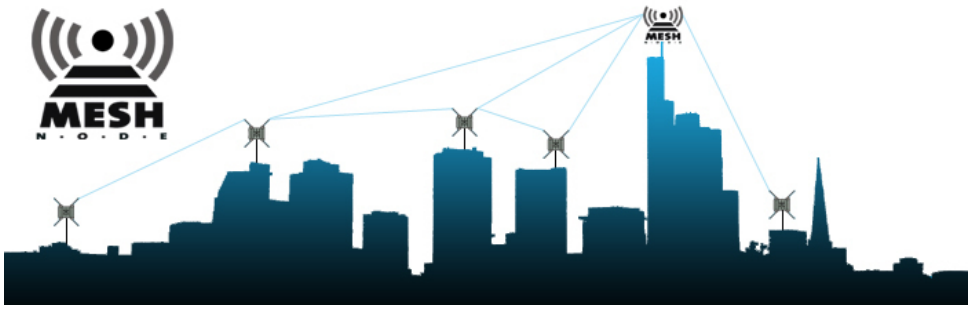
Mesh routing protocols: proprietary extensions

- 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.
- **Market** is in dynamic development.
- Open platforms and standards enable **open development.**

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 Processor: BCM4712
- Price: circa EUR 60 (WRT54G) / 70 (WRT54GS)

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: 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, ...

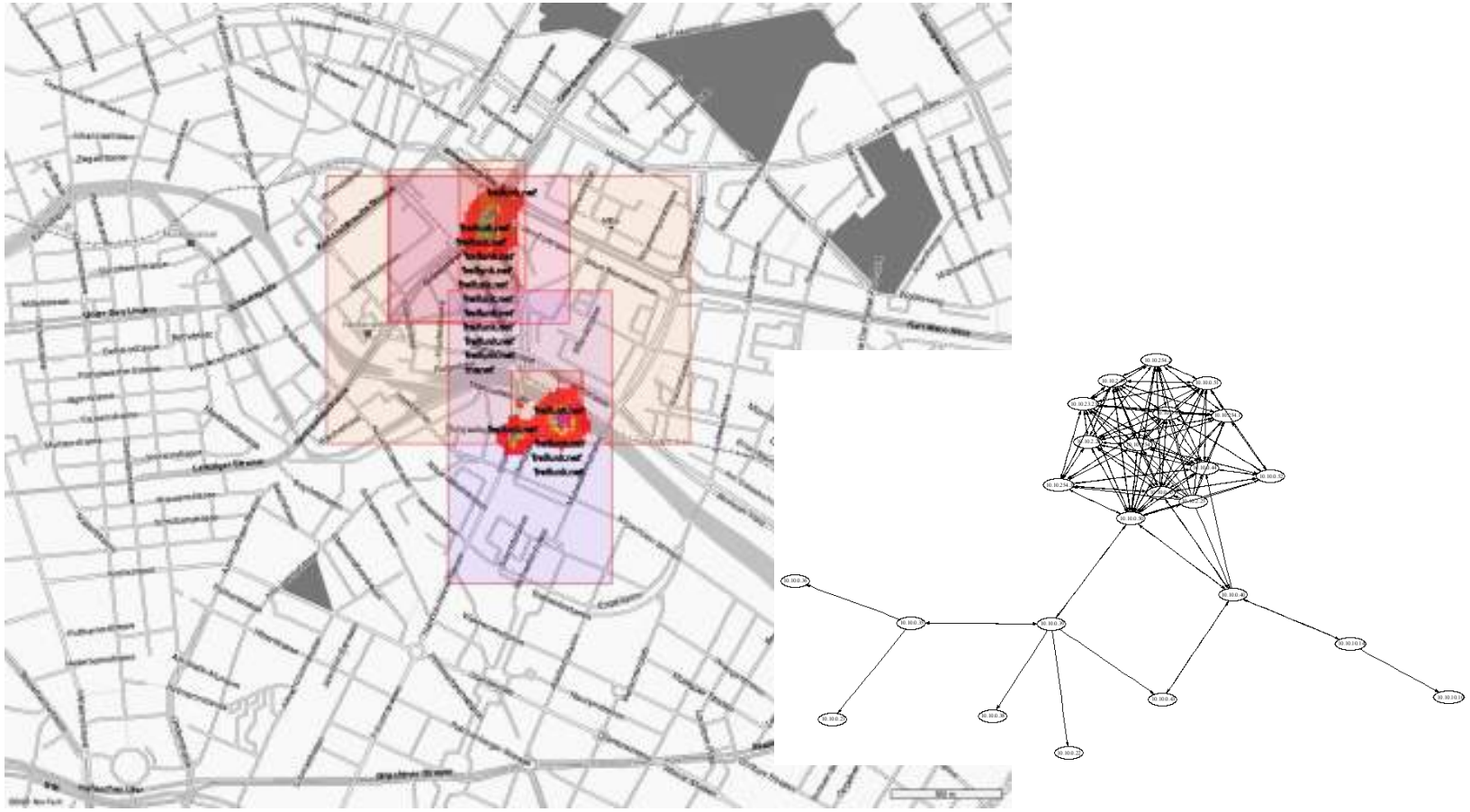
Mesh software packages: FreifunkFirmware

- 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

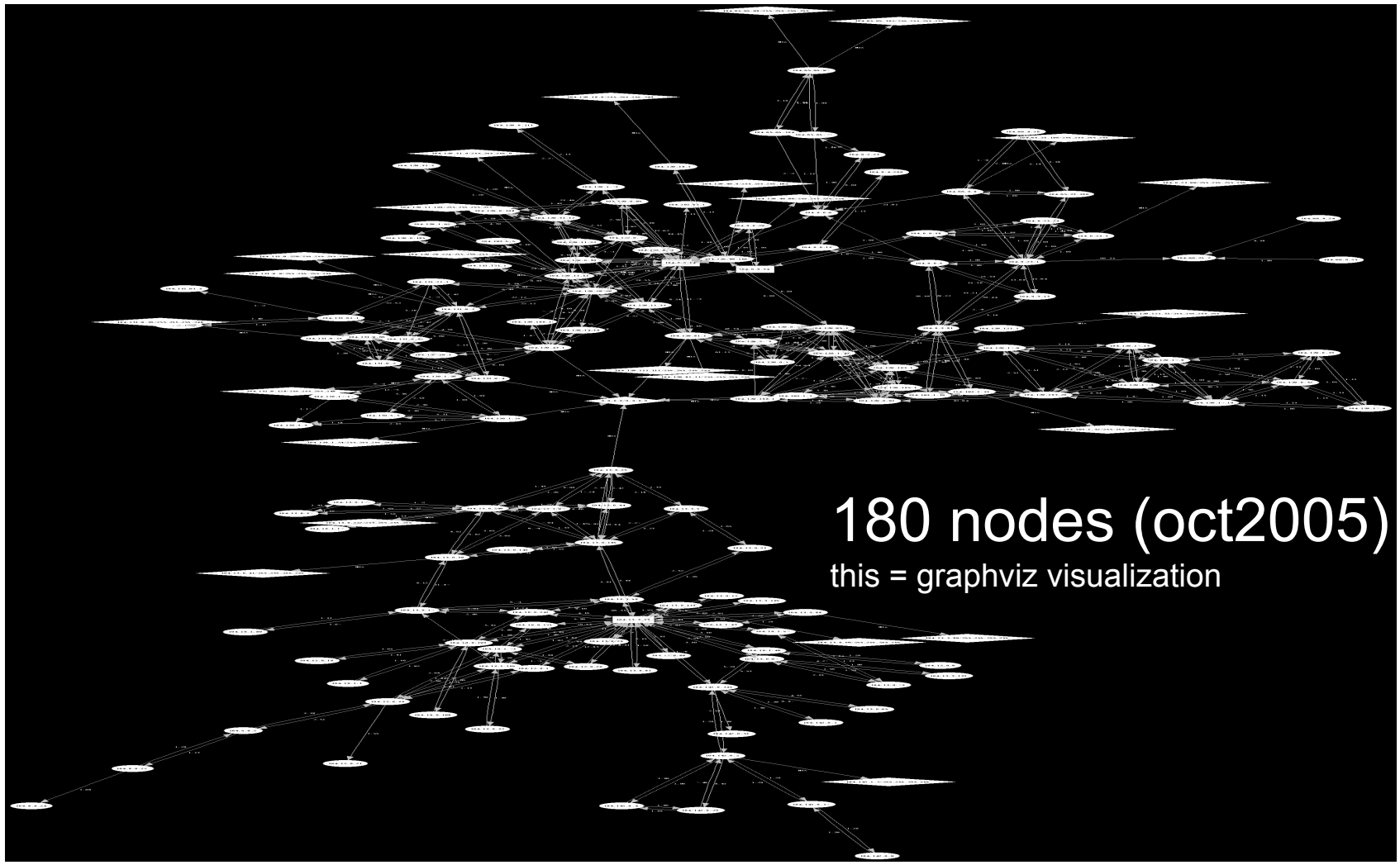
- Not aiming at completeness or listing of “most famous” cases
- A representation of different approaches

Mesh cases: OLSRFreifunk, Berlin, Germany



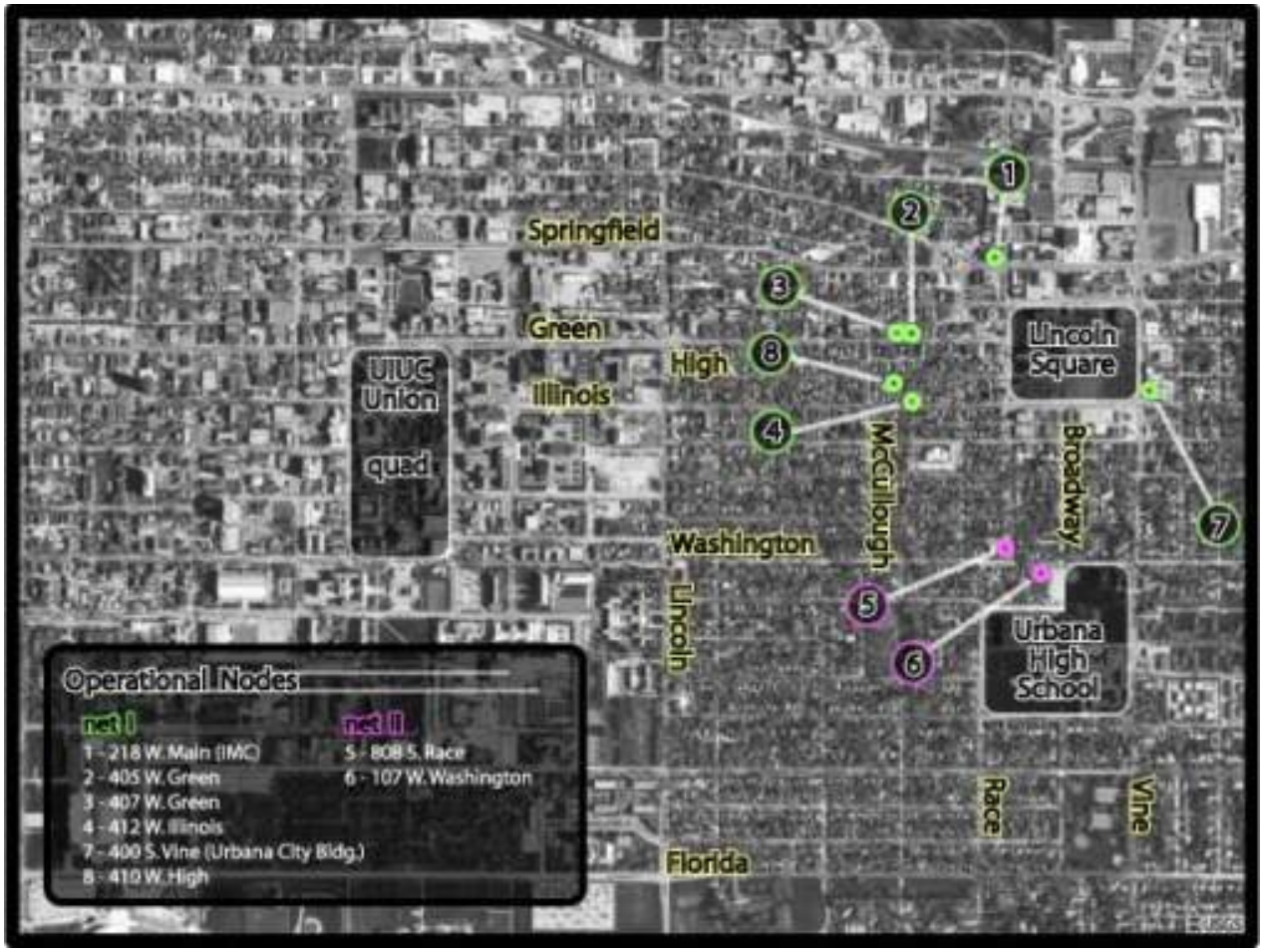
Mesh cases: OLSR Freifunk

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

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

Thank you for your attention

For more details about the topics presented in this lecture, please see the book ***Wireless Networking in the Developing World***, available as free download in many languages at:

http://wndw.net