Wireless Mesh Networks under FreeBSD

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Typical wireless network

- Relatively easy to setup
- Pricey if you want to cover a wide area
- Bandwidth shared by all wireless STAs on the same BSS
What's a wireless mesh network?

- Stations talk between each other (no central Access Point)
- Incorporates routing algorithms
- Local neighbors (peers) reachable with 0 hops
- Other nodes reachable with $\geq 1$ hop(s)
- Several technologies available. We'll talk about 802.11s
Why use a mesh network?

- Self configuring solution to expand existing wireless network
- Low cost
- Complicated topologies, including no line-of-sight
- Implement a WAN/MAN on wireless with low cost
- University campus, hotels, etc.
- Public safety services and military
What does it look like?

- Group of Mesh STAs: MBSS
- Mesh peers of Mesh STA 1 are Mesh STA 3 and Mesh STA 5
- Mesh Portals (bridges) connect the mesh to the rest of the world
- Mesh Portals are: Mesh STA 1, 2, 9
What does it look like?

- Note that 802.x LAN can be wired or wireless
- So we can combine Mesh + AP or Mesh + Wired
- The result is called ESS (Extended Service Set)
Examples of mesh networks

• Meraki Mesh (special long range radio)
• Mesh Dynamics (multiple radios)
• OLPC XO-1 children's laptop
• Smesh (fast roaming)
• SolarMesh (mesh STA power comes from solar energy)
• SONOS multi-room music system
Introducing 802.11s

- IEEE implementation of wireless mesh networks
- Amendment of 802.11-2007
- No changes on the 802.11 MAC
- Currently under draft status – expected final version in 2010
- Most of the mesh configuration is optional – you can use your own routing algorithm
- Mandatory algorithms need to be implemented
Introducing 802.11s

- Works at OSI layer 2
- Mesh networks are identified by two parameters: Mesh ID and Mesh Configuration
- Mesh Configuration contains routing protocol ID, link metric protocol ID, and other protocol IDs
- These IEs are present on 802.11 beacon frames
- Peering with neighbor STAs happens when our parameters match with the ones in the beacon
802.11s Peer discovery

- Mesh STA 1 peers with Mesh STA 2
- Mesh STA 3 peers with Mesh STA 2
- Mesh STA 2 peers with both
802.11s Peer discovery

- Mesh STA 1 and Mesh STA 3 can now talk to each other via Mesh STA 2
- You can use MAC ACLs to stop nodes from peering
802.11s Mesh Header

<table>
<thead>
<tr>
<th>Frame Control</th>
<th>Duration/ID</th>
<th>Addr 1</th>
<th>Addr 2</th>
<th>Addr 3</th>
<th>Sequence Control</th>
<th>Addr 4</th>
<th>QoS Control</th>
<th>HT Control</th>
<th>Body</th>
<th>FCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octets: 2</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td>0-7955</td>
<td>4</td>
</tr>
</tbody>
</table>

MAC Header

Mesh Flags | Mesh Time To Live (TTL) | Mesh Sequence Number | Mesh Address Extension (present in some configurations)

Octets: 1 | 1 | 4 | 0, 6, 12, or 18
802.11s Algorithms

- Hybrid Wireless Mesh Protocol (HWMP) is the default routing algorithm (mandatory)
- Radio Aware Optimized Link State Routing (RA-OLSR) is the optional routing suggested by the spec
- FreeBSD implements HWMP for now – code is modular enough that it should be easy to support RA-OLSR
802.11s Algorithms

- Airtime is the default link metric algorithm (mandatory) – metric based on tx rate and error rate
- Authentication uses Simultaneous Authentication of Equals (SAE) (pre-shared secret)
- FreeBSD doesn't implement authentication, because we are waiting for the final standard
Hybrid Wireless Mesh Protocol

- Based on AODV (Ad-hoc On-Demand Distance Vector)
- On-Demand routing requires an exchange of path setup packets before actual data transmission
- Extended to enable proactive routing
- Proactive routing enables a root mesh STA to discover all nodes on the mesh
Hybrid Wireless Mesh Protocol

- Mesh STAs use the root mesh STA as a way to reach other mesh nodes faster
- “Hybrid” comes from on-demand + proactive
- Let's look at some of the common scenarios with HWMP
HWMP Path Request (STA 1 to STA 8)
HWMP Path Request (STA 1 to STA 8)
HWMP Path Request (STA 1 to STA 8)
HWMP Path Request (STA 1 to STA 8)
HWMP Path Reply (STA 8 to STA 1)
HWMP Path Reply (STA 8 to STA 1)
HWMP Path Reply (STA 8 to STA 1)
HWMP Path Reply (STA 8 to STA 1)
HWMP Path: STA 1 to STA 8
HWMP Topology Change
HWMP Topology Change
HWMP Topology Change
HWMP Topology Change
Notes on HWMP

- Sequence numbers are used to drop old packets & to avoid loops
- Each station tracks the last seq. number seen from the other stations
- Path setup may take a while (seconds) if the number of hops is high
- Packets must be queued while node discovery happens
802.11s on net80211

- Second public implementation of 802.11s
- Experimental status
- First release in FreeBSD 8.0
- Sponsored by The FreeBSD Foundation
- Started on late April. Working implementation on late July.
- Linux compatibility is coming
802.11s on net80211

- Each wlan driver needs to be changed for mesh support
- Drivers working already: ath(4), ral(4) and mwl(4)
- Firmware-based drivers (like ipw, iwi, wpi, etc.) won't work
- Drivers that do hostap, can be changed to work with mesh mode easily
- Next step is to play with USB wlan drivers
802.11s on net80211 – user side

- ifconfig wlan0 create wlanmode mesh channel <chan> meshid freebsd-mesh

wlan0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST> metric 0 mtu 1500
  ether 00:0b:6b:2d:dc:d8
  media: IEEE 802.11 Wireless Ethernet autoselect mode 11a <mesh>
  status: running
  meshid freebsd-mesh channel 36 (5180 Mhz 11a) bssid 00:0b:6b:2d:dc:d8
  regdomain ETSI country PT ecm authmode OPEN privacy OFF txpower 17
  mcastrate 6 mgmtrate 6 scanvalid 60 wme burst bintval 1000 meshttl 31
  meshpeering meshforward meshmetric AIRTIME meshpath HWMP
  hwmprootmode DISABLED hwmpmaxhops 31
802.11s on net80211 – user side

- `ifconfig wlan0 list sta`

<table>
<thead>
<tr>
<th>ADDR</th>
<th>CHAN</th>
<th>LOCAL</th>
<th>PEER</th>
<th>STATE</th>
<th>RATE</th>
<th>RSSI</th>
<th>IDLE</th>
<th>TXSEQ</th>
<th>RXSEQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:0b:6b:2d:dc:d8</td>
<td>36</td>
<td>0</td>
<td>0</td>
<td>IDLE</td>
<td>0M</td>
<td>18.5</td>
<td>15</td>
<td>1</td>
<td>192</td>
</tr>
<tr>
<td>00:0b:6b:2d:db:ac</td>
<td>36</td>
<td>9827</td>
<td>a5b3</td>
<td>ESTAB</td>
<td>54M</td>
<td>14.0</td>
<td>0</td>
<td>2</td>
<td>28752</td>
</tr>
<tr>
<td>00:0b:6b:2d:dd:17</td>
<td>36</td>
<td>afdb</td>
<td>ab30</td>
<td>ESTAB</td>
<td>54M</td>
<td>19.0</td>
<td>0</td>
<td>5</td>
<td>25024</td>
</tr>
<tr>
<td>00:0b:6b:87:1c:f0</td>
<td>36</td>
<td>1904</td>
<td>825c</td>
<td>ESTAB</td>
<td>54M</td>
<td>6.0</td>
<td>0</td>
<td>30</td>
<td>192</td>
</tr>
</tbody>
</table>

- `ifconfig wlan0 list mesh`

<table>
<thead>
<tr>
<th>DEST</th>
<th>NEXT HOP</th>
<th>HOPS</th>
<th>METRIC</th>
<th>LIFETIME</th>
<th>MSEQ</th>
<th>FLAGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:0b:6b:2d:dd:17</td>
<td>00:0b:6b:2d:dc:d8</td>
<td>1</td>
<td>2842</td>
<td>5000</td>
<td>9</td>
<td>V</td>
</tr>
<tr>
<td>00:0b:6b:2d:dc:d8</td>
<td>00:0b:6b:2d:dc:d8</td>
<td>0</td>
<td>0</td>
<td>5000</td>
<td>0</td>
<td>V</td>
</tr>
<tr>
<td>00:0b:6b:2d:db:ac</td>
<td>00:0b:6b:2d:dc:d8</td>
<td>1</td>
<td>347</td>
<td>5000</td>
<td>4</td>
<td>V</td>
</tr>
</tbody>
</table>
802.11s on net80211 – user side

- **ifconfig wlan0 hwmprootmode NORMAL**
  Root mesh station discovers nodes using PREQ packets.

- **ifconfig wlan0 hwmprootmode PROACTIVE**
  Root mesh station discovers nodes and asks for proactive PREPs. This means that the mesh STA will always send a PREP even if it already has a path to the root mesh STA.

- **ifconfig wlan0 hwmprootmode RANN**
  Root mesh station discovers nodes using RANN packets.
Performance measurements

- For 0 hops performance is the same as adhoc mode
- As hops increase, performance decreases about 50%
- E.g.:
  - 0 hop: ~28Mbps / 1 hop: ~14Mbps / 2 hops: ~7Mbps / 3 hops: ~3.5Mbps / etc.
- You can also use a 802.11n card which makes the mesh significantly faster
Performance measurements

- Performance can be increased by use of Mesh Coordinated Channel Access (MCCA)
- MCCA works a bit like TDMA
- Mesh STA reserves a time slot and coordinates that time slot with all the neighbors
- Currently looking at how it works – we'll try to implement it in the future
Acknowledgments

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- Cozybit for the Wireshark patches enabling mesh sniffing - www.cozybit.com
- Your donations to the FreeBSD Foundation made this project possible!
References + Q&A

- http://wiki.freebsd.org/WifiMesh
- http://o11s.org/ - Linux implementation