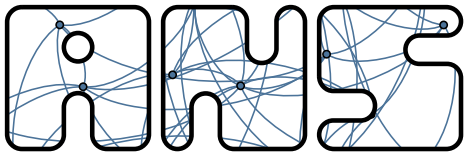

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The Optimized Link-State Protocol

Leonardo Maccari

December 1, 2017

Link State Routing[1]

The next slides describe how a link state routing protocol works, not necessarily a protocol for Wireless Mesh Networks (WMNs).

- link-state routers exchange messages to allow each router to learn the entire network topology.
- Based on this learned topology, each router is then able to compute its routing table by using a shortest path computation (with Dijkstra's algorithm).
- For link-state routing, a network is modelled as a directed weighted graph. Each router is a node, and the links between routers are the edges in the graph.
- A positive weight is associated to each directed edge and routers use the shortest path to reach each destination.

[1] http://cnp3book.info.ucl.ac.be/principles/linkstate.html

Link Weights

- In practice, different types of weight can be associated to each directed edge:
  - unit weight. If all links have a unit weight, shortest path routing prefers the paths with the least number of intermediate routers.
  - weight directly or inversely proportional to some link quality metric
- We will see two ways of defining the link weight, ETX and Airtime Metric

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- When a link-state router boots, it first needs to discover to which routers it is directly connected.
- Each router picks for itself one unique address from the ones it is configured with.
- it sends a H every $t_{\mathtt{H}}$ seconds on all of its interfaces.
- This message contains the router's address.

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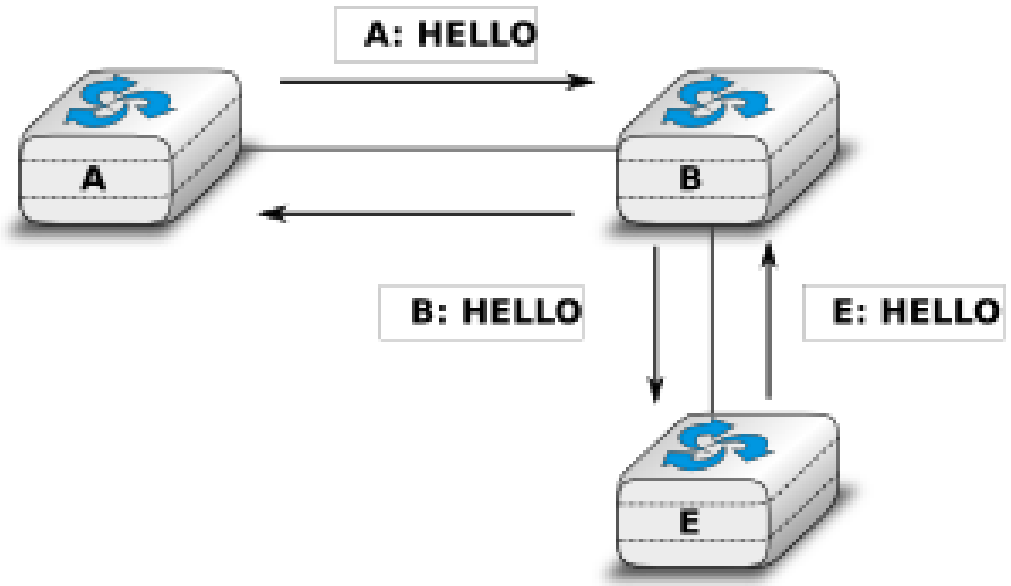
- Its neighbouring routers also send H messages, the router automatically discovers to which neighbours it is connected.
- H are only sent to neighbours who are directly connected to a router, a router never forwards an H
- H are also used to detect link and router failures.
- A link is considered to have failed if no H has been received from the neighbouring router for a period of k $\times$ t_{H} seconds.

HELLO Exchange



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- Once a router has discovered its neighbours, it must reliably distribute its local links to all routers.
- Each router builds a link-state packet (LSP) containing the following information :
  - LSP.Router: identification (address) of the sender of the LSP
  - LSP.age: age or remaining lifetime of the LSP
  - LSP.seq: sequence number of the LSP (incremented at each LSP)
  - LSP.Links[]: links advertised in the LSP.
    - LSP.Links[i].Id: identification of the neighbour
    - LSP.Links[i].cost: cost of the link

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- These LSPs must be reliably distributed before the routers have a working routing table.
- A Flooding algorithm is used to efficiently distribute the LSPs of all routers.
- Each router that implements flooding maintains a link state database (LSDB) containing the most recent LSP received by each other router.

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- When a router receives an LSP, it first verifies whether this LSP is already stored inside its LSDB using the sequence number.
- If so, the router has already distributed the LSP earlier and it does not need to forward it.
- Otherwise, the router forwards the LSP on all links except the link over which the LSP was received.

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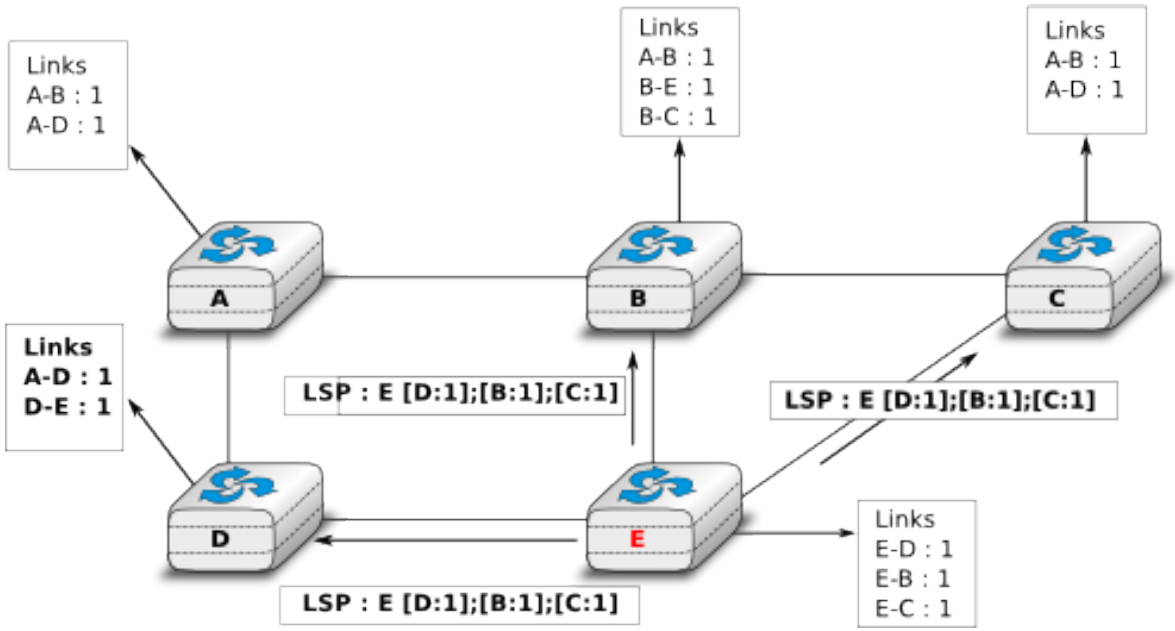
```
# links is the set of all links on the router
# Router R LSP arrival on link l
if newer(LSP, LSDB(LSP.Router)) :
  LSDB.add(LSP)
  for i in links :
    if i!=l :
      send(LSP,i)
else:
 # LSP has already been flooded
 pass
```

H flooding

- E learns by H its neighbors D, B and C.
- E sends LSP with seq 0 containing links E->D, E->B and E->C.
- E sends LSP on all links
- routers D, B and C insert the LSP in their LSDB and forward it over their other links.



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- To ensure that all routers receive all LSPs, even when there are transmissions errors, link state routing protocols use reliable flooding.
- routers use acknowledgements and if necessary retransmissions to ensure that all link state packets are successfully transferred to all neighbouring routers.

Failure Detection

- When a link fails, the two routers attached to the link detect the failure by the lack of H messages received in the last k $\times$ t_H seconds.
- Once a router has detected a local link failure, it generates and floods a new LSP that no longer contains the failed link and the new LSP replaces the previous LSP in the network.
- As the two routers attached to a link do not detect this failure exactly at the same time, some links may be announced in only one direction.
- uni-directional links are not considered for routing

Criticalities

Using link-state routing in WMN requires modifications due to critical issues:

- Wireless links are not necessarily symmetric

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- Wireless links are not necessarily symmetric
- The generated control traffic is high
- There is not way to estimate link quality
- There is no way to estimate path quality

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OLSR is a routing protocol that tries to solve the previous issues. Its two main features are:

- Link state detection using `H` messages to avoid asymmetric links
- Proactive control message diffusion using MPR nodes to reduce control messages
- OLSRv2 was introduced by RFC 7181 in 2014, it does not change the basic behaviour but fixes some issues and improves some other ones.

Some definitions:

N: number of nodes in the network

D_i: set of 1-hop neighbors of node n_i

D_i^2: set of 2-hop neighbors of node n_i

M_i: set of MPR nodes chosen by node n_i

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- To avoid broken links each node will include in `H` its full 1-hop neighbor set.
- For each neighbor in the `H` a status is added that may be SYM/ASYM
- When node n_i receives an `H` by neighbor node n_j, n_i will include n_j in its `H` messages as an ASYM neigh.
- If n_j is able to receive `H` from n_i it will do the same
- When n_i receives `H` messages from n_j containing address of n_i in the neighbors, n_i will sponsor n_j as a symmetric neighbor. n_j will do the same.
- There are hysteresis mechanisms in order to avoid wireless fluctuations.

Topology Control messages (TC)

- In OLSR, LSP messages are named Topology Control (TC) messages
- TC contain only symmetric links

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OLSR Step 1

Every node must include in Hs the IP address of nodes in D_i, with the SYM/ASYM bit set. From now on we will simply call neighbors only the SYM neighbors.

Two main consequences:

- The HELLO messages are larger than naive approach
- Using HELLO messages each node knows not only its 1-hop neighborhood but its 2-hop neighborhood

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- OLSR does not impose the generation of a new TC when a link fails
- This is (probably) because a wireless link can be extremely flaky, and oscillate much more than a wired link
- In this case, n_i may repeatedly send `TC`s when the link breaks down and when it comes back up
- Recall that a `TC` not only occupies airtime, but it also triggers re-computation of routing tables on other nodes.
- It is wiser to let the link have a bad quality, and just let the routing metric take care of it.

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Each node of a network with N nodes with in average d neighbors periodically generates:

- Hs: few bytes containing own address (size s) and neighbour addresses, generated every $t_{\mathtt{H}}$ (defaults to 2 sec).
- TCs: contains the set of IPs of all the neighbors (size $s * d$) at interval $t_{\mathtt{TC}}$ (defaults to 5 sec), re-broadcast by every node in the network (multiply by N).

A total of

$$\frac{(s * (d + 1)) * N}{t_{\mathtt{H}}} + \frac{(s * d) * N^2}{t_{\mathtt{TC}}}$$

bytes per second generated on the whole network (plus protocol overhead). Since the number of links instead grows linearly with N, control traffic *per link* scales $\propto N$.

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- Consider that all these messages are sent to the broadcast address.
- Broadcast messages at layer 2 are sent at the basic rate, which can be 100 times slower than the maximum rate (for instance in 802.11n broadcast is sent at 6mb/s Vs 600 mb/s maximum rate).
- It means that every time you send a broadcast message, you occupy the airtime for the equivalent time of 100 unicast packets of the same size

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MPR set definition

The MPR set M_i of a node n_i is an arbitrary subset of its symmetric 1-hop neighborhood D_i which satisfies the following condition: every node in the 2-hop neighborhood D_i^2 of n_i must have at least a symmetric link towards a node in M_i

- Basically, M_i is a subset of the neighbors of n_i that can be used to reach any node in D_i^2 (i.e. they *cover* all the nodes in D_i^2)

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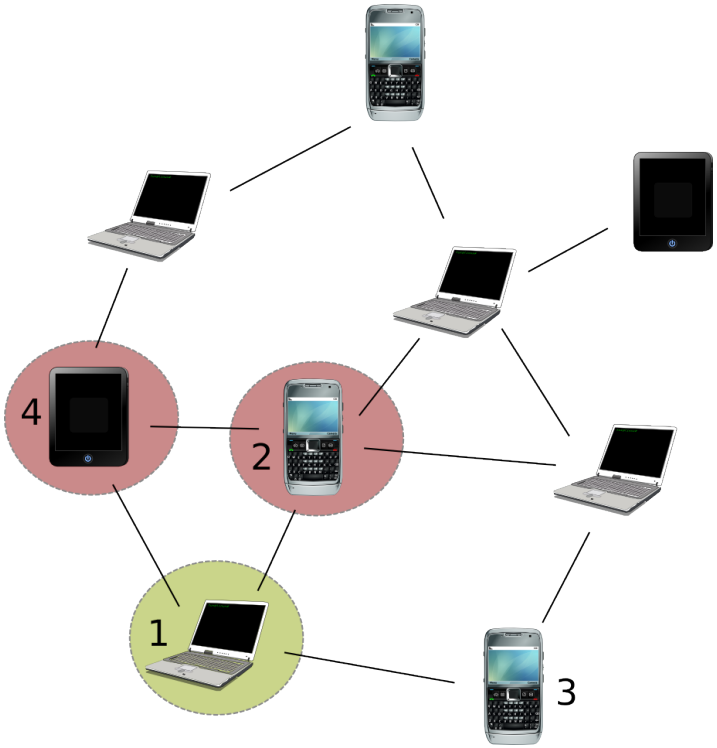
Node 2 and 4 are MPR for node 1 and node 1 is a *selector* for node 2 and 4. Node 3 is not necessary to cover n_1^2.



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- When n_i needs to broadcast a message to all the nodes in D_i^2, it will send it in MAC layer broadcast with IP Time-To-Live set to 1.
- If only nodes in M_i rebroadcast the message, it will reach all nodes in D_i^2.
- The smaller M_i compared to D_i the less packets are sent, compared to naive broadcast.

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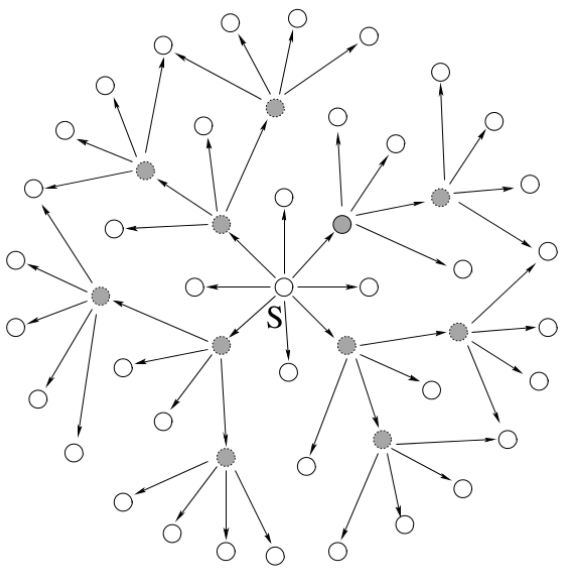
- If n_i does a network-wide broadcast, it sends a packet to the broadcast MAC address and broadcast IP address, with TTL>1
- Every node in D_i receive it
- If only nodes in M_i broadcast it again, and the process follows on if there are no losses every node n_j receives the packet
  - MPR guarantes broadcast communication to all the network



using only a subset of nodes

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- Two-hop distance is preserved: Choosing MPRs does not change the connectivity of the network.
- If n_j is in D_i^2 its distance from n_i remains 2
- There exist a shortest path from n_i to n_k made of MPR nodes
- If every MPR generates TCs, n_k knows every MPR and their neighborhood
- Since every node in the network (excluding trivial topologies) must be selector of at least one MPR node, n_k can compute a shortest path to any other node

$$\rightarrow \text{shortest paths are preserved.}$$

TC Size Reduction

- There is no need for a MPR to include in TC messages its full neighborhood
- Since every node is a selector of at least one MPR, then an MPR includes in its TCs not its full neighborhood, but its selectors only.

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OLSR Step 2

Each node must select a subset M_i as small as possible. In the `Hs` for each neighbor another bit (MPR/NOT_MPR) is added, so each MPR knows its selector set. Only the MPRs re-broadcast flooded messages, and only from their selectors.

Step 3

Only MPR nodes generate `TCs`. Each `TC` includes the selector set of the MPR that generated it

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With MPRS the network-wide average overhead passes from:

$$\frac{s * N}{t_{\mathrm{H}}} + \frac{(s * d) * N^2}{t_{\mathrm{TC}}}$$

to

$$\frac{s * N}{t_{\mathrm{H}}} + \frac{(s * \mathbf{m}) * \mathbf{M}^2}{t_{\mathrm{TC}}}$$

where m = average size of the selector set

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OLSR: summing up

- If all the nodes apply step 1,2,3 and there is no loss, than all the nodes have enough information to compute the shortest path to any node in the network.
- Since only the MPR generate TC messages and each TC includes only a fraction of the neighborhood of the MPR that generated it the overall control traffic is reduced
- It is very important that each node selects a minimal MPR set, since M depends on that (not that easy).

Examples[2]

- Only 3 nodes over 5 in the network generate TC messages
- Each TC message is forwarded exactly 2 times

[2] dashed edges are wireless links, arrows go from a selector to the MPR (only the most important ones). Solid vertexes are MPRs.

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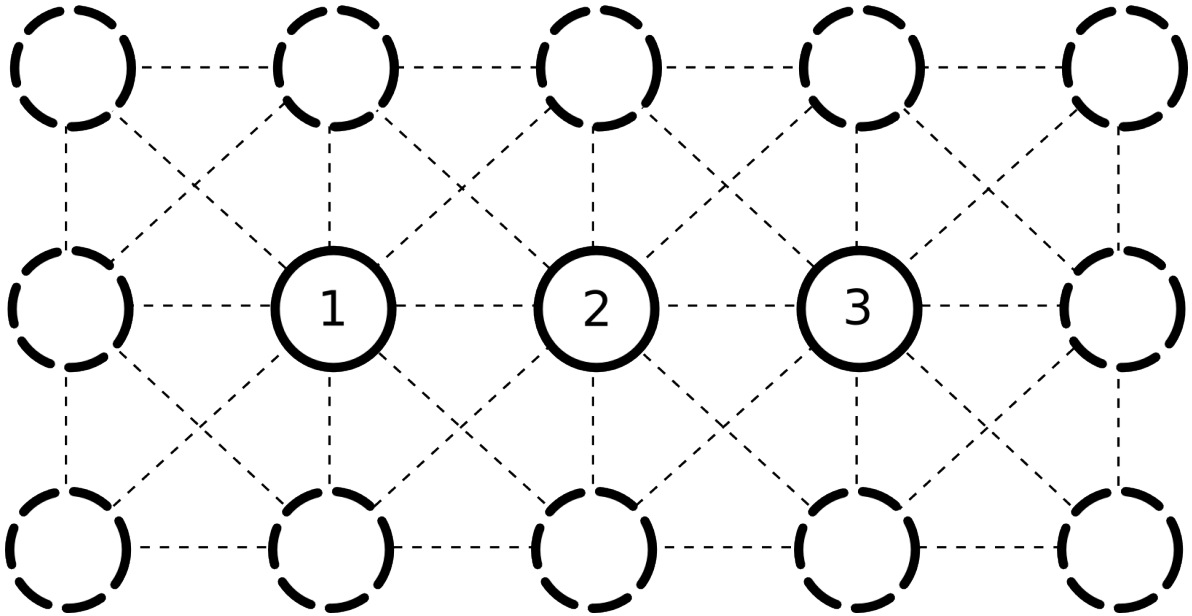

- Only 3 nodes over 15 in the network generate TC messages
- Each TC message is forwarded exactly 2 times

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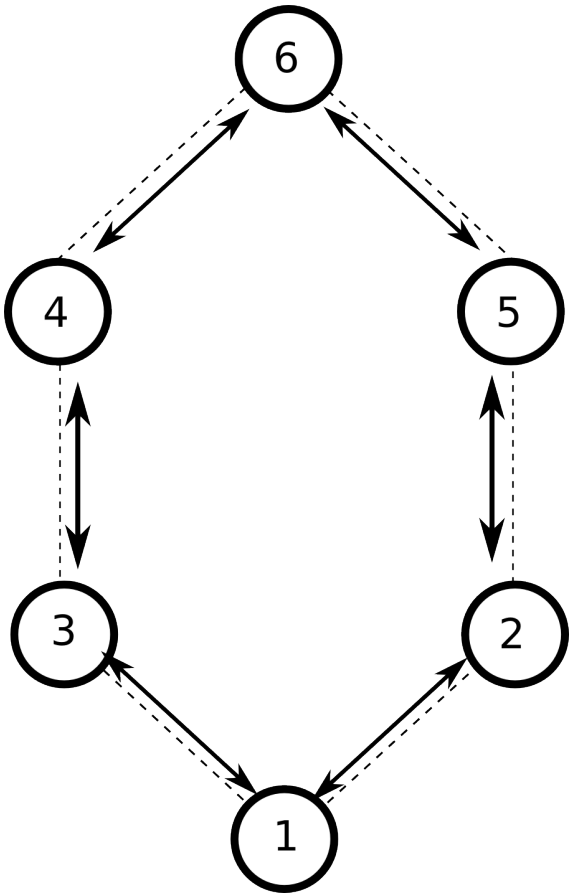

- All the nodes in the network generate TC messages
- Each TC message is forwarded exactly 5 times

Not Enough

- OLSR so far solved the asymmetrical link problem, and alleviated the overhead problem, compared to a classical link state.
- We still need to improve on the quality
- We still have room for improvement in overhead

OLSR Extensions

- OLSR has been extended by developers:
  - Introduction of a link-quality measure → ETX
  - Further reduction of overhead → Fisheye

Problem

- Is it always better to use a "short" path?
- In some cases, a very bad link (say, with 50% loss) is there.
- Probably it is better to avoid that link, even if this means taking a longer path.

QOLSR

- Each node makes an estimation of the link quality for its links (a numeric value).
- Each node includes this value in its HELLO and possibly TC messages.
- The adjacency matrix now has weights on the edges and distance can be computed on a weighted graph.

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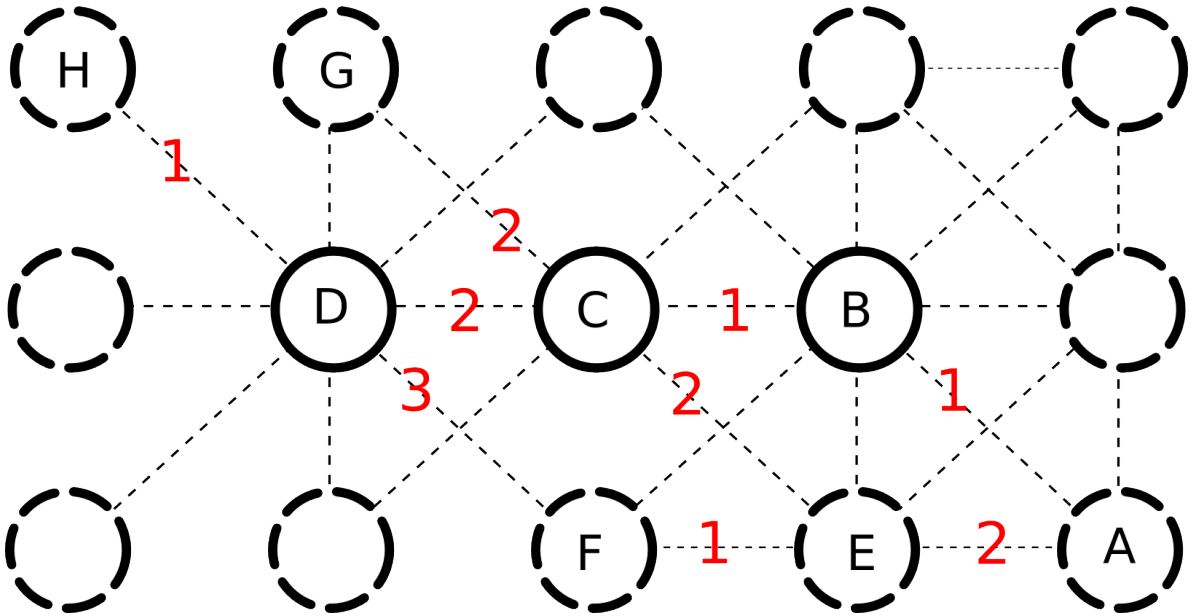

- Without weights, path A-B-C-D-H and A-E-C-D-H have the same cost
- With weights A-B-C-D-H costs 5 while A-E-C-D-H costs 7

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ETX (Expected Transmission Count) is the simplest, yet one of the most used metrics to estimate link quality. Take two neighbor nodes n_i and n_j

- In each `H` n_i includes the value of $t_{\texttt{H}}$
- n_j now knows the estimated time of arrival of the next `H`
- n_j now can sense the loss of a `H`
- n_j keeps a time-window in which it counts received and missed Hs.
- The ratio received/lost is called the Link Quality (LQ) measured by n_j for neighbor n_i.

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- In each `H`, n_j includes the LQ towards n_i, same does n_j.
- When n_j receives `Hs` from n_i it receives LQ computed by n_i: the reverse link quality (RLQ)
- Finally, ETX metric is given by:

$$ETX = \frac{1}{LQ * RLQ}$$

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Note:

- LQ: probability to successfully send a packet from n_i to n_j
- RLQ: probability to successfully send a packet from n_j to n_i
- Since each 802.11 packet to be successfully transmitted requires two packets (data packet + ACK in the other direction) then the probability of successfully transmit a packet is estimated by RLQ*LQ.
- ETX thus is the inverse of this probability, that is, the average number of transmission attempts n_j needs to do to successfully send a packet to n_i
- ETX is symmetric

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- Broadcast packets are sent at the base rate, unicast packets are sent at the negotiated rate, the highest the rate, the highest the loss.

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  - **ETX is pessimistic**
- ETX does not say anything about other quality features of the link: capacity, delay etc. . .
  - **ETX is just imprecise**

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On the other hand

- ETX does not require any cross-layer interaction, it is based only on layer 3
- It can be safely implemented in any driver/hardware/OS
- It is larger or equal to one, and thus can be used as an additive metric

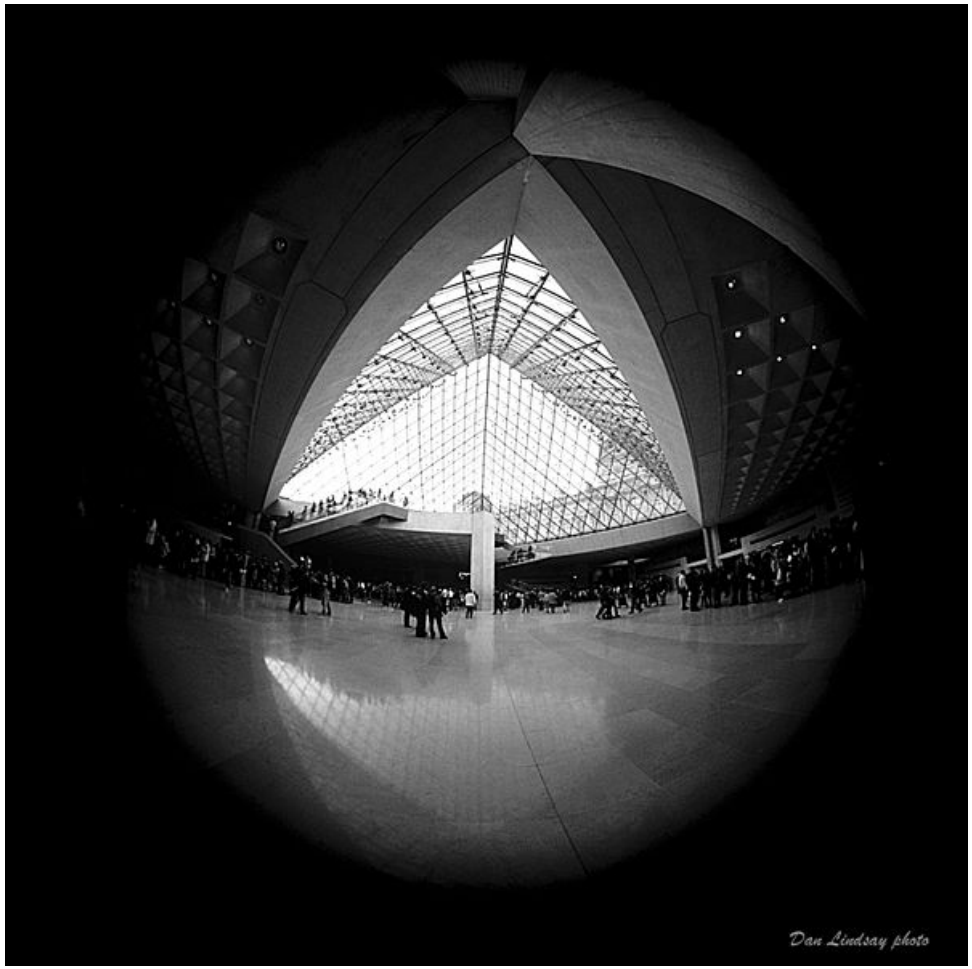
Fisheye

- A node needs only the necessary information to decide what is the next hop on the shortest path to the destination.
- We have seen that nodes already have a limited view of the topology outside their 2-hop neighborhood
- This approach can be enhanced with fisheye strategies

Fisheye

- The word fisheye refers to the view of the world a fish has under the water
- If you look up from below the water you see the whole 180 degrees horizon compressed in a cone with a smaller angle
- Basically, you have better vision on the close thinks and a fading compressed vision on objects far away. The same happens if you use a *fisheye* lens on a camera

Fisheye [3]



[3] http://en.wikipedia.org/wiki/File:Museumfisheye.jpg

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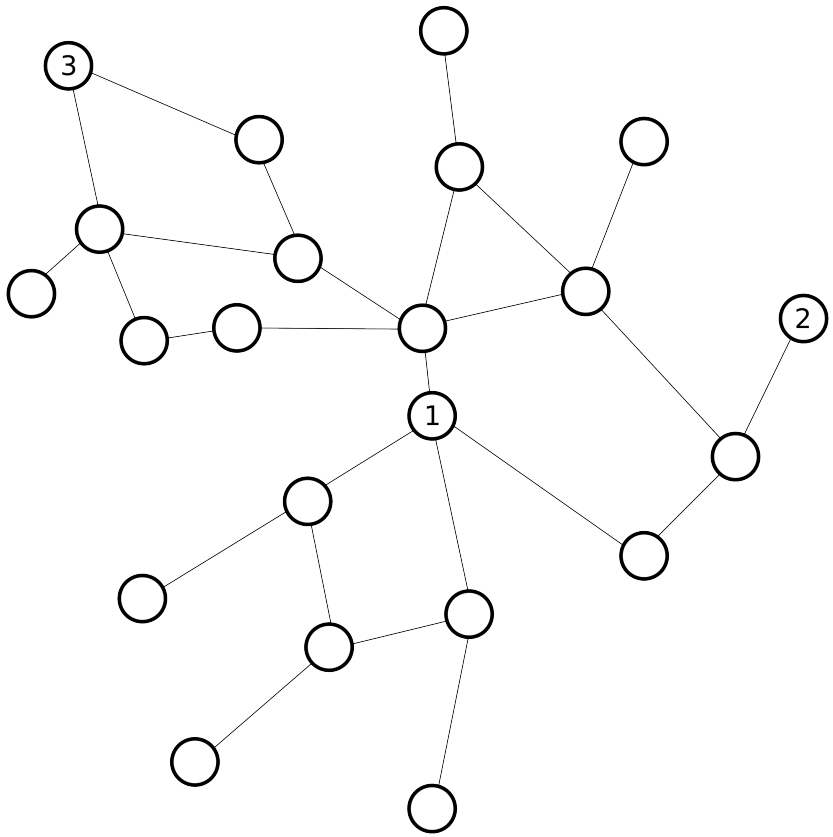
Fisheye transforms the network from this . . .



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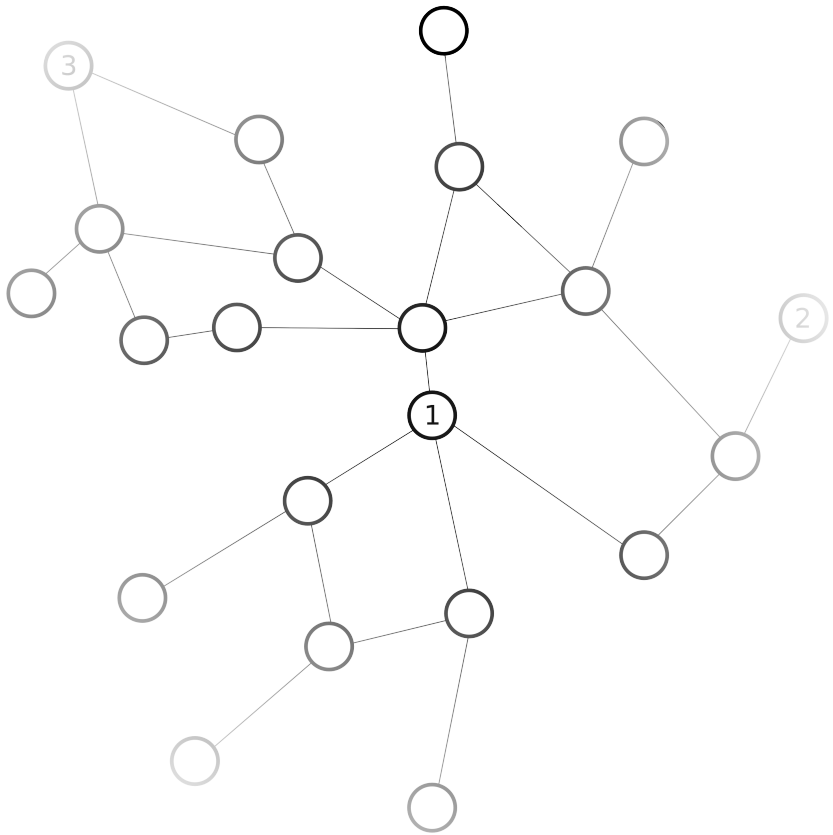
. . . to this



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- To obtain this effect, the TTL of the TC messages is not always to the maximum.
- a sequence of TTL can be used to control the diffusion of TC messages, for instance {2,4,16}
- Doing this, the first TC message will be sent only to nodes that are 2-hops away, the second to nodes that are 4-hops away, the third to all the nodes in the network
- Periodically every node receives enough information to build all the routing table, but the information is more accurate (it is fresher) for closer nodes

Fisheye

- With Fisheye, the total overhead cease to be *linear* with the number of MPR nodes
- How to define the TTL sequence is an open issue

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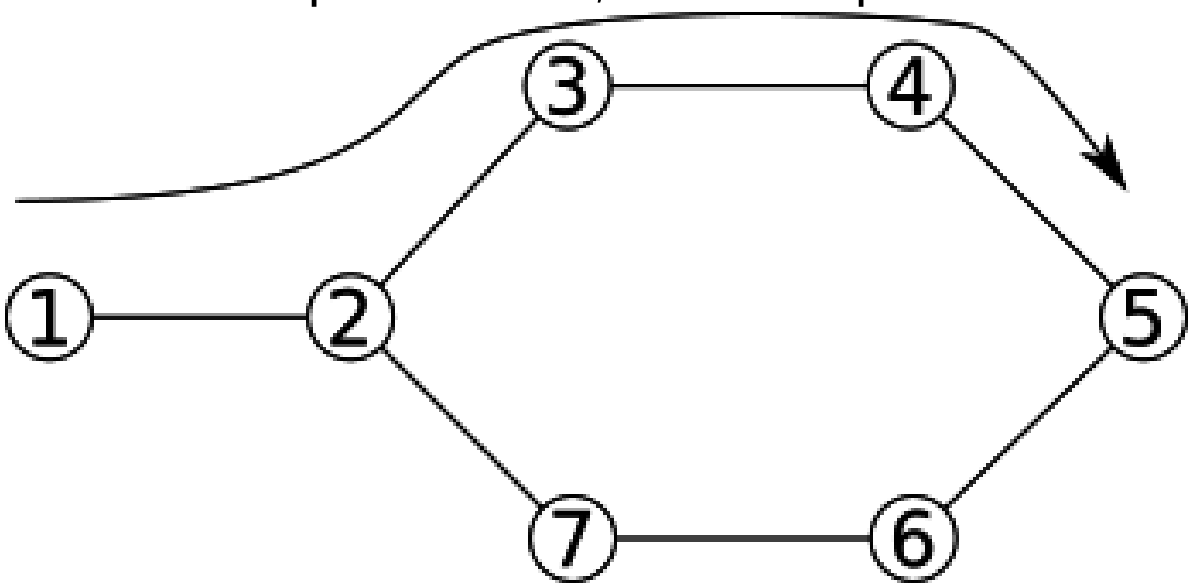
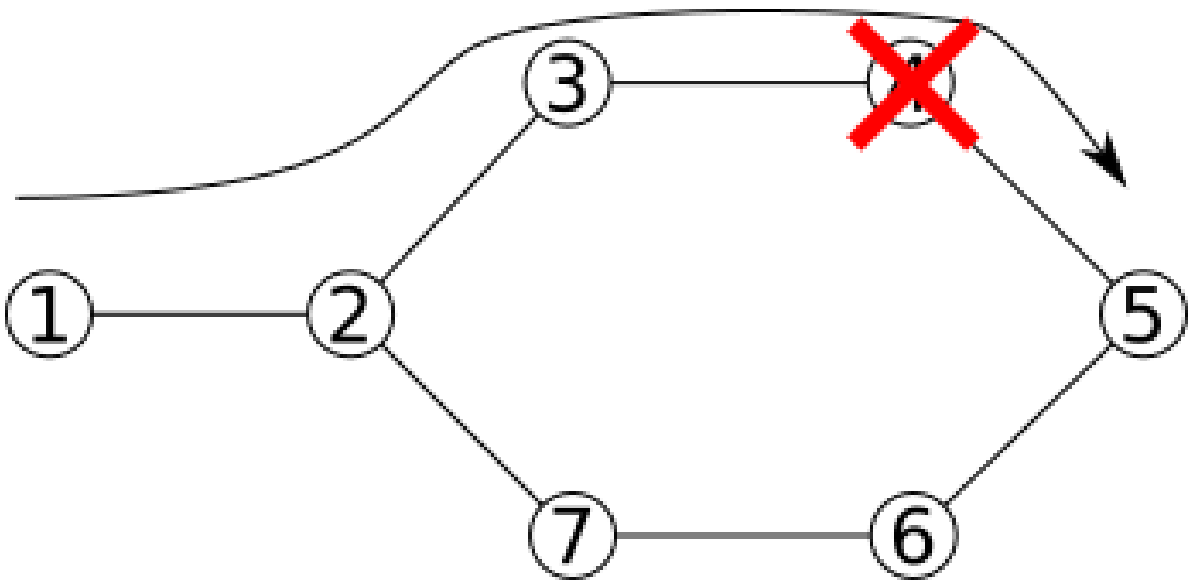
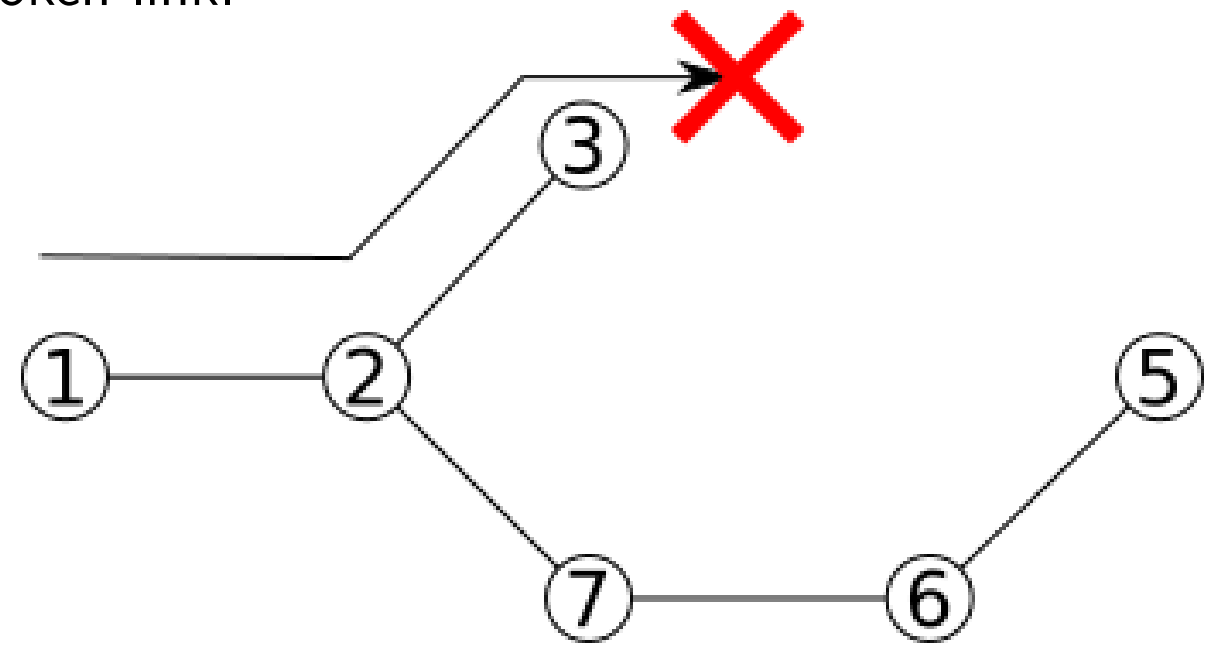
Let's consider this simple network, with the path 1-5 as shown:



Imagine node 4 breaks



Up to when node 3 does not sense the broken link, packets are lost on the broken link.



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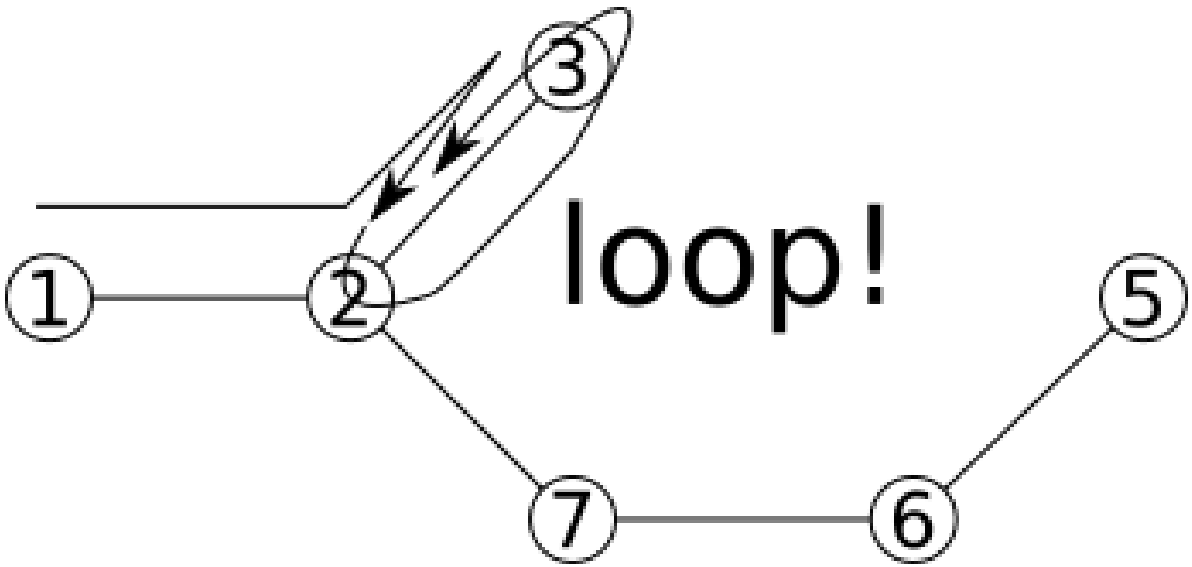
When node 3 looses enough HELLOs from 4, it will recalculate its own path to node 5.



Node 2 still doesn't know that node 4 died, a loop is created!

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- The loop is due to the fact that node 3 and node 2 have a different knowledge of the network topology
- Node 3 in fact receives HELLOs from node 4 with a higher frequency than node 2 receives TCs.

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- But this is what Fisheye does all the time!
- Fisheye create regions of nodes with different (more or less updated) knowledge of the topology.
- Nodes in the border between regions can create loops.