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It sends a packet to the intended destination, but with an artificially small time-to-live

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Repeat for increasing values of TTL to get the entire route

```
% traceroute mary.bath.ac.uk
traceroute to mary.bath.ac.uk (138.38.32.14), 30 hops max, 46 byte packets
 1  136.159.7.1 (136.159.7.1)  0.779 ms  1.131 ms  0.642 ms
 2  136.159.28.1 (136.159.28.1)  1.369 ms  0.910 ms  1.489 ms
 3  136.159.30.1 (136.159.30.1)  2.339 ms  1.937 ms  0.988 ms
 4  136.159.251.2 (136.159.251.2)  1.458 ms  1.071 ms  1.831 ms
 5  192.168.47.1 (192.168.47.1)  1.434 ms  1.554 ms  1.008 ms
 6  192.168.3.25 (192.168.3.25)  29.192 ms  30.094 ms  25.374 ms
 7  REGIONAL2.tac.net (205.233.111.67)  25.413 ms  33.002 ms  32.677 ms
 8  * * *
 9  * 117.ATM3-0.XR2.CHI6.ALTER.NET (146.188.209.182)  82.403 ms  58.747 ms
10  190.ATM11-0-0.GW4.CHI6.ALTER.NET (146.188.209.149)  56.376 ms  67.898 ms  7
11  if-4-0-1-1.bb1.Chicago2.Teleglobe.net (207.45.193.9)  66.853 ms  46.089 ms
12  if-0-0.core1.Chicago3.Teleglobe.net (207.45.222.213)  48.817 ms *  75.093 m
13  if-8-1.core1.NewYork.Teleglobe.net (207.45.222.209)  106.198 ms  94.249 ms
14  ix-5-3.core1.NewYork.Teleglobe.net (207.45.202.30)  75.286 ms  89.873 ms  9
15  us-gw.ja.net (193.62.157.13)  143.686 ms  159.212 ms  166.020 ms
16  external-gw.ja.net (193.63.94.40)  172.803 ms  189.216 ms  191.260 ms
17  external-gw.bristol-core.ja.net (146.97.252.58)  206.403 ms  185.438 ms  19
18  bristol.bweman.site.ja.net (146.97.252.102)  196.685 ms  206.221 ms  183.76
19  man-gw-2.bwe.net.uk (194.82.125.210)  197.968 ms *  174.809 ms
20  bath-gw-1.bwe.net.uk (194.82.125.198)  209.307 ms  221.512 ms  199.168 ms
21  * * *
22  mary.bath.ac.uk (138.38.32.14)  250.670 ms *  186.400 ms
```

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Hop 8: no error packet was received for this TTL. There are many possible reasons, e.g., on a long route it is possible the router is setting an initial TTL on the reply that is too small to reach us

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Hop 8: no error packet was received for this TTL. There are many possible reasons, e.g., on a long route it is possible the router is setting an initial TTL on the reply that is too small to reach us

An increasingly common possibility is that the router refuses to send ICMP errors for TTL exceeded in a weak attempt at security

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Exercise Traceroute usually sends out UDP packets as probes, while some implementations use ICMP pings, while others use TCP SYNs. Find out why

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Eight bytes contains the interesting parts of the next layer headers (in particular the ports of UDP and TCP) and this will be enough to identify which outgoing packet this is a reply to

ICMPv6

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Exercise Read about this and compare with ARP

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So how do the routers do that?

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- And so on (c.f., the TOS field in IP)

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At one point, there was a law in Canada that said all traffic that starts and ends in Canada must never leave Canada. Even if it would be cheaper and faster to go via the USA, say

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Very different requirements, with exterior protocols mostly driven by politics and economics

Host Routing

We should revisit small routing tables:

Destination	Gateway	Genmask	Flags	Metric	Ref	Use	Iface
213.121.147.69	*	255.255.255.255	UH	0	0	0	ppp0
172.18.0.0	*	255.255.0.0	U	0	0	0	eth0
172.17.0.0	*	255.255.0.0	U	0	0	0	eth1
127.0.0.0	*	255.0.0.0	U	0	0	0	lo
default	213.121.147.69	0.0.0.0	UG	0	0	0	ppp0

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The destination address on a packet is ANDed with each netmask (`Genmask`) in turn: if the result is equal to the `Destination`, route via the given interface

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Use the first match moving from the longest mask to the shortest: top to bottom in this table

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- M: this entry was modified by an ICMP *redirect*

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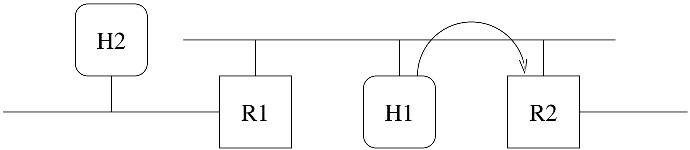
In this context, DHCP is regarded as "setting by hand"

However, sometimes routing tables are not perfectly set up

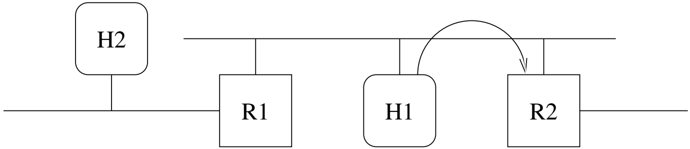
Host Routing



ICMP Redirect

H1 wants to send to H2 but H1's routing table tells it to route via R2;

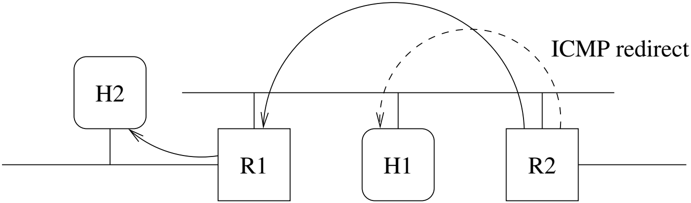
Host Routing



ICMP Redirect

When the packet reaches R2, R2 sees it should be routed out on the interface it came in on: so R2 knows H1's table needs improving;

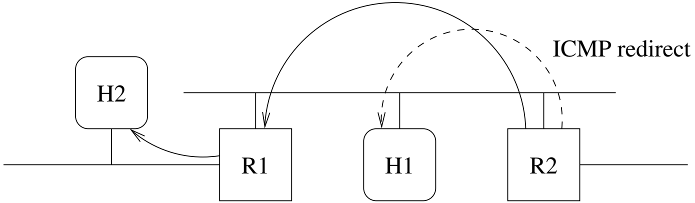
Host Routing



ICMP Redirect

R2 forwards the packet to R1 and sends an ICMP *redirect* to H1;

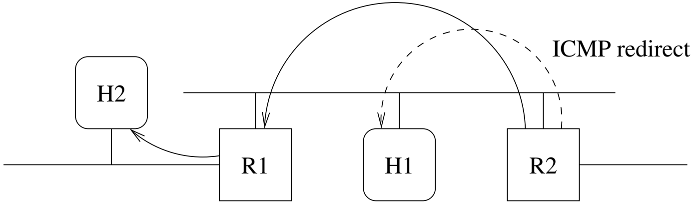
Host Routing



ICMP Redirect

H1 gets the redirect and uses it to update its routing table. The route will be marked D or M;

Host Routing



ICMP Redirect

Next time H1 will be able to route directly to R1

Routing

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Dynamic routing is the passing of routing information between routers

Dynamic Routing

There are many dynamic routing protocols:

- Routing Information Protocol (RIP)
- Open Shortest Path First (OSPF)
- Border Gateway Protocol (BGP)
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- And so on

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Each protocol is suited to a certain purpose, no single protocol fits all

Dynamic Routing

We start at routing the top level, namely the Internet. Local networks have different requirements

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We start at routing the top level, namely the Internet. Local networks have different requirements

The Internet is managed as a collection of *Autonomous Systems* (AS), each administered by a single entity, e.g., a University or company

Between ASs run *exterior gateway protocols* (EGP), currently BGP and formerly EGP (now obsolete)

Each AS chooses a suitable routing protocol to direct packets *within* itself: these might be interior gateway protocols, e.g., RIP and OSPF. Large institutions might even run BGP internally and have their own internal ASs

BGP

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Top-level routers will need an entry in their tables for each AS

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In fact JANET runs BGP internally. Bath has internal AS64857 within JANET

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- distance-vector protocols
- link-state protocols

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  - distance-vector
  - path-vector
- link-state protocols

And distance-vector is usually sub-divided into distance-vector and path-vector

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Distance-vector gathers collections (vectors) of hop counts (distances) from its neighbouring routers to selected destinations. From this it computes its own vector of distances

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Link-state is more complex, but has advantages

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A message would be “My view of the network is this. . . ” in the case of link-state

Or “I know a route to this destination using this number of hops” in the case of distance vector

Routing

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For example, in distance vector:

- suppose a router knows a route (i.e., the next hop router) for a given destination of a given number n of hops
- it receives a message from another neighbour that includes a route of m hops to that destination
- if $m + 1 < n$ it can update its route to now go through that neighbour, as that is a shorter (fewer hops) route