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And talk about IPv6 later

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“best-effort”: no guarantee of delivery, or of any special features, like quality of service

“connectionless”: each packet is independent of all others, there is no relationship between individual packets (in this layer)

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But, first, some vocabulary

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These are not mutually exclusive: gateways and routers can be hosts; gateways do trivial routing

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It should really mean “a box that engages in routing protocols”

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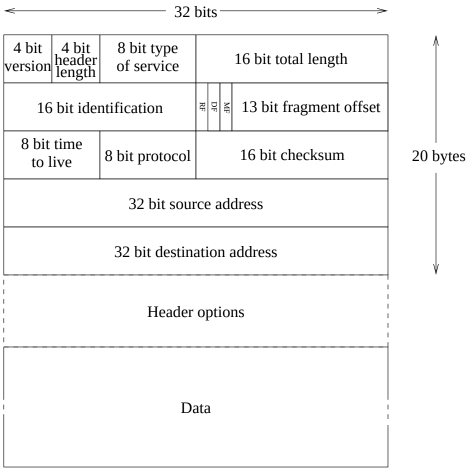
We return to the IP header

IP



IPv4 datagram header

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E.g., for audio it is better to get data through quickly rather than 100% reliably as the human ear is more sensitive to gaps than occasional errors

IP

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- Minimise delay. Do not hold onto this datagram longer than necessary, and perhaps prioritise it over others

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- Minimise cost. For this datagram cost is more important than reliability or speed. This datagram can be delayed if it makes transmission cheaper

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Exercise Look up the problems *Explicit Congestion Notification* (ECN) had when it was introduced

IP

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As usual, larger packet sizes mean lower overheads:

- Time overhead in hosts of splitting data into datagrams, adding headers, then removing headers and reassembling
- Bandwidth overhead as each header is 20 or more bytes that is not data; plus more gaps between datagrams
- Time overhead in routers of processing packets

IP

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Thus we get better independence from the MAC/PHY layers

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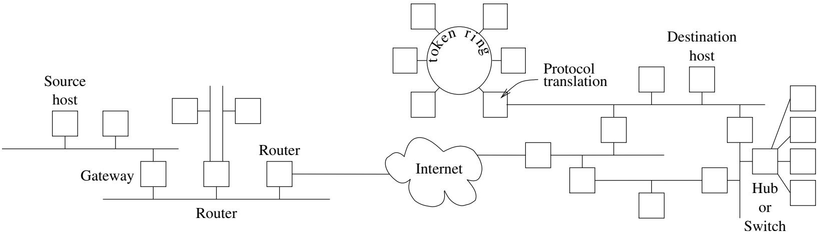
So we need to discuss fragmentation

IP

Fragmentation



Many kinds of hardware in the Internet

The path a packet takes from source to destination will typically go through a wide variety of differing kinds of hardware

IP

Fragmentation

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Thus IP must face the problem of differing link layer properties, in particular maximum frame size

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The fragmentation fields in the IP header deal with this

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3. MF. More fragments. All fragments except the end fragment have this set

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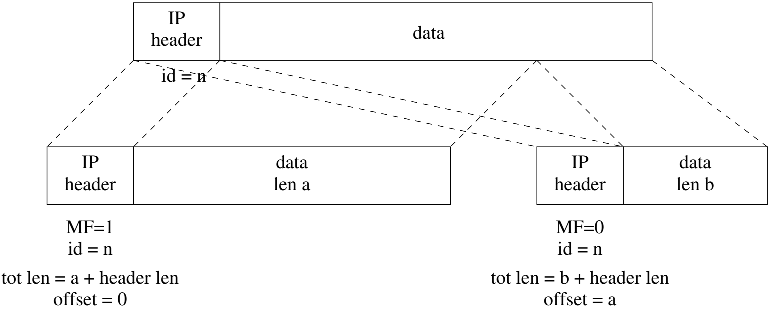
Fragment Offset. Where this fragment came from in the original datagram



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Note that a datagram may be split into any number of smaller fragments, not just two

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In more detail: each fragment header will be a copy of the original header apart from

- total length: set to the fragment size
- MF: set to 1 if this is not the end fragment
- fragment offset: set appropriately
- (TTL and checksum: set appropriately)

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Fragments are IP datagrams, so as always, they can arrive in any order; or not at all

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- More datagrams means a greater probability one will be lost or corrupted

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Exercise Consider what happens when a fragment is further fragmented. Differentiate the cases of $\mathrm{MF} = 0$ and $\mathrm{MF} = 1$

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Fragmentation is such a costly process that modern implementations try very hard to avoid it

They employ *MTU Discovery*

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MTU Discovery works by sending variously sized datagrams with DF set, and monitors the errors returned

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Note: a host is not required to implement MTU Discovery in IPv4: it's just good if it does as fragmentation is such a large overhead

IP

Back to the IPv4 header fields

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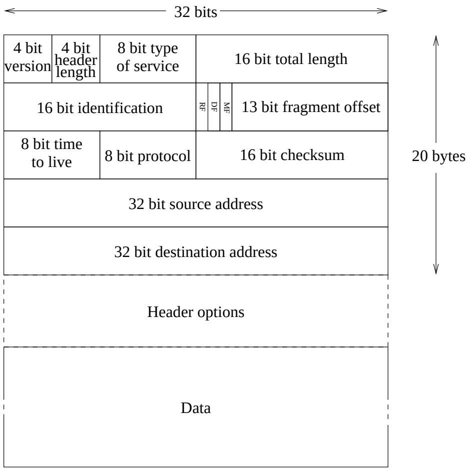

IPv4 datagram header

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The TTL starts at 64, or 32, say, and is reduced by one as it passes through each router

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The *width* of the Internet is the length of the longest path: this is uncertain and constantly changing but definitely over 32

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Exercise Why doesn't everyone simply put 255 into the TTL field?

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- Header checksum. As for the Ethernet header, this is a simple function of the bytes in the IP header. If the checksum is bad, the datagram is silently dropped. A higher layer must detect this and perform whatever action it needs. Recall that the IP layer is not guaranteed reliable

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Note the checksum includes the TTL field so it must be recomputed and rewritten in the datagram by each router the datagram passes through (this increases the time a router must spend on each datagram)

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We will come back to this very important problem later