Link Layer Protocols

We now turn to some other link layer protocols

Link Layer Protocols

We now turn to some other link layer protocols

Serial Line Internet Protocol (SLIP) is an early protocol used on modems to encapsulate IP traffic over serial (telephone) lines

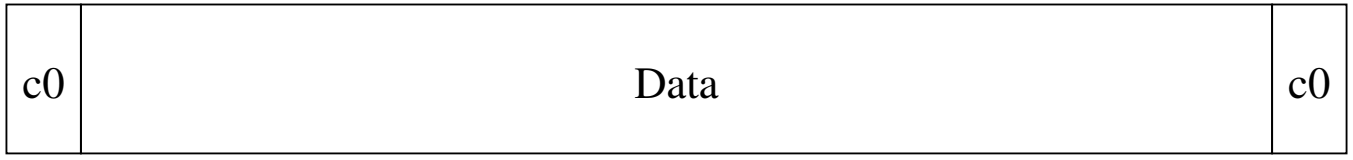
Link Layer Protocols

We now turn to some other link layer protocols

Serial Line Internet Protocol (SLIP) is an early protocol used on modems to encapsulate IP traffic over serial (telephone) lines

It is a *point-to-point* protocol, meaning it links just two machines to each other: the normal requirement in early dial-up systems

SLIP



SLIP frame

A very simple frame encapsulation with a terminating byte (hex) `c0`; also often a starting `c0` byte, too

SLIP

So how to send data that contains the byte `c0`?

SLIP

So how to send data that contains the byte `c0`?

Use *byte stuffing*

SLIP

So how to send data that contains the byte `c0`?

Use *byte stuffing*

To send `c0` actually send two bytes `db dc`

SLIP

So how to send data that contains the byte `c0`?

Use *byte stuffing*

To send `c0` actually send two bytes `db dc`

The pair `db dc` is reconstructed as `c0` at the other end

SLIP

So how to send data that contains the byte `c0`?

Use *byte stuffing*

To send `c0` actually send two bytes `db dc`

The pair `db dc` is reconstructed as `c0` at the other end

Stuff `db` as the pair `db dd`, which the other end reconstructs as `db`

SLIP

So how to send data that contains the byte `c0`?

Use *byte stuffing*

To send `c0` actually send two bytes `db dc`

The pair `db dc` is reconstructed as `c0` at the other end

Stuff `db` as the pair `db dd`, which the other end reconstructs as `db`

A minor expansion of data, but it enables transparent transmission of data

SLIP

There is no frame size limit, but it is suggested you should support at least 1006 bytes

SLIP

There is no frame size limit, but it is suggested you should support at least 1006 bytes

296 bytes was common (40 bytes of TCP/IP headers plus 256 bytes of data)

SLIP

There is no frame size limit, but it is suggested you should support at least 1006 bytes

296 bytes was common (40 bytes of TCP/IP headers plus 256 bytes of data)

Larger frames have relatively less overhead, but at 9600b/s (a typical early modem speed) 1006 bytes takes roughly 1 sec to transmit

SLIP

There is no frame size limit, but it is suggested you should support at least 1006 bytes

296 bytes was common (40 bytes of TCP/IP headers plus 256 bytes of data)

Larger frames have relatively less overhead, but at 9600b/s (a typical early modem speed) 1006 bytes takes roughly 1 sec to transmit

If there is a bulk transfer of full-sized frames at the same time as an interactive session, the interactive session's frames would have to wait 0.5 sec on average to get through, much too slow

SLIP

There is no frame size limit, but it is suggested you should support at least 1006 bytes

296 bytes was common (40 bytes of TCP/IP headers plus 256 bytes of data)

Larger frames have relatively less overhead, but at 9600b/s (a typical early modem speed) 1006 bytes takes roughly 1 sec to transmit

If there is a bulk transfer of full-sized frames at the same time as an interactive session, the interactive session's frames would have to wait 0.5 sec on average to get through, much too slow

An interactive response of over 100-200ms is felt to be slow

SLIP

296 is a compromise: not too slow for interactive, not too small for bulk transfer, but not particularly good for either

SLIP

296 is a compromise: not too slow for interactive, not too small for bulk transfer, but not particularly good for either

On more modern modems (56Kb/s) it was increased to 1500 bytes

SLIP

296 is a compromise: not too slow for interactive, not too small for bulk transfer, but not particularly good for either

On more modern modems (56Kb/s) it was increased to 1500 bytes

Exercise Compute the average latency for 296 byte frames on 9600b/s; and 1500 byte frames on 56Kb/s

Exercise And how big a frame could we have on a 10Mb/s Ethernet for the same latency?

SLIP

SLIP has several problems

SLIP

SLIP has several problems

Only IP in the next layer is supported (no type field in frame)

SLIP

SLIP has several problems

Only IP in the next layer is supported (no type field in frame)

The ends must have pre-agreed IP addresses: no mechanism for agreeing addresses

SLIP

SLIP has several problems

Only IP in the next layer is supported (no type field in frame)

The ends must have pre-agreed IP addresses: no mechanism for agreeing addresses

No checksum: telephone lines were noisy and created data corruption

SLIP

SLIP has several problems

Only IP in the next layer is supported (no type field in frame)

The ends must have pre-agreed IP addresses: no mechanism for agreeing addresses

No checksum: telephone lines were noisy and created data corruption

No authentication: no way to check *who* is connecting

PPP

Thus the *Point-to-Point Protocol* (PPP) was developed

PPP

Thus the *Point-to-Point Protocol* (PPP) was developed

Like SLIP it is a point to point protocol

PPP

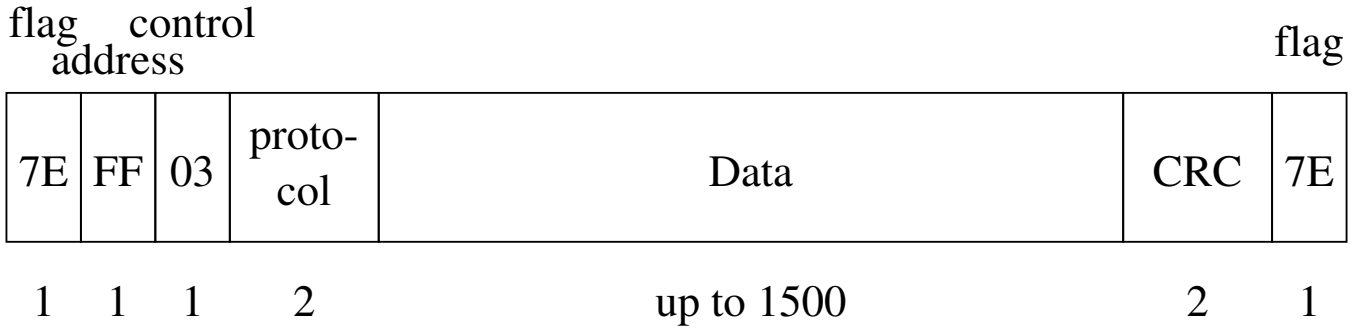
Thus the *Point-to-Point Protocol* (PPP) was developed

Like SLIP it is a point to point protocol

It has three parts

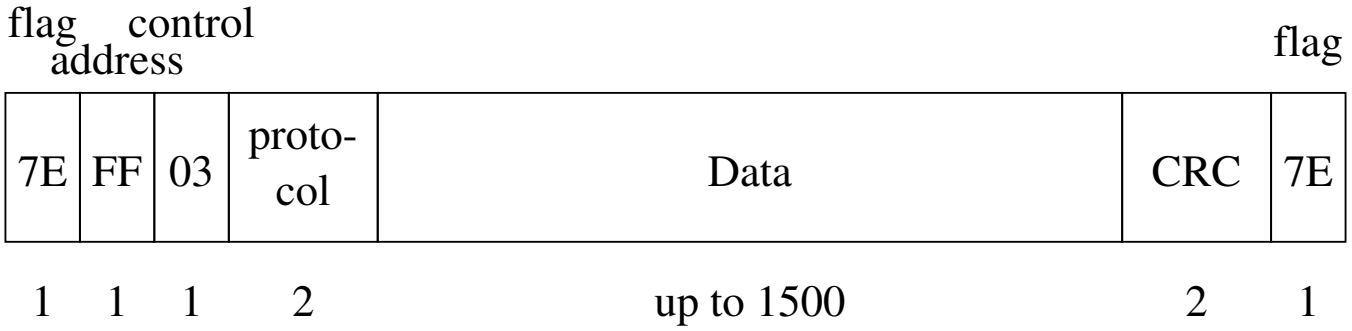
- A framing layout for packets
- A link control protocol (LCP) for managing and configuring links
- A set of network control protocols (NCP) to manage network layer specific options

PPP



PPP frame

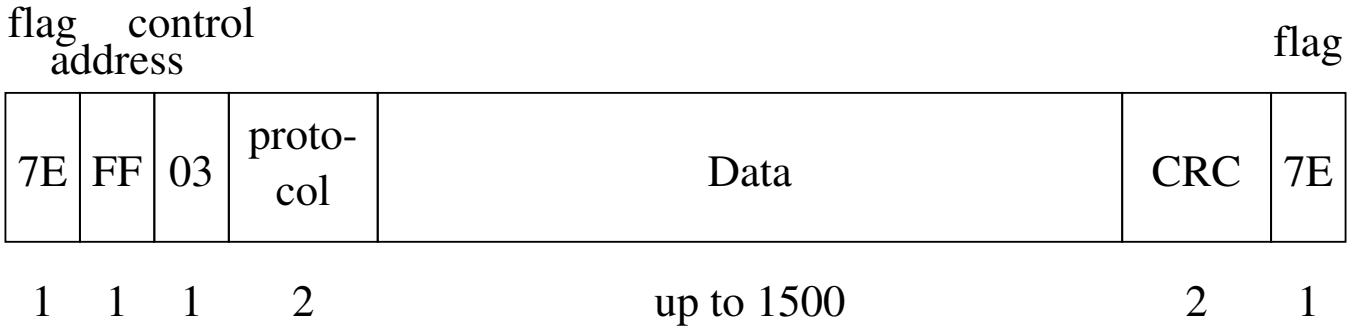
PPP



PPP frame

- Frame delimiters `7E`, start and end

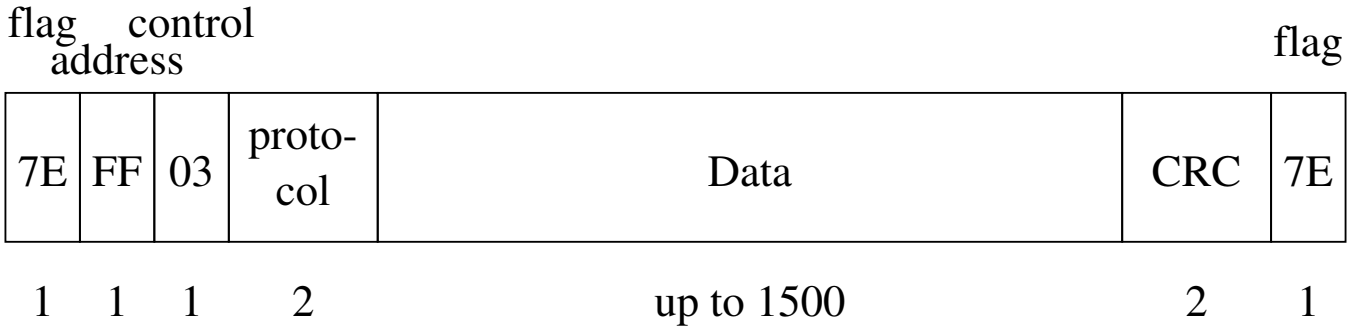
PPP



PPP frame

- Frame delimiters `7E`, start and end
- Address (always `ff`), Control (always `03`)

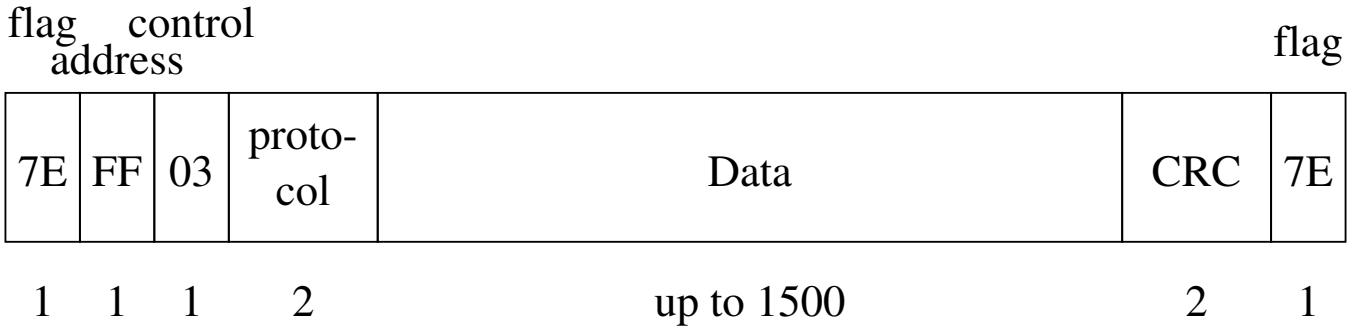
PPP



PPP frame

- Frame delimiters `7E`, start and end
- Address (always `ff`), Control (always `03`)
- Protocol: tells us what the next layer is, e.g., IP is `0021`, LCP is `C021` and NCPs are `80xy`

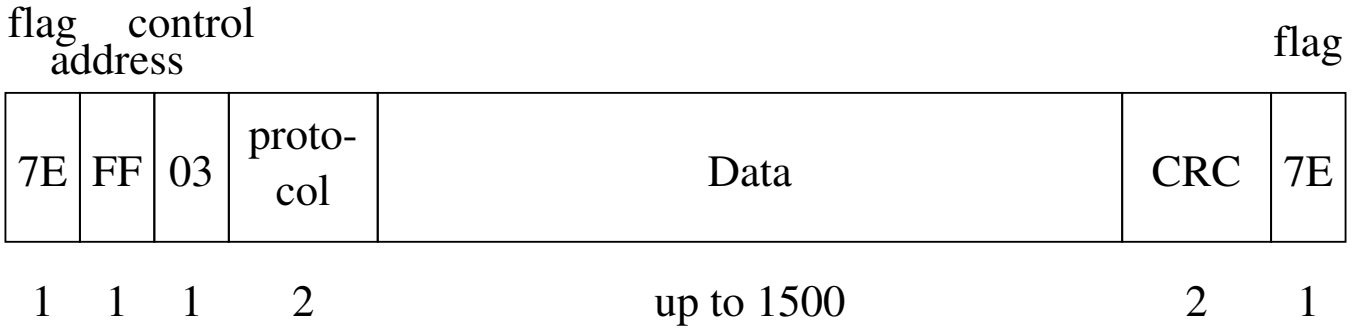
PPP



PPP frame

- Frame delimiters `7E`, start and end
- Address (always `ff`), Control (always `03`)
- Protocol: tells us what the next layer is, e.g., IP is `0021`, LCP is `C021` and NCPs are `80xy`
- Cyclic redundancy check to spot corruption

PPP



PPP frame

- Frame delimiters `7E`, start and end
- Address (always `ff`), Control (always `03`)
- Protocol: tells us what the next layer is, e.g., IP is `0021`, LCP is `C021` and NCPs are `80xy`
- Cyclic redundancy check to spot corruption
- But no address fields (**Exercise** why not?)

PPP

- Up to 1500 bytes of data (but can be negotiated)

PPP

- Up to 1500 bytes of data (but can be negotiated)
- Values are escaped (like SLIP) by `7d`

PPP

- Up to 1500 bytes of data (but can be negotiated)
- Values are escaped (like SLIP) by `7d`

- `7e` $\rightarrow$ `7d 5e`

PPP

- Up to 1500 bytes of data (but can be negotiated)
- Values are escaped (like SLIP) by `7d`

- `7e` $\rightarrow$ `7d 5e`
- `7d` $\rightarrow$ `7d 5d`

PPP

- Up to 1500 bytes of data (but can be negotiated)
- Values are escaped (like SLIP) by `7d`

- `7e` $\rightarrow$ `7d 5e`
- `7d` $\rightarrow$ `7d 5d`
- x, where $x < 20_{16}$ $\rightarrow$`7d` [x+`20`], so, e.g., `01`$\rightarrow$`7d 21`

PPP

NCPs can negotiate extras, like compression, frame size, etc.

PPP

NCPs can negotiate extras, like compression, frame size, etc.

And authentication, e.g., passwords

PPP

NCPs can negotiate extras, like compression, frame size, etc.

And authentication, e.g., passwords

While it was devised to be used over telephone modems, PPP is still actively used, e.g., in PPP over Ethernet (PPPoE) as it allows authentication of a connection

PPP

NCPs can negotiate extras, like compression, frame size, etc.

And authentication, e.g., passwords

While it was devised to be used over telephone modems, PPP is still actively used, e.g., in PPP over Ethernet (PPPoE) as it allows authentication of a connection

Current FTTC products use PPPoE over VDSL to pass authentication to the ISP

PPP

NCPs can negotiate extras, like compression, frame size, etc.

And authentication, e.g., passwords

While it was devised to be used over telephone modems, PPP is still actively used, e.g., in PPP over Ethernet (PPPoE) as it allows authentication of a connection

Current FTTC products use PPPoE over VDSL to pass authentication to the ISP

Exercise Read about this

PPP

NCPs can negotiate extras, like compression, frame size, etc.

And authentication, e.g., passwords

While it was devised to be used over telephone modems, PPP is still actively used, e.g., in PPP over Ethernet (PPPoE) as it allows authentication of a connection

Current FTTC products use PPPoE over VDSL to pass authentication to the ISP

Exercise Read about this

Exercise Look at the configuration of your home ADSL or VDSL “router”

Link Layers

Several other link layers exist: too many to talk about in any detail

Link Layers

Several other link layers exist: too many to talk about in any detail

We have already seen the Ethernet frame for a local area network

Link Layers

Several other link layers exist: too many to talk about in any detail

We have already seen the Ethernet frame for a local area network

There are many link layers for carrying data over long distances, at high data rates, both electrical and optical

Link Layers

For example, *Asynchronous Transfer Mode* (ATM) was popular for a while

Link Layers

For example, *Asynchronous Transfer Mode* (ATM) was popular for a while

Designed by telephone engineers, it was really a *connection oriented* digital voice network into which you could squeeze data packets

Link Layers

For example, *Asynchronous Transfer Mode* (ATM) was popular for a while

Designed by telephone engineers, it was really a *connection oriented* digital voice network into which you could squeeze data packets

Exercise Read about ATM and PPPoA, that layers (IP over) PPP over ATM, as used in ADSL and DOCSIS

Link Layers

Multiprotocol Label Switching (MPLS) was designed post-ATM when the technology decisions that drove the design of ATM were deemed no longer applicable

Link Layers

Multiprotocol Label Switching (MPLS) was designed post-ATM when the technology decisions that drove the design of ATM were deemed no longer applicable

Designed by network engineers to be a general long-distance network, it is much better suited to modern data networks

Link Layers

Multiprotocol Label Switching (MPLS) was designed post-ATM when the technology decisions that drove the design of ATM were deemed no longer applicable

Designed by network engineers to be a general long-distance network, it is much better suited to modern data networks

Exercise Read about MPLS and how BT uses it in its 21C Network

Networks

Ethernet Link Layer

We want to move up to the network layer: but before doing so there is one more remark on the link layer

Networks

Ethernet Link Layer

We want to move up to the network layer: but before doing so there is one more remark on the link layer

Recall Ethernet. The data on the wire:

Ethernet frame

Networks

Ethernet Link Layer

The interesting fields here are the *addresses*

Networks

Ethernet Link Layer

The interesting fields here are the *addresses*

The addresses allow a frame to identify the intended destination (and source)

Networks

Ethernet Link Layer

The interesting fields here are the *addresses*

The addresses allow a frame to identify the intended destination (and source)

This works well enough when the destination is on the local Ethernet network

Networks

Ethernet Link Layer

The interesting fields here are the *addresses*

The addresses allow a frame to identify the intended destination (and source)

This works well enough when the destination is on the local Ethernet network

Which is shared (or switched), so the frame has no problem being seen by the destination host

Networks

Ethernet Link Layer

What to do when the destination is non-local?

Networks

Ethernet Link Layer

What to do when the destination is non-local?

We can’t simply treat the world as a shared medium and broadcast the packet to everybody

Networks

Ethernet Link Layer

What to do when the destination is non-local?

We can't simply treat the world as a shared medium and broadcast the packet to everybody

And the network at the destination might not even be an Ethernet and will not have an Ethernet address

Networks

Ethernet Link Layer

What to do when the destination is non-local?

We can't simply treat the world as a shared medium and broadcast the packet to everybody

And the network at the destination might not even be an Ethernet and will not have an Ethernet address

So we need *hardware independent addresses* to identify hosts that work independently of the physical network

Networks

Ethernet Link Layer

What to do when the destination is non-local?

We can't simply treat the world as a shared medium and broadcast the packet to everybody

And the network at the destination might not even be an Ethernet and will not have an Ethernet address

So we need *hardware independent addresses* to identify hosts that work independently of the physical network

In the Internet Protocol, these addresses live in the network layer

Networks Link Layer

IP

The network layer used in the Internet Protocol is called the *Internet Protocol* (IP)

Networks Link Layer

IP

The network layer used in the Internet Protocol is called the *Internet Protocol* (IP)

It has the major function of dealing with *routing*, determining where a packet should go

Networks Link Layer

IP

The network layer used in the Internet Protocol is called the *Internet Protocol* (IP)

It has the major function of dealing with *routing*, determining where a packet should go

Amongst a lot of other stuff, the IP header has network layer addresses

Networks Link Layer

IP

The network layer used in the Internet Protocol is called the *Internet Protocol* (IP)

It has the major function of dealing with *routing*, determining where a packet should go

Amongst a lot of other stuff, the IP header has network layer addresses

These are hardware independent, and in the same format across the entire Internet

Networks

IP

Each host on the Internet has an IP address that identifies it uniquely over the entire Internet

Networks

IP

Each host on the Internet has an IP address that identifies it uniquely over the entire Internet

At least, that was the original intention

Networks

IP

Each host on the Internet has an IP address that identifies it uniquely over the entire Internet

At least, that was the original intention

This is certainly no longer true, for reasons we shall explore later

Networks

IP

Each host on the Internet has an IP address that identifies it uniquely over the entire Internet

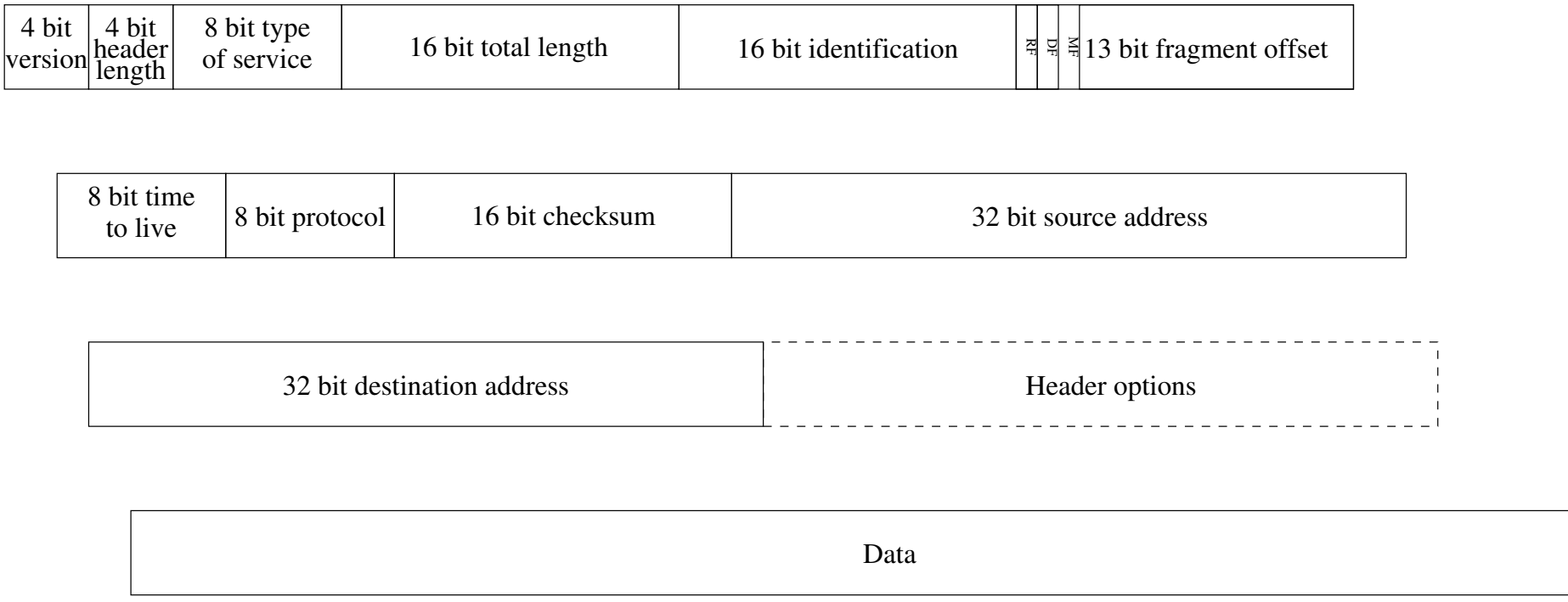
At least, that was the original intention

This is certainly no longer true, for reasons we shall explore later

But, for now, assume this is true

Networks

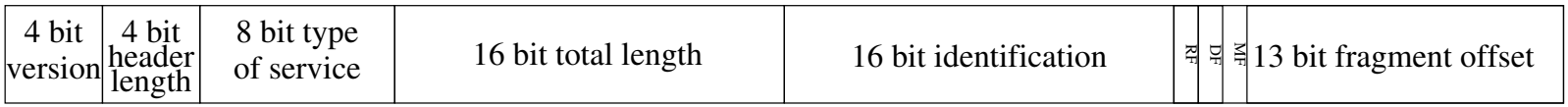
IP Header

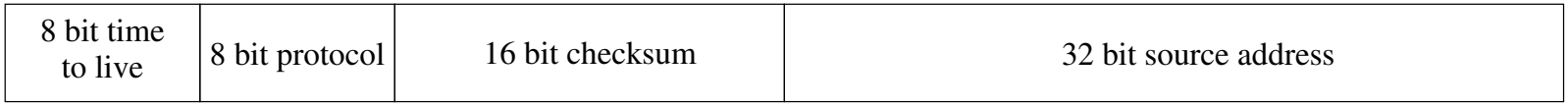


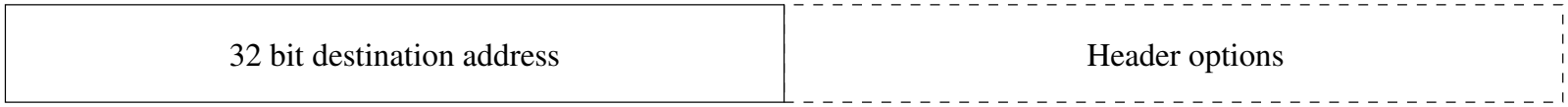
IP header (poor layout)

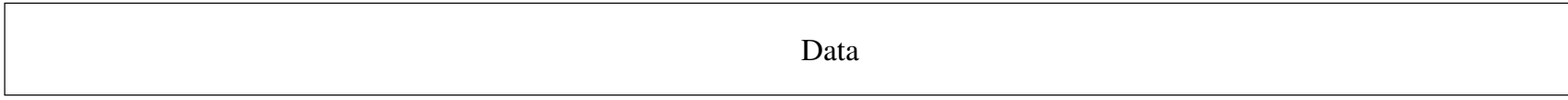
Networks

IP Header







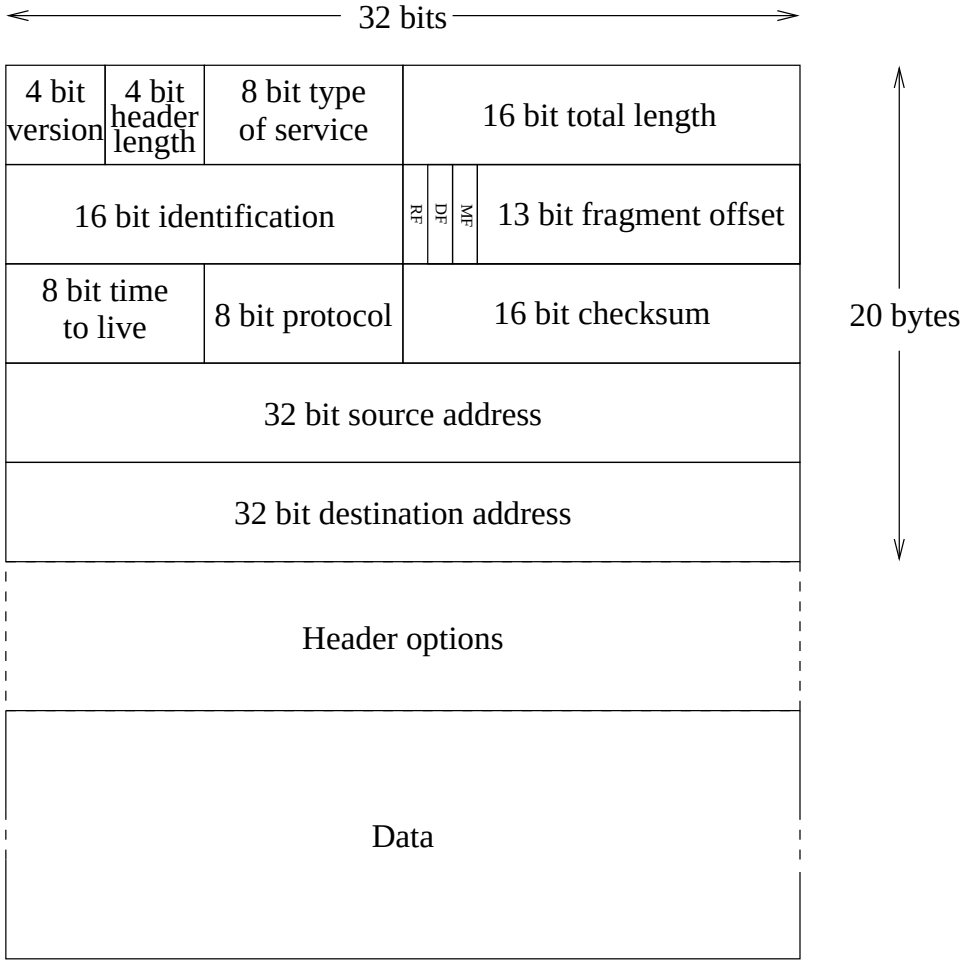


IP header (poor layout)

A bit hard to see, so conventionally we stack the header vertically

Networks

IP Header



IP header (usual layout)

Networks

IP

The source and destination addresses are both four bytes long: we shall come back to the other fields later

Networks

IP

The source and destination addresses are both four bytes long: we shall come back to the other fields later

`10001010001001100010000000001110` is an example IP address, a 32-bit value

Networks

IP

The source and destination addresses are both four bytes long: we shall come back to the other fields later

`10001010001001100010000000001110` is an example IP address, a 32-bit value

This is 2317754382 in decimal: not terribly easy to work with

Networks

IP

The source and destination addresses are both four bytes long: we shall come back to the other fields later

`10001010001001100010000000001110` is an example IP address, a 32-bit value

This is 2317754382 in decimal: not terribly easy to work with

So for convenience we write this as `138.38.32.14`, decimal representations of four 8-bit values. The dots are purely to make the number visually easier to read

Networks

IP

The source and destination addresses are both four bytes long: we shall come back to the other fields later

`10001010001001100010000000001110` is an example IP address, a 32-bit value

This is 2317754382 in decimal: not terribly easy to work with

So for convenience we write this as `138.38.32.14`, decimal representations of four 8-bit values. The dots are purely to make the number visually easier to read

But, importantly, there is *structure* in an IP address which helps with routing

Networks

IP

In this example, `138.38.32.14`. the first half `1000101000100110` (`138.38`) is a 16-bit *network* address, which identifies the University of Bath

Networks

IP

In this example, `138.38.32.14`. the first half `1000101000100110` (`138.38`) is a 16-bit *network* address, which identifies the University of Bath

And `32.14` is a 16-bit host address, which identifies a single machine on the University's network

Networks

IP

In this example, `138.38.32.14`. the first half `1000101000100110` (`138.38`) is a 16-bit *network* address, which identifies the University of Bath

And `32.14` is a 16-bit host address, which identifies a single machine on the University's network

Note that we write `138.38`, but this should really be thought of as `1000101000100110`, a bunch of 16 bits

Networks

IP

In this example, `138.38.32.14`. the first half `1000101000100110` (`138.38`) is a 16-bit *network* address, which identifies the University of Bath

And `32.14` is a 16-bit host address, which identifies a single machine on the University's network

Note that we write `138.38`, but this should really be thought of as `1000101000100110`, a bunch of 16 bits

Always remember that the dotted decimal notation is just a convenient way of writing a chunk of bits: there are no decimal numbers in the header!

Networks

IP

This division into network and host parts helps immensely in routing, as all packets destined for the University of Bath can be routed in the same manner

Networks

IP

This division into network and host parts helps immensely in routing, as all packets destined for the University of Bath can be routed in the same manner

Only when a packet reaches the University is some local knowledge of the network needed

Networks

IP

This division into network and host parts helps immensely in routing, as all packets destined for the University of Bath can be routed in the same manner

Only when a packet reaches the University is some local knowledge of the network needed

Indeed, the host part of this address splits further into *subnet* addresses that help local routing within the University

Networks

IP

This division into network and host parts helps immensely in routing, as all packets destined for the University of Bath can be routed in the same manner

Only when a packet reaches the University is some local knowledge of the network needed

Indeed, the host part of this address splits further into *subnet* addresses that help local routing within the University

But the main point for now is that this IP address is independent of Ethernet and so can be used regardless of the hardware used

Networks

IP

So we have hardware independent addresses: but, now, there is an new problem

Networks

IP

So we have hardware independent addresses: but, now, there is an new problem

Suppose I want to send a packet to `138.38.3.40` on the local network. My data is (ultimately) encapsulated in an IP packet, with my IP address as source and `138.38.3.40` as the destination

Networks

IP

So we have hardware independent addresses: but, now, there is an new problem

Suppose I want to send a packet to `138.38.3.40` on the local network. My data is (ultimately) encapsulated in an IP packet, with my IP address as source and `138.38.3.40` as the destination

(The question of how do we know the destination IP address must be answered later)

Networks

IP

So we have hardware independent addresses: but, now, there is an new problem

Suppose I want to send a packet to `138.38.3.40` on the local network. My data is (ultimately) encapsulated in an IP packet, with my IP address as source and `138.38.3.40` as the destination

(The question of how do we know the destination IP address must be answered later)

Now the IP packet must be further encapsulated in a hardware frame, Ethernet in this example. The OS can't send the packet on the physical medium until it knows the Ethernet address of the destination

Networks

IP

Ethernet does not know about IP addresses: it can carry any kind of data

Networks

IP

Ethernet does not know about IP addresses: it can carry any kind of data

IP does not know about Ethernet addresses: it can run on many kinds of hardware

Networks

IP

Ethernet does not know about IP addresses: it can carry any kind of data

IP does not know about Ethernet addresses: it can run on many kinds of hardware

And this separation of layers, as we know, is desirable

Networks

IP

We need some kind of *address discovery*, so given the IP address we can find the corresponding Ethernet address

Networks

IP

We need some kind of *address discovery*, so given the IP address we can find the corresponding Ethernet address

This is done by the *Address Resolution Protocol* (ARP)

Networks

IP

We need some kind of *address discovery*, so given the IP address we can find the corresponding Ethernet address

This is done by the *Address Resolution Protocol* (ARP)

ARP is a very simple link-layer protocol that essentially broadcasts a special frame on the local medium to the effect of "who has IP address `138.38.3.40`?"

Networks

IP

We need some kind of *address discovery*, so given the IP address we can find the corresponding Ethernet address

This is done by the *Address Resolution Protocol* (ARP)

ARP is a very simple link-layer protocol that essentially broadcasts a special frame on the local medium to the effect of "who has IP address `138.38.3.40`?"

All hosts on the local network hear this broadcast and the host with that address replies "Me: and I have Ethernet address `08:00:20:9a:34:dd`"

Networks

IP

We need some kind of *address discovery*, so given the IP address we can find the corresponding Ethernet address

This is done by the *Address Resolution Protocol* (ARP)

ARP is a very simple link-layer protocol that essentially broadcasts a special frame on the local medium to the effect of "who has IP address `138.38.3.40`?"

All hosts on the local network hear this broadcast and the host with that address replies "Me: and I have Ethernet address `08:00:20:9a:34:dd`"

(Another security problem...)

Networks

IP

The OS gets the ARP reply and can now use this information to write the correct address in the Ethernet frame

Networks

IP

The OS gets the ARP reply and can now use this information to write the correct address in the Ethernet frame

Only now can the original packet be sent

Networks

IP

We don't want to use ARP for *every* packet we send, so there is an ARP cache kept by the OS kernel that records the relation

`138.38.3.40` $\leftrightarrow$ `08:00:20:9a:34:dd`

Networks

IP

We don't want to use ARP for *every* packet we send, so there is an ARP cache kept by the OS kernel that records the relation
`138.38.3.40` $\leftrightarrow$ `08:00:20:9a:34:dd`

Entries in the cache time out and are removed after, say, 20 minutes

Networks

IP

We don't want to use ARP for *every* packet we send, so there is an ARP cache kept by the OS kernel that records the relation `138.38.3.40` $\leftrightarrow$ `08:00:20:9a:34:dd`

Entries in the cache time out and are removed after, say, 20 minutes

This is in case the host using `138.38.3.40` goes away and is replaced by a different host with the same IP address, but a different Ethernet address: recall IP addresses are *not* associated with the hardware

Networks

IP

We don't want to use ARP for *every* packet we send, so there is an ARP cache kept by the OS kernel that records the relation `138.38.3.40` $\leftrightarrow$ `08:00:20:9a:34:dd`

Entries in the cache time out and are removed after, say, 20 minutes

This is in case the host using `138.38.3.40` goes away and is replaced by a different host with the same IP address, but a different Ethernet address: recall IP addresses are *not* associated with the hardware

Once expired, the next packet to `138.38.3.40` will need a fresh ARP