Internet Protocol (IP): Packet Format, Fragmentation, Options

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- **IP features**
- **IP datagram format**
- **Fragmentation**
- **IP options**

Ref: RFC 791, Chap 3, 11.5-11.8, Lab 1

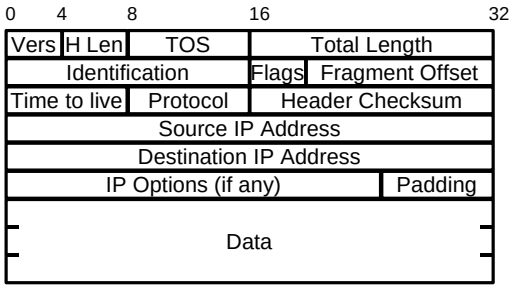
IP Features

- **Connectionless service**
- **Addressing**
- **Data forwarding**
- **Fragmentation and reassembly**
- **Supports variable size datagrams**
- **Best-effort delivery: Delay, out-of-order, corruption, and loss possible. Higher layers should handle these.**
- **Provides only "Send" and "Delivery" services Error and control messages generated by Internet Control Message Protocol (ICMP)**

What IP does NOT provide

- **End-to-end data reliability & flow control (done by TCP or application layer protocols)**
- **Sequencing of packets (like TCP)**
- **Error detection in payload (TCP, UDP or other transport layers)**
- **Error reporting (ICMP)**
- **Setting up route tables (RIP, OSPF, BGP etc)**
- **Connection setup (it is connectionless)**
- **Address/Name resolution (ARP, RARP, DNS)**
- **Configuration (BOOTP, DHCP)**
- **Multicast (IGMP, MBONE)**

IP Datagram Format



IP Datagram Format

- First Word purpose: info, variable size header & packet.
  - Version (4 bits)
  - Internet header length (4 bits): *units of 32-bit words.* Min header is 5 words or 20 bytes.
  - Type of service (TOS: 8 bits): Reliability, precedence, delay, and throughput. Not widely supported
  - Total length (16 bits): header + data. *Units of bytes.* Total must be less than 64 kB.

IP Header (Cont)

- 2nd Word Purpose: fragmentation
  - Identifier (16 bits): Helps uniquely identify the datagram between any source, destination address
  - Flags (3 bits): More Flag (MF):more fragments
    Don't Fragment (DF)
    Reserved
  - Fragment offset (13 bits): *In units of 8 bytes*

IP Header (Cont)

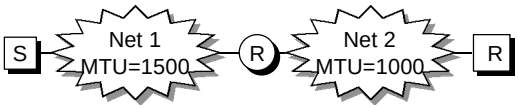
- Third word purpose: demuxing, error/looping control, timeout.
  - Time to live (8 bits): Specified in router hops
  - Protocol (8 bits): Next level protocol to receive the data: for de-multiplexing.
  - Header checksum (16 bits): 1's complement sum of all 16-bit words in the header.
    - Change header => modify checksum using 1's complement arithmetic.
- Source Address (32 bits): Original source. Does not change along the path.

Header Format (contd)

- Destination Address (32 bits): Final destination. Does not change along the path.
- Options (variable length): Security, source route, record route, stream id (used for voice) for reserved resources, timestamp recording
- Padding (variable length):
  Makes header length a multiple of 4
- Payload Data (variable length): Data + header $\leq$ 65,535 bytes

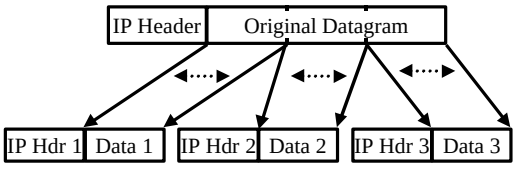
Maximum Transmission Unit

- Each subnet has a maximum frame size
  Ethernet: 1518 bytes
  FDDI: 4500 bytes
  Token Ring: 2 to 4 kB
- Transmission Unit = IP datagram (data + header)
- Each subnet has a maximum IP datagram length (header + payload) = MTU

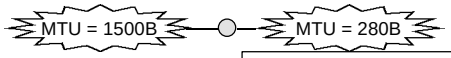


Fragmentation

- Datagrams larger than MTU are fragmented
- Original header is copied to each fragment and then modified (fragment flag, fragment offset, length,...)
- Some option fields are copied (see RFC 791)



Fragmentation Example



IHL = 5, ID = 111, More = 0
Offset = 0W, Len = 472B

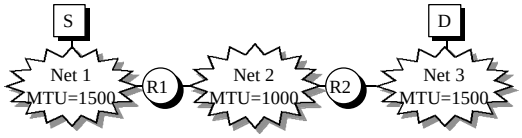
IHL=5, ID = 111, More = 1
Offset = 0W, Len = 276B

IHL=5, ID = 111, More = 0
Offset = 32W, Len = 216B

- Payload size 452 bytes needs to be transmitted across a Ethernet (MTU=1500B) and a SLIP line (MTU=280B)
- Length = 472B, Header = 20B => Payload = 452B
- Fragments need to be multiple of 8-bytes.
  - Nearest multiple to 260 (280 -20B) is 256B
  - First fragment length = 256B + 20B = 276B.
  - Second fragment length = (452B- 256B) + 20B = 216B

Reassembly

- Reassembly only at the final destination
- Partial datagrams are discarded after a timeout
- Fragments can be further fragmented along the path. Subfragments have a format similar to fragments.
- Minimum MTU along a path ⇒ Path MTU



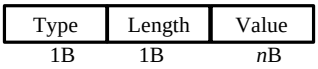
Further notes on Fragmentation

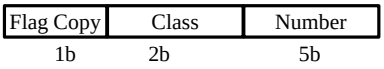
- Performance: single fragment lost => entire packet useless. Waste of resources all along the way. Ref: Kent & Mogul, 1987
- Don't Fragment (DF) bit set => datagram discarded if need to fragment. ICMP message generated: may specify MTU (default = 0)
- Used to determine Path MTU (in TCP & UDP)
- The transport and application layer headers do not appear in all fragments. Problem if you need to peep into those headers.

IP Protocol Numbers

Decimal	Key word	Protocol
0		Reserved
1	ICMP	Internet Control Message Protocol
2	IGMP	Internet Group Management Protocol
4	ST	Stream Protocol
5	TCP	Transmission Control Protocol
8	EGP	Exterior Gateway Protocol
9	IGP	Interior Gateway Protocol
17	UDP	User Datagram Protocol

IP Options Coding



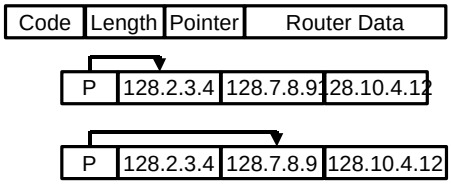


- **Flag Copy: 0 = Copy the option only into the first fragment of a fragmented datagram**
  1 = Copy into all fragments
- **Class: 0 =User or control, 1=Reserved, 2=Diagnostics, 3=reserved**

IP Options

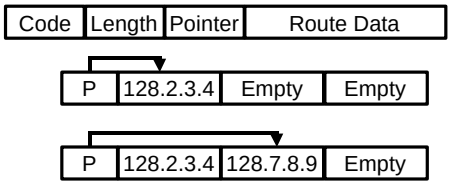
Class	Number	Length	Description
0	0	0	End of Options
0	1	0	No Op
0	2	11	Security
0	3	Var	Loose Source Routing
0	7	Var	Record Route
0	8	4	Stream ID (obsolete)
0	9	Var	Strict Source Routing
2	4	Var	Internet Time-Stamp

IP Source Routing



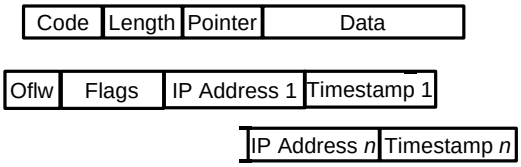
- **Loose Source Routing (LSSR): Specify partial route list**
- **Strict Source Routing: Specify full route.**

Route Recording



- **Need to allow enough space to record IP addresses on route. Datagram size does not change as it goes through internet.**

Timestamp Option



- **Record timestamps along route**
- **Overflow (Oflw) counter incremented if out of space**
- **Flags: allows some further options for flexibility**

Discussion on IP Header Design

- **If fragmentation is going to be avoided all the time, why not have the 4-bytes of fragmentation info as an IP option ?**
- **Is 32-bit addresses going to be enough ?**
- **Why mess with variable length headers ? Can the variability in header length be controlled to allow better encoding ?**
- **Are the IP options really that useful ? Why variable length option headers ?**
- **Many of these issues addressed in IPv6.**

Summary

- **IP header: supports connectionless delivery, variable length pkts/headers/options, fragmentation/reassembly,**
- **Fragmentation/Reassembly, Path MTU discovery.**
- **Options: Source routing, Record route, Timestamp**