IPv6 Header Compression

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Outline

- ➢ **Introduction**

- **Background on IETF Hop-by-Hop Header Compression Mechanisms**
  - Fundamentals of Header Compression
  - Header Compression Algorithms
  - Commercial Applications
  - General Header Compression Considerations

- **Extension of Header Compression to Backbones and Mobile Ad Hoc Networks**
  - Motivation and Challenges of Applying Traditional HC Algorithms to Backbones
  - Backbone-Applicable Adaptations to Header Compression Techniques
  - Motivation and Application of HC Algorithms to MANETs
  - Considerations with the Application of HC Algorithms to MANETs

- **Summary**

Introduction

- **Internet Protocol version 6 (IPv6) provides extended features compared to IPv4**
  - Extended address space
  - Enhanced mobility
- **With the DoD’s move to IPv6, migration plans from legacy IPv4 networks to IPv6 networks are beginning to take shape**
- **Implementation of IPv6 introduces concerns related to expanded packet headers**
  - Packet header size doubled from 20 Bytes (IPv4) to at least 40 Bytes (IPv6)
  - Incorporation of network-layer encryption mechanism (i.e., Internet Protocol Security, or IPsec) nearly doubles IP operational overhead
  - Undesirable for many wireless and SATCOM networks, which are already bandwidth constrained
  - IPv6 in the low bandwidth/mobile environment identified as a “transition challenge” by Marilyn Kraus at the December 2003 NAIPv6 Summit
- ***Methods that reduce this expanded overhead will increase user throughput and/or the number of users a network can support***

Benefits of Reducing Header Size

- **Given the need to reduce overhead, simplified calculations can highlight the benefits of header compression**

1 Mbps packet throughput

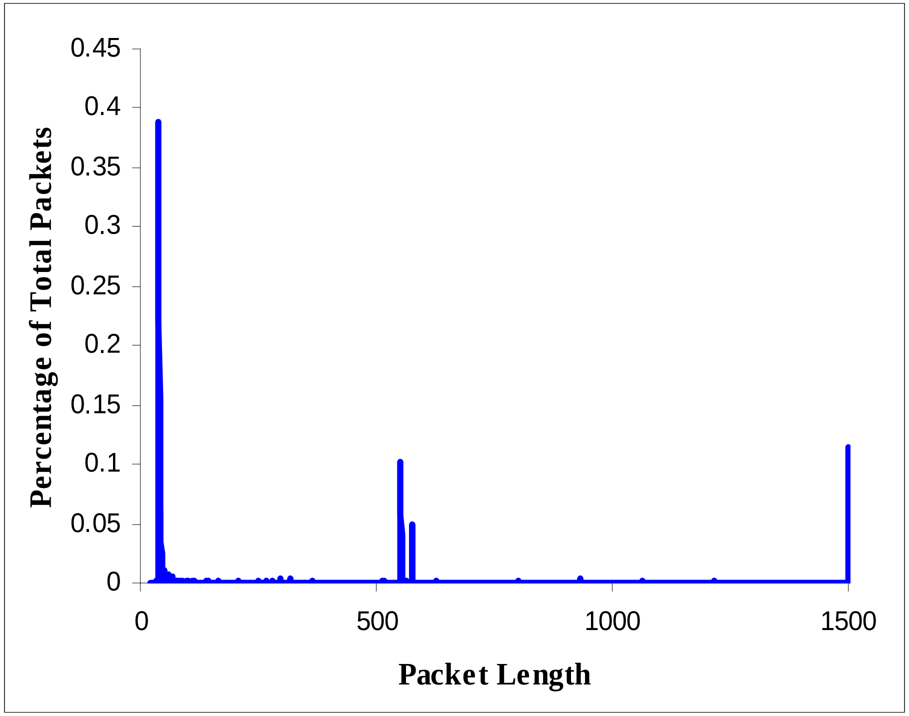
- Scenario A: ***40 Byte IPv6 Header***
  - Constant 20 Byte packet payloads
  - ~2083 packets sent per second transmitted across link
  - Over a 1 second period, ~666 kb transmitted is IPv6 overhead, ~333 kb transmitted is actual user data (i.e., 66% of data transmitted is overhead)

- Scenario B: ***2 Byte Compressed Header***
  - Constant 20 Byte packet payloads
  - ~5680 packets sent per second
  - Over a 1 second period, ~90 kb transmitted is IPv6 overhead, ~910 kb transmitted is actual user data (i.e., 9% of data transmitted is overhead)

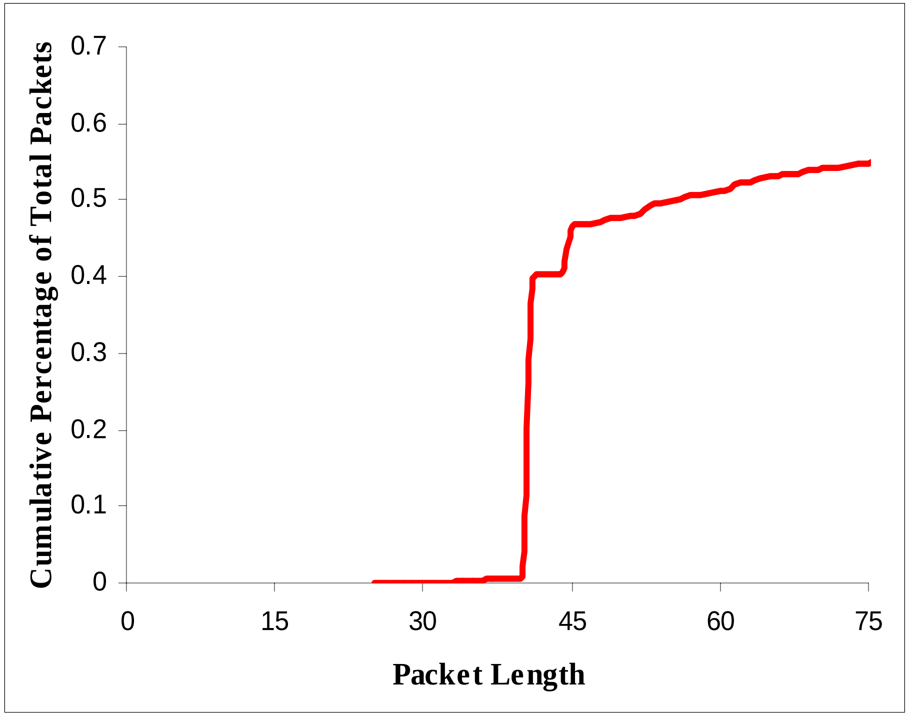
Under The Best Case Scenario, HC Can Theoretically Decrease Header Overhead By 95%

Packet Profiles In the Internet

- **Data values below are taken from a 1 minute IPv4 packet trace performed on an OC-3 link on MCI’s backbone**



(a) Packet length probability distribution function



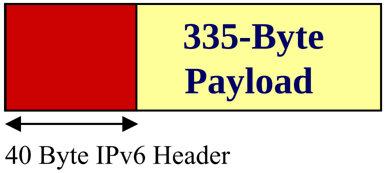
(b) Packet length cumulative distribution function

- **As shown, 40% of packets that traverse the Internet are 40 bytes in length**
- **In IPv6, headers will expand by 20 bytes**
  - Significant percentage of the total packet, as a 40 byte header will be used to transport 20 bytes of payload

Source: Data values taken from http://www.nlanr.net/NA/Learn/packetsizes.html

Numerical Application of Simplified Header Compression to Internet Traffic

- **Distribution of packet lengths from Internet adjusted according to IPv6**
  - Average packet length in previous slide calculated to be ~355 bytes (Header and Payload)
  - Average packet length increases by 20 bytes for IPv6 header



- **Assuming that no header compression is applied, IP header overhead is calculated as follows:**
  - $\text{Overhead} = \frac{\text{IP Header Bytes}}{\text{Total Bytes Transmitted}} = \frac{\text{40 Bytes}}{\text{375 Bytes}} = \boxed{\text{10.67 \% overhead}}$

- **Assuming header compression algorithm is applied to the ESP/IP header, overhead calculations can be made:**
  - Assuming header size is reduced to 2 bytes per packet
  - $\text{\% Overhead} = \frac{\text{Compressed Header Bytes}}{\text{Total Bytes Transmitted}} = \frac{\text{2 Bytes}}{\text{337 Bytes}} = \boxed{\text{0.59 \% overhead}}$

Compression of IP Packet Headers Alone Provides ~10% Increase in System Throughput

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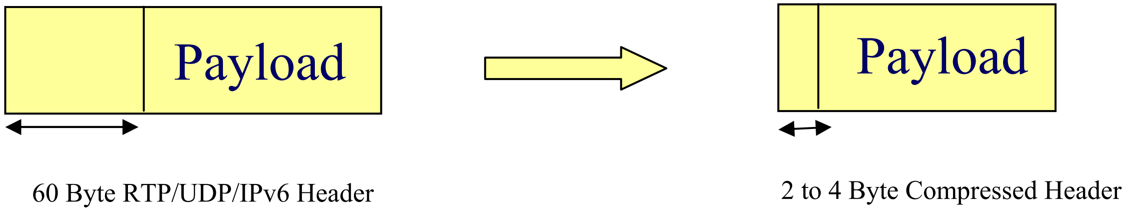
Background

- **Citing the need to reduce the size of IP headers, the IETF has led the development of HC algorithms**

- **In general, HC solutions provide reduction in the operational overhead required by protocols**
  - Compression applied to Layer 3 (IP) and several Layer 4 protocol headers
  - For example, RTP/UDP/IPv6 headers can be compressed from 60 bytes to 2-4 bytes

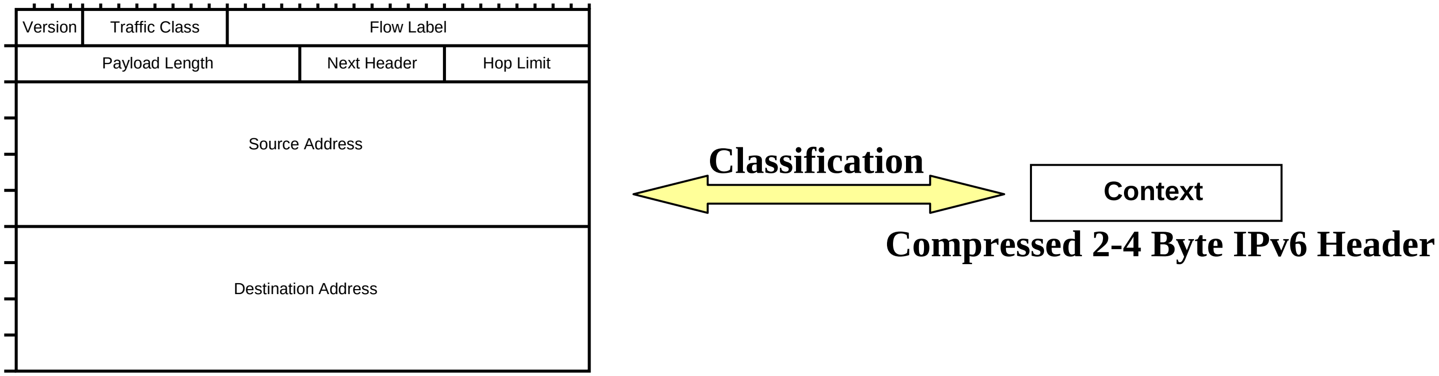


- **HC solutions can reduce the additional overhead introduced by network-layer encryption mechanisms (e.g., IPSec)**
  - Compression algorithms instantiated on encryption/decryption devices have the ability to:
    - Compress inner headers before encryption
    - Compress outer ESP/IP headers after encryption

Header Compression Fundamentals

- **Compression is applied over a link between a source node (i.e., compressor), and a destination node (i.e., decompressor)**

- **HC algorithms exploit protocol inter-packet header field redundancies to improve overall efficiency**



Version
Traffic Class
Flow Label
Payload Length
Next Header
Hop Limit
Source Address
Destination Address

Original 40-Byte IPv6 Header

Classification

Context

Compressed 2-4 Byte IPv6 Header

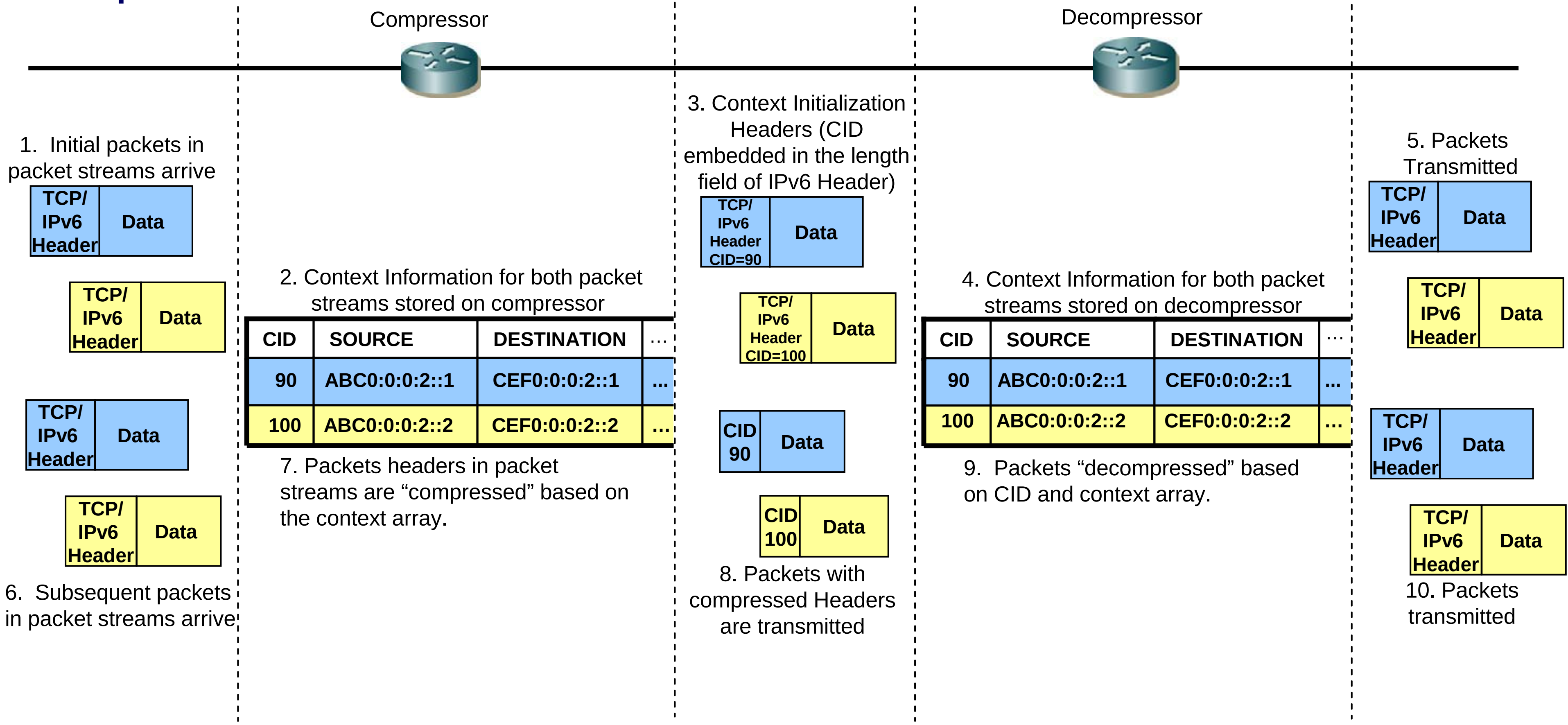
- **Both compressor and decompressor store header fields of each packet stream, and associate each stream with a context identifier (CID)**

- **Upon reception of a packet with an associated context, the compressor removes the IPv6 header fields from packet header and appends a CID**

- **Upon reception of a packet with a CID, the decompressor inserts IPv6 header fields back into packet header and transmits packet**

Header Compression Operation

- **Diagram below illustrates initialization and operation of header compression protocols**



1. Initial packets in packet streams arrive

6. Subsequent packets in packet streams arrive

2. Context Information for both packet streams stored on compressor

CID	SOURCE	DESTINATION	…
90	ABC0:0:0:2::1	CEF0:0:0:2::1	...
100	ABC0:0:0:2::2	CEF0:0:0:2::2	...

7. Packets headers in packet streams are “compressed” based on the context array.

3. Context Initialization Headers (CID embedded in the length field of IPv6 Header)

8. Packets with compressed Headers are transmitted

4. Context Information for both packet streams stored on decompressor

CID	SOURCE	DESTINATION	…
90	ABC0:0:0:2::1	CEF0:0:0:2::1	...
100	ABC0:0:0:2::2	CEF0:0:0:2::2	...

9. Packets “decompressed” based on CID and context array.

5. Packets Transmitted

10. Packets transmitted

Reduction In The Number Of Full Headers Transmitted Can Result In Overall Decreased Overhead

Header Compression Algorithms

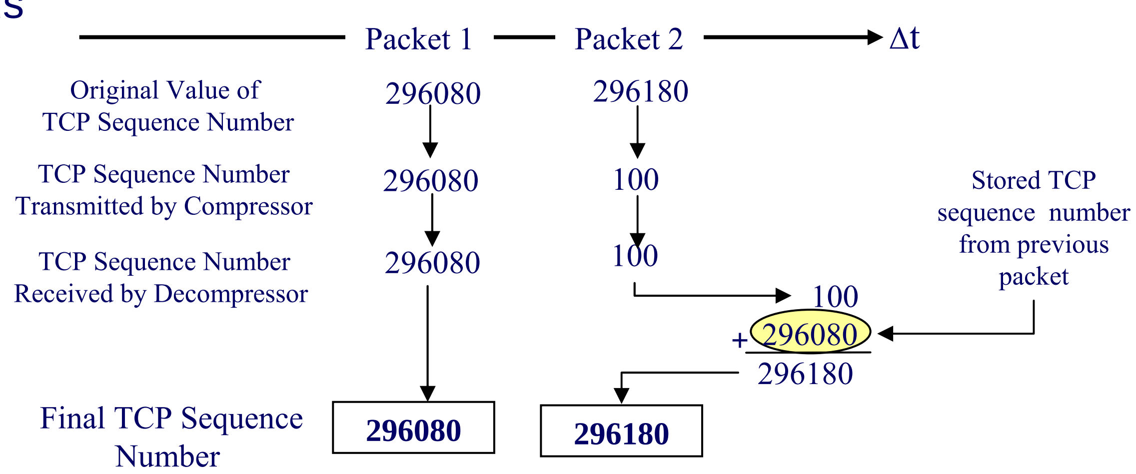
- **Two compression protocols emerged from the IETF**

- **Internet Protocol Header Compression (IPHC)**
  - HC scheme designed for low bit error rate links
  - Compression profiles defined in [RFC 2507] and [RFC 2508]
  - Compression of TCP/IP, UDP/IP, RTP/UDP/IP, and ESP/IP headers
    - “Enhanced” Compression of RTP/UDP/IP (ECRTP) headers defined in [RFC 3545]

- **ROHC Working Group: Robust Header Compression (ROHC)**
  - HC scheme designed for wireless links
    - ***Provides greater compression compared to IPHC at the cost of greater implementation complexity***
    - More suitable for high BER, long RTT links
  - Compression profiles defined in [RFC 3095] and [RFC 3096]
  - Compression of ESP/IP, UDP/IP, RTP/UDP/IP headers
    - Profile for compression of TCP/IP headers currently in IETF internet draft stages

Overview of IPHC

- **Fundamental basics of IPHC algorithm detailed in the previous slide**
- **Mechanisms that facilitate compression of dynamic header fields exist (e.g., TCP sequence numbers)**
  - Delta-based differential encoding mechanism provides compression of incremental header fields



Packet 1 Packet 2 Δt

Original Value of TCP Sequence Number: 296080 296180

TCP Sequence Number Transmitted by Compressor: 296080 100

TCP Sequence Number Received by Decompressor: 296080 100

Stored TCP sequence number from previous packet

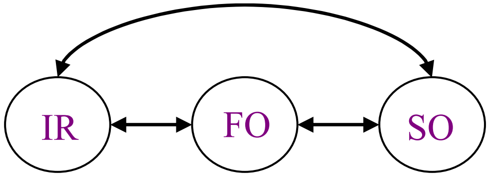
100
+ 296080
296180

Final TCP Sequence Number: **296080** **296180**

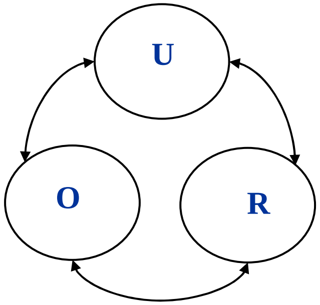
  - However, if sequential packets are lost, compressor-decompressor contexts will desynchronize
  - Resynchronization depends on how quickly the compressor notices desynchrnoization
    - For example, by peeking into the TCP sequence number, and noticing a retransmission
  - Compressor reestablishes context by transmitting a full header
- **IPHC algorithm performs poorly over high BER, long RTT links [Degermark et. Al]**

Overview of ROHC

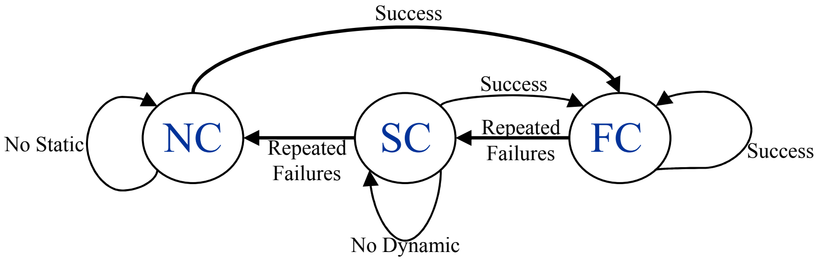
- **Fundamental basics of ROHC detailed in the previous slide**
- **ROHC provides improved header compression over IPHC in high bit error rate (BER), and high round-trip time wireless links [5]**
    - Benefits come at a cost, as ROHC implementation is significantly more complex than IPHC



Compressor States



Modes of Operation

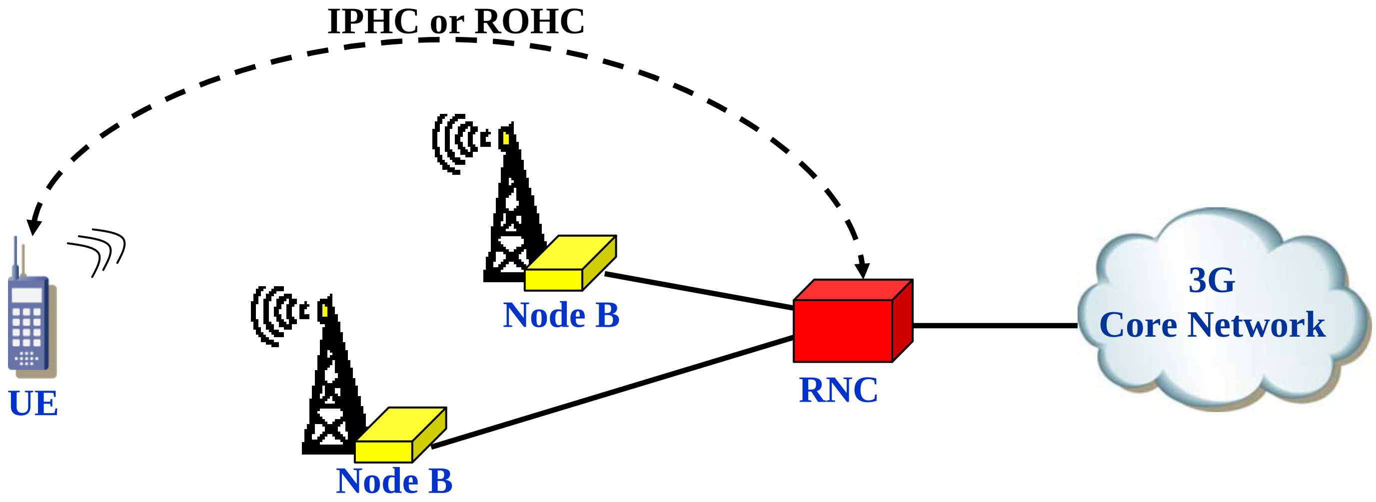


Decompressor States

-
    - Details of state machines (e.g., logic at each state, state transitions, etc.) are left to [RFC 3095]
    - ROHC incorporates enhanced mechanisms compared to IPHC
        - Implementation flexibility—capability to compress headers with or without a feedback mechanism
        - Improved compression ratios
            - Equipped with the ability to compress, for example, TCP SYN and FIN messages and timestamps
            - Optimized encoding schemes (e.g., Window-based Least Significant Bit (W-LSB))
- **Provides greater compression compared to IPHC at the cost of greater implementation complexity**

Commercial Applications of Header Compression

- **Application of HC in commercial networks is rare**
- **Cisco Systems router Internetwork Operating System (IOS) provides IPHC implementation**
- **Both IPHC and ROHC are Specified in Release 4 and Release 5 of the 3rd Generation Partnership Project (3GPP)**
  - Function of the Packet Data Convergence Protocol (PDCP)
  - PDCP specification applies HC between the Radio Network Controller (RNC) and the User Endpoint (UE)



  - Version 6.0 specifies context relocation during a Service Radio Network Subsystem (SRNS) relocation, between two RNCs (only for ROHC)

General Header Compression Considerations

- **Incorporation of HC between two nodes places restrictions on underlying link layer**
  - IPv6 payload length must be inferred from the underlying link layer
  - Decompressor must receive the packets in the same order that the compressor sends them
  - Packets are not duplicated by the link layer between the compressor and decompressor
  - RFC 3241, RFC 3544 defines PPP extensions for realizing ROHC and IPHC over PPP, respectively

- **HC requires extra resources on nodes that instantiate the compression algorithms**
  - Additional memory required on nodes for storage of context information
  - Additional processing required on nodes for compression and decompression of packets

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Motivation for Header Compression in Network Backbones

- **The amount of traffic that flows through a commercial backbone network provides motivation for HC in Wide Area Networks (WAN)**

- **With the increased utilization of voice and video over IP, a significant amount of backbone resources will be devoted to packet overhead**
  - On a VoIP WAN, 300 million calls per day could consume on the order of about 20-40 Gbps for headers alone [Ash et. Al]

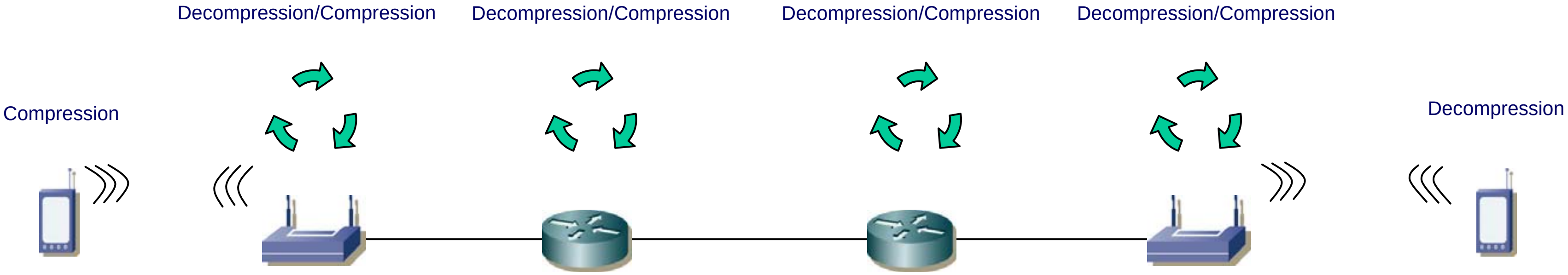
- **Overprovisioning provides an expensive solution for increasing transport network bandwidth**
  - Requires a core transport network bandwidth upgrade
  - Translates to increased end-user cost

- **In most hybrid communication networks, overprovisioning is not an option**

Challenges Associated With Implementing HC in IP Backbones

- **Scalability issues in core network nodes**
  - Large number of contexts hampers performance of core network nodes
    - Significant memory requirements to store contexts
    - Significant processing requirements to compress/decompress packets

- **E2E packet path may include several compression-decompression cycles**
  - Extra compression/decompression cycles in core network may increase packet delay



Recent Internet-Drafts In The IETF Attempt To Modify Standard, Per-Hop, HC Techniques To Solve These Challenges

IETF Requirements for HC over Multiple Hop Paths in MPLS Backbones

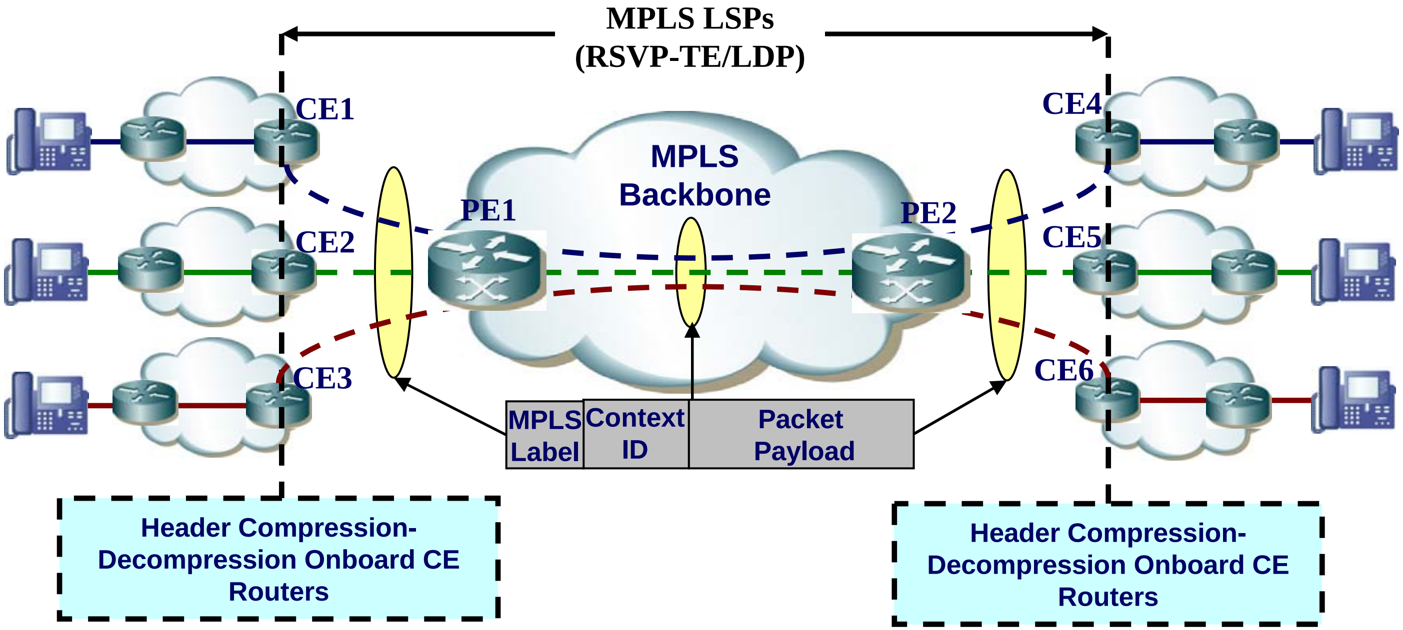
- **Recent drafts in the IETF are defining requirements to adapt header compression schemes over multiple hop paths**

- **<draft-ietf-avt-hc-mpls-reqs-00.txt>, April 2004**
  - Authored by J. Ash (AT&T), B. Goode (AT&T), J. Hand (AT&T) and R. Zhang (Infonet)
  - Describes motivation for header compression over multiple-hop paths
    - A multiple-hop header compression scheme would eliminate the drawbacks associated with multiple compression-decompression cycles in core networks
  - Goal is to resolve core network implementation issues associated with header compression

- **[Ash et. Al] requires that multi-hop header compression techniques must:**
  - Be independent of existing compression algorithms (e.g., IPHC, ROHC, ECRTP)
  - Allow HC over an MPLS LSP, thereby avoiding hop-by-hop compression/decompression cycles
  - Allow use of standard protocols to signal context identification and control information (e.g., [RSVP], [RSVP-TE], [LDP])
  - Minimize incremental performance degradation due to increased delay, packet loss and jitter introduced by HC

[Ash. et Al]: Header Compression Over Multiple Hops in MPLS Backbones

- **Diagram below illustrates the envisioned application of HC at customer edge devices, through MPLS label switching between CE devices**



  - RSVP-TE or LDP used to establish LSPs between CE routers with (de) compression being performed at the CE routers
  - Packet with compressed header is switched from CE1 to CE2 according to LSP

- **Leverages MPLS LSPs to navigate packet with compressed header through MPLS backbone, alleviating core network from (de)compression processing**

- **Internet-Draft <draft-ash-avt-ecrtp-over-mpls-protocol-01.txt>, May 2004**
  - Defines protocol extensions for ECRTP over MPLS LSPs using RSVP-TE between CE routers

Challenges of Backbone-Applicable Multi-Hop Header Compression

- **[Ash et al.] mentions several issues that need to be resolved to achieve HC over multiple hops**
  - Protocol extensions are required
    - Header compression algorithms (e.g., ROHC, IPHC)
    - Extensions to MPLS signaling to negotiate:
      - HC algorithm used
      - HC protocol parameters
      - Session context ID (SCID) space
  - Resynchronization of compression algorithms over multiple hops, as HC algorithms are designed for application on a hop-by-hop basis
  - Scalability of extending MPLS to CE networks, in terms of LSP signaling mechanisms (i.e., LDP, RSVP-TE, etc.)
  - Packet reordering issues which increase probability of context desynchrnoization

Header Compression and MANETs

- **Mobile Ad Hoc Networking Goal [RFC 2501]**
  - "… to extend mobility into the realm of autonomous, mobile, wireless domains where a set of nodes … form the network routing infrastructure in an ad-hoc fashion."

- **MANETs are multi-hop networks that are self-organizing, rapidly-changing, and dynamic**
  - Do not require the support of a fixed infrastructure
    - Eliminates the need for home agents

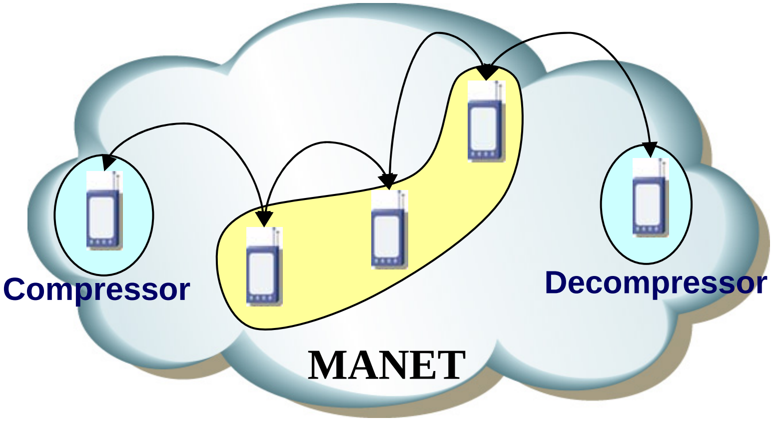
- **MANET node resource constraints include**
  - Bandwidth
  - Processing
  - Power

- **Use of header compression algorithms can increase throughput in bandwidth-constrained ad-hoc networks**
  - *Reduction in the number of transmitted bits reduces the probability that a packet will be dropped due to a bit error*

Application of HC to MANETs

- **Hop by hop header compression applicable on point to point ad-hoc links**

- **Multiple-hop header compression schemes can be utilized to achieve end-to-end MANET bandwidth efficiency**
  - Reduces the overhead transmitted through intermediate node(s)



- **Suggest applying ROHC, which is designed for high BER links**

- **Operational Mode for ROHC in MANETs**
  - Unidirectional mode (i.e., no feedback) provides a simple solution to achieve HC in MANETs – no new logic needed to be added to the states
  - Bi-directional modes (i.e., feedback) will offer a greater compression, but will introduce signaling into the MANET between compressor/decompressor
    - May require modification to state logic specified in RFC 3095

Considerations with the Application of HC Algorithms to MANETs

- **Hop by hop HC schemes**
  - Undesirable to apply hop-by hop HC schemes to achieve end-to-end HC, as it requires compression/decompression cycles on intermediate nodes

- **Multiple-hop HC schemes**
  - MPLS-based multiple-hop HC scheme unfeasible
    - Possibly identify a “lighter” way to achieve end to end header compression (?)
  - Intermediate nodes frequently entering and leaving MANET should not be included in end to end compression schemes
  - IPv6 Traffic Class header field issues
    - Intermediate routers need to know the Differential Service Code Point (DSCP) values to enforce Quality of Service
    - Intermediate routers marking of Explicit Congestion Notification (ECN) bits

- **Context management in a mobile network**
  - Volatile nature of ad hoc networks requires more advanced schemes for managing contexts between compressor and decompressor

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- **Traditional Header compression techniques provide savings in protocol operational overhead**
  - Applied to a link, on a per-hop basis

- **Application of hop-by-hop header compression techniques to backbones is rare**
  - To achieve compression through Provider network, multiple compression-decompression cycles required
  - Scalability and resource issues on core network nodes

- **New developments in the IETF provide framework for applying header compression over multiple-hops to backbone networks**
  - Internet-Draft applies header compression techniques to MPLS backbones
  - Idea of multiple-hop HC can be applied to MANETs to increase efficiency over bandwidth-constrained links
    - In implementing header compression in a MANET, a trade needs to be made between computational processing, power requirements, and bandwidth savings

- **HC algorithms can reduce the impact of expanded IPv6 packet headers**

Thank you! Questions?

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