Robust Header Compression for CCNx 1.0

Draft 3

Marc Mosko

Aug 26, 2015

ROHC Overview (RFC 5795)

- Modes of operation
  - Unidirectional mode (U-mode)
  - Bidirectional Optimistic (O-mode)
  - Bidirectional Reliable (R-mode)
- Compressor/decompressor states
  - Initialization and Refresh (IR) state
  - First Order (FO) state
  - Second Order (SO) state

Modes

- Unidirectional
  - Only from compressor to decompressor
- Bidirectional Optimistic
  - Reverse channel used for error and recovery of optional ack of significant updates.
- Bidirectional Reliable
  - More use of feedback for updates and prevent loss of synch between compressor/decompressor.

States

- Initialization and Refresh
  - Full packet headers sent
- First Order
  - Detected and stored static fields
  - Some dynamic packet field differences
- Second Order
  - Suppress all dynamic fields (e.g. sequence numbers)

ROHC Mode Applicability to CCN

- CCN relies on bidirectional channels
  - O-mode and R-mode most applicable
  - U-mode not necessary
- Initialization and Refresh
  - CCN encoding has some static structures that could be compressed even before First Order mode.

ROHC State Applicability To CCNx

- Initialization and Refresh State
  - Compress common TL pairs
  - Compress FixedHeader
- First Order State
  - Compress common values
    - Name prefixes, KeyIDs, EndChunkNumber, etc.
- Second Order State
  - Compress larger dynamic structures
    - ValidationAlg, Chunked Name, time fields

Motivation

- Network packets are small
  - Gzip, bzip2, etc. usually expand packet because of their block encoding structure.
  - Microsoft point-to-point compress (MCCP, RFC 2118) only has minor savings, sometimes bigger.
- Dictionary and window algorithms
  - Require state exchange, lost packets result in burst errors or decoding delay.

What we want to develop

- Static TL compression
  - Allows reducing the overhead caused by TL encoding (2+2 and 1/3/5) *without state exchange*.
  - Streaming operation, does not require going back to fix-up values.
- Dictionary learned replacement
  - Learn strings like Key IDs and Public Keys. Those are random byte strings.
  - Use (base, offset) encoding for things like Chunks or times or serial numbers.

Outline of Algorithm

- Fixed header has a “compressed” flag
  - If not set, uses 8 byte FH and 2+2 TLs
  - If set, used 3, 4, or 8 byte FH and 1 – 5 byte TLs
- In “compressed” mode
  - Uses dictionary replacement
    - Static TL pair or (TL)*TL string (in to 1 byte)
    - Static T, variable L (in to 1, 2, 3, 4 or 5 bytes)
    - Learned TLV replacement (in to 2, 3, or 4 bytes)
    - Learned TLV counter (only send offset from base)

Initialization

- Before using compression
  - Peers exchange willingness to compress.
  - Peers exchange capabilities
    - Maximum buffer size (used for in-band window based dictionary definitions).
    - Name of static dictionary used, if not the default.
  - If using non-standard static dictionary
    - Exchange the dictionaries.
  - Done at link initialization or with in-band link management.
  - Determine a Context ID (CID) for this state.

Dictionary Exchange

```
Exchange := DICT Validation
DICT := SEQNUM 1*ENTRY
ENTRY := RESET / DEF
DEF := TOKEN / COUNTER
TOKEN := LEARNED_Z / STATIC_Z
LEARNED_Z := Z_STRING / Z_OFFSET
Z_STRING := Z STRING
Z_OFFSET := Z OFFSET
OFFSET := BACK LENGTH
STATIC_Z := Z STRING LENGTH
COUNTER := Z BASE

RESET := <0-length token>
Z := <Defined Z value>
STRING := *OCTET
BASE := Number
BACK := Number
LENGTH := Number
Validation := <normal Validation section>
```

- A dictionary is a SEQNUM and one or more entries.
- A RESET entry clears all previous definitions.
- A definition can be a TOKEN or a COUNTER.
- A COUNTER is a Z value taken from the ‘Learned’ types followed by the base to apply an offset to.
- A TOKEN is Learned or Static.
  - Static used to transfer non-standard initial dictionaries.
- Learned TOKENs can be defined immediately (out-of-band) or in footer of packet (in-band).

State Exchange

- Out-of-band
  - Use a separate packet with FixedHeader PacketType = Dictionary
  - Sends one or more definitions of Token Type and Counter Type.
- In-band
  - To facilitate streaming, a packet is sent with learned values uncoded.
  - Footer sends dictionary definitions, using (backwards_offset, length) back in to the packet.
  - Still carries seqnum for reliable state exchange.
  - Has own CRC

Bi-directional Exchanges

- Each dictionary is one-way
  - So there is bi-directional state exchange.
  - Can piggyback ACK on token definitions.
- TBD:
  - Is this the right approach?
  - Fields like KeyID and the name prefix will always be symmetric.

State Exchange (out of band)

- Uses FixedHeader with PacketType=Dictionary
  - A link-local packet, not forwarded
  - Includes sequence number for reliable delivery
  - Peer sends ACKs
  - Has Validation section
    - CRC32C, HMAC, or signature
  - Can use one of the encrypted formats
    - AES-GCM authenticated encryption
    - See separate encryption document

State exchange ACK

```
Packet := FixedHeader ACK Validation
ACK := SEQNUM [ACCEPTED / NACK_FLAG]
SEQNUM := number
ACCEPTED := <list of Z values>
NACK_FLAG := <0-length TLV>
Validation := <normal, e.g. HMAC or CRC or signature)
```

When using backwards references with in-band state exchange, it is the responsibility of the sender to not go backwards beyond the receivers buffer size (defined in initialization).

A receiver can ACK all Z values defined by sending ACK without a SELECTIVE section. It can REJECT all Z values by sending an empty ACCEPTED section. It can ACK some and REJECT some by including a subset of Z values in the ACCEPTED section.

If a receiver rejects a SEQNUM, it SHOULD send a REJECT rather than time out.

If the receiver rejects a SEQNUM because of validation failure, it MAY send a NACK, though if it is an attack and remaining silent could be better. A NACK does not REJECT Z values, it only indicates a reception error.

State exchange processing

- SEQNUM is monotonically ordered
- Definitions applied in order
  - In order by SEQNUM and in order as listed.
- Withdrawing a definition

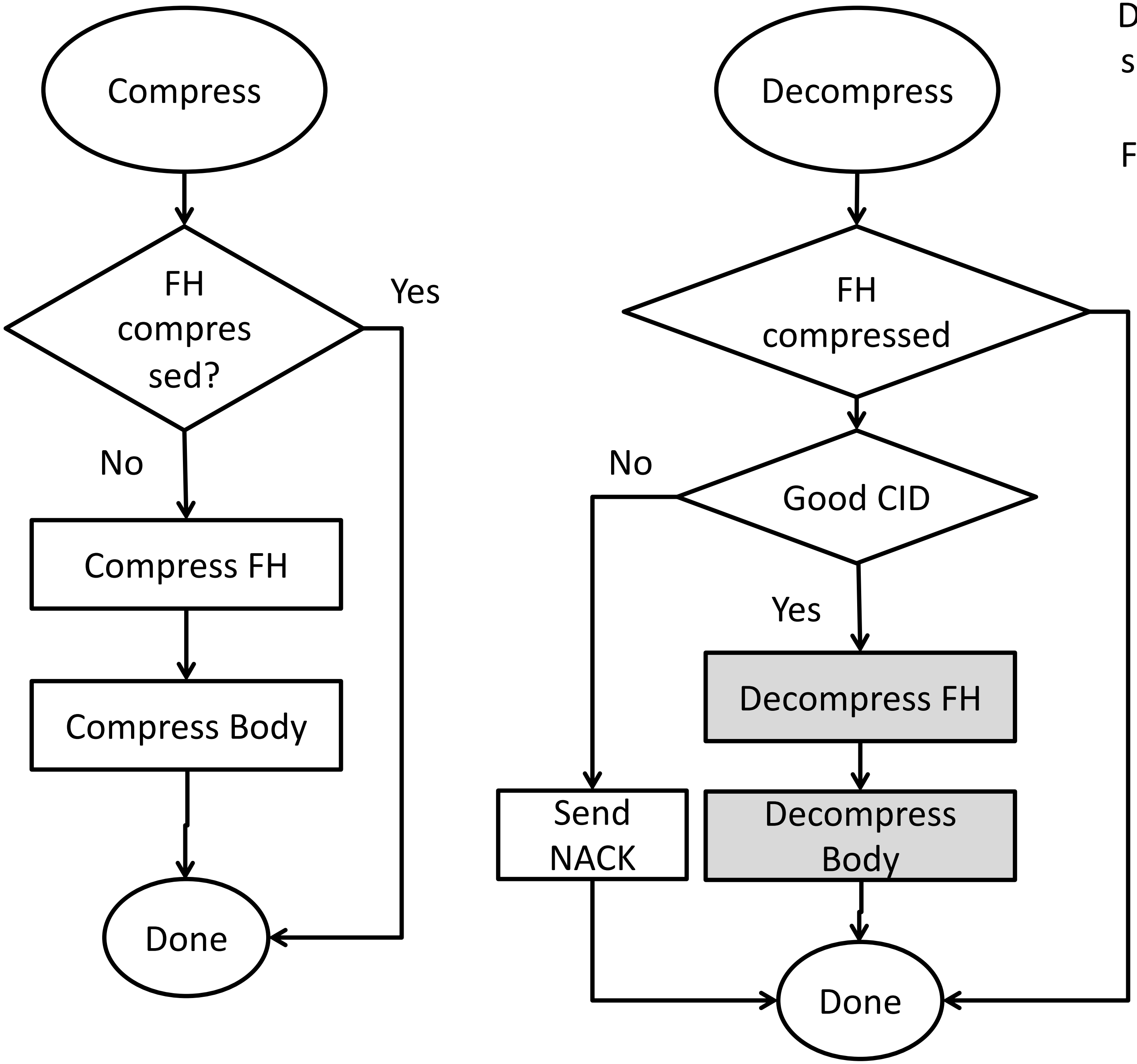
In-band exchange

- Add a footer of type T_DICT
  - Same type as used in out-of-band
  - Comes after the packet's Validation section
- The 'V' is always compressed
  - Contains seqnum (for ACK)
  - Contains one or more T_TOKEN or T_COUNTER definitions.
  - Each definition uses {back_offset, length} pair to indicate which part of packet is the string to match.

Why backward offsets

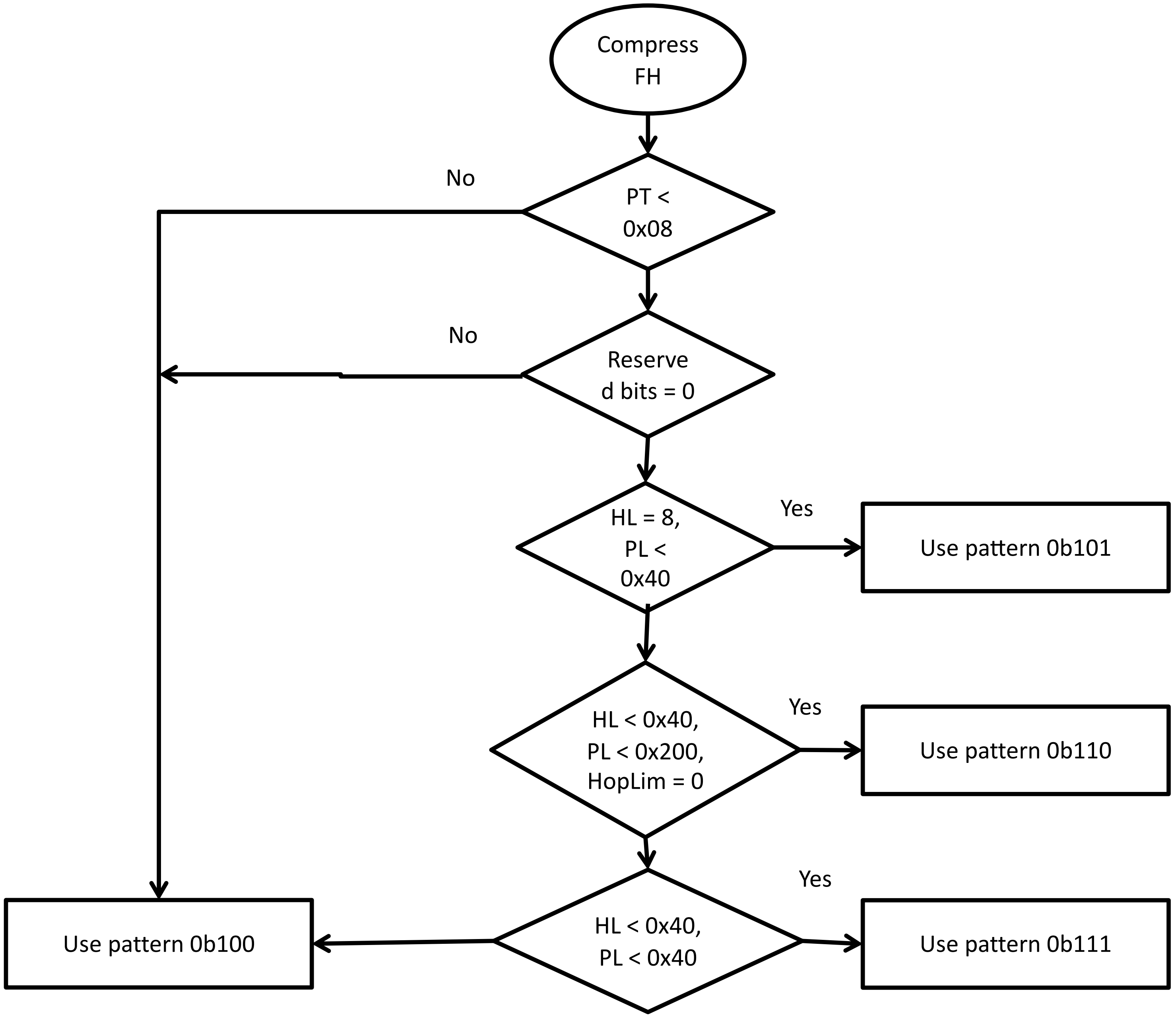
- Allows different implementations to keep different size buffers.
  - Can throw away head of packet, if desired.
  - Use Selective ACK to only accept what could be buffered.

ALGORITHM FLOWCHARTS

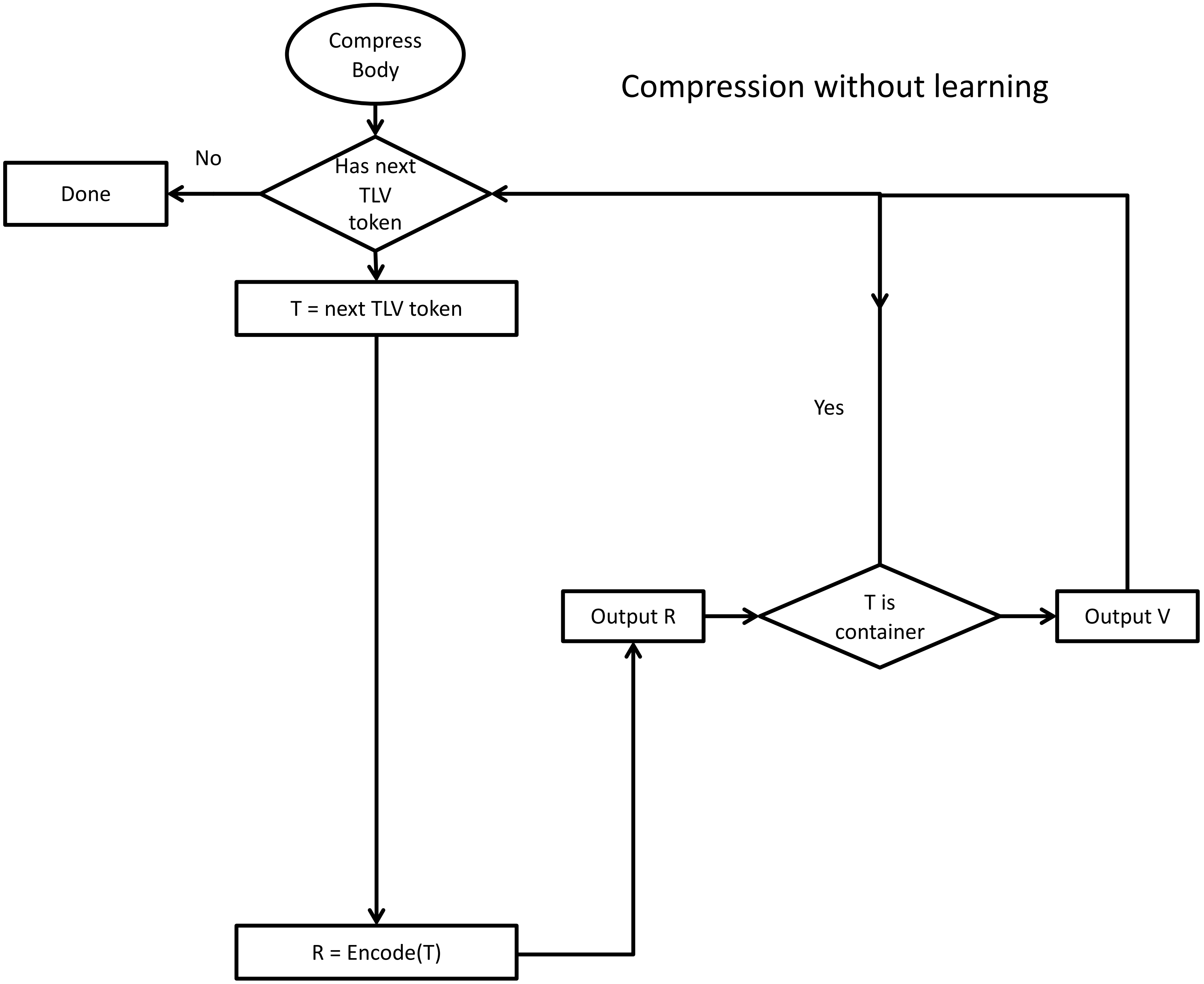


Decompress not shown in detail.

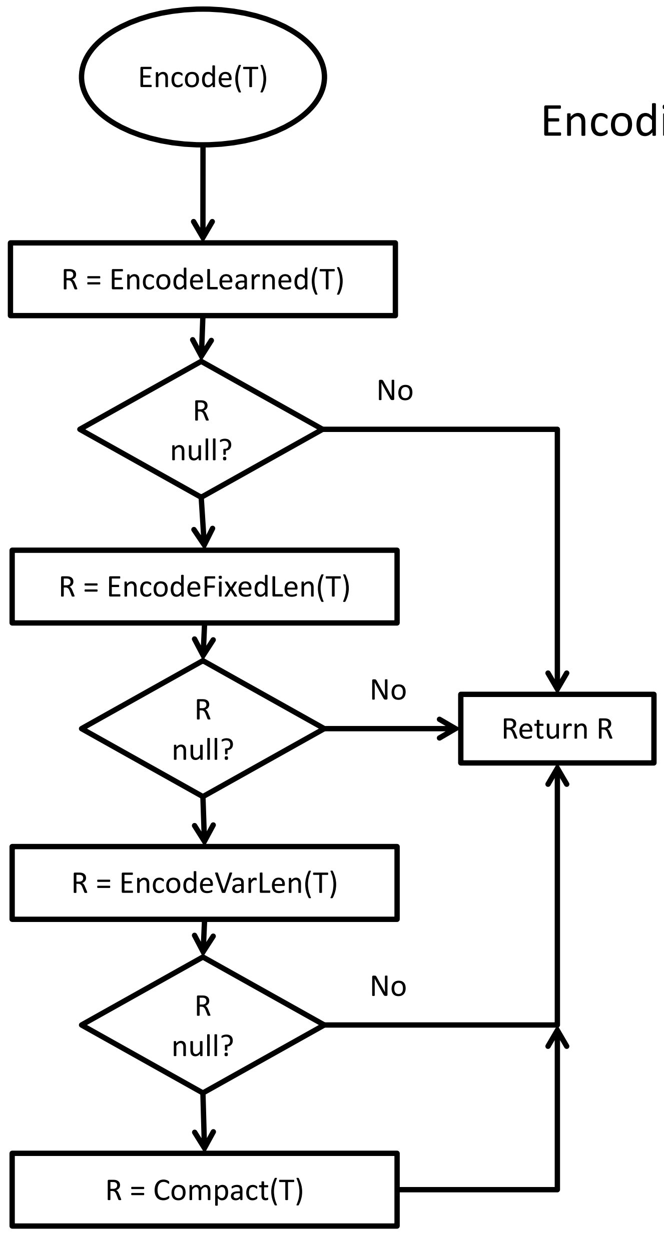
Follows obvious inverse of compress.


Compress FH
PT < 0x08
No
Reserved bits = 0
No
HL = 8, PL < 0x40
Yes
Use pattern 0b101
HL < 0x40, PL < 0x200, HopLim = 0
Yes
Use pattern 0b110
HL < 0x40, PL < 0x40
Yes
Use pattern 0b111
Use pattern 0b100

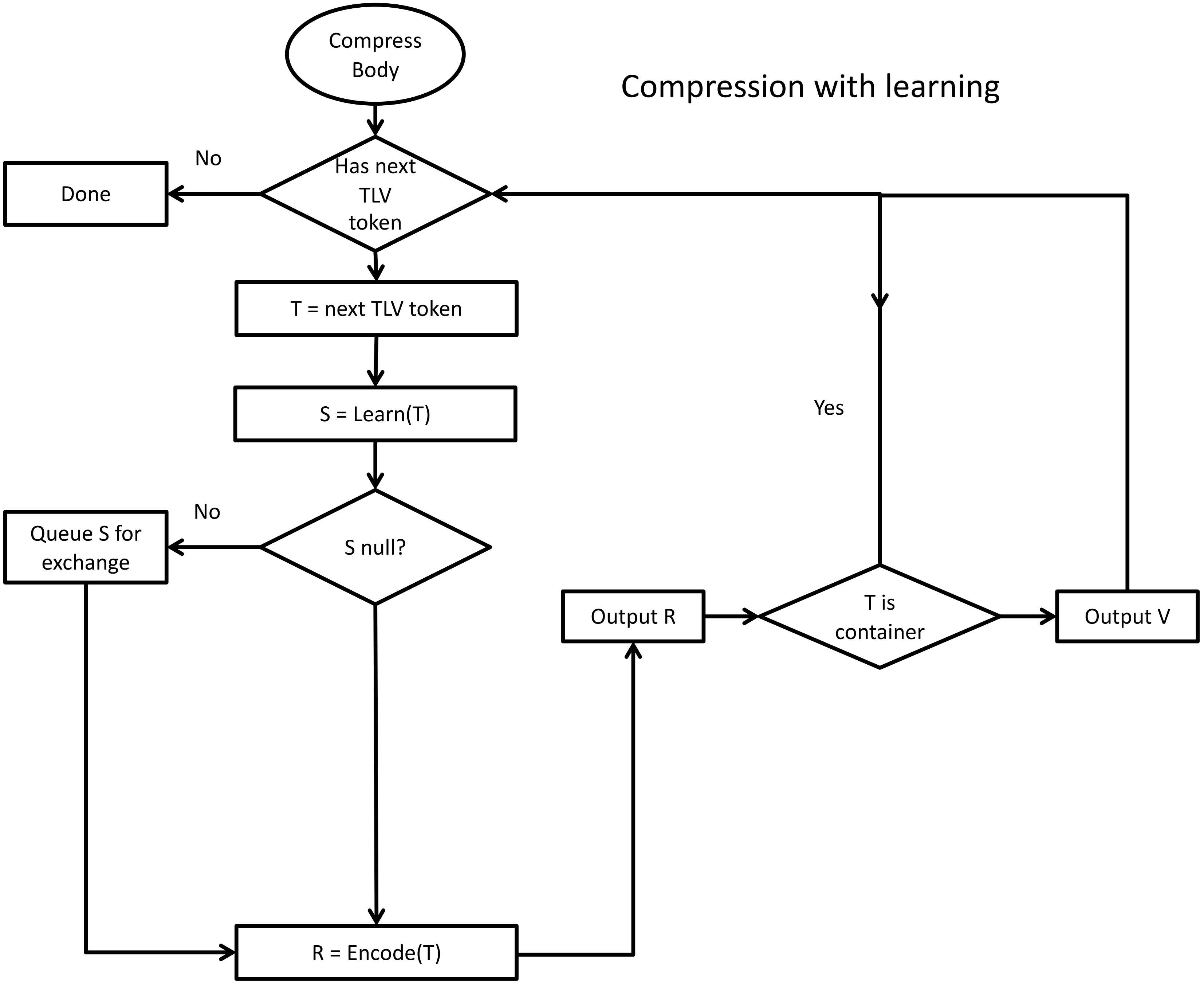
Compression without learning

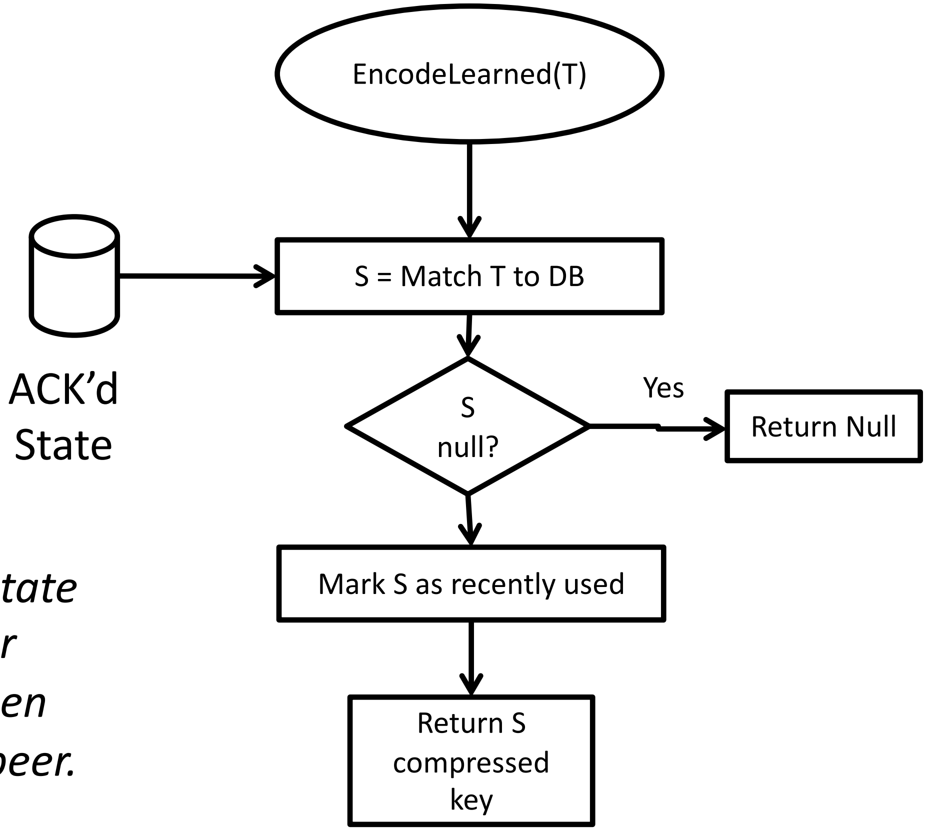


Encoding

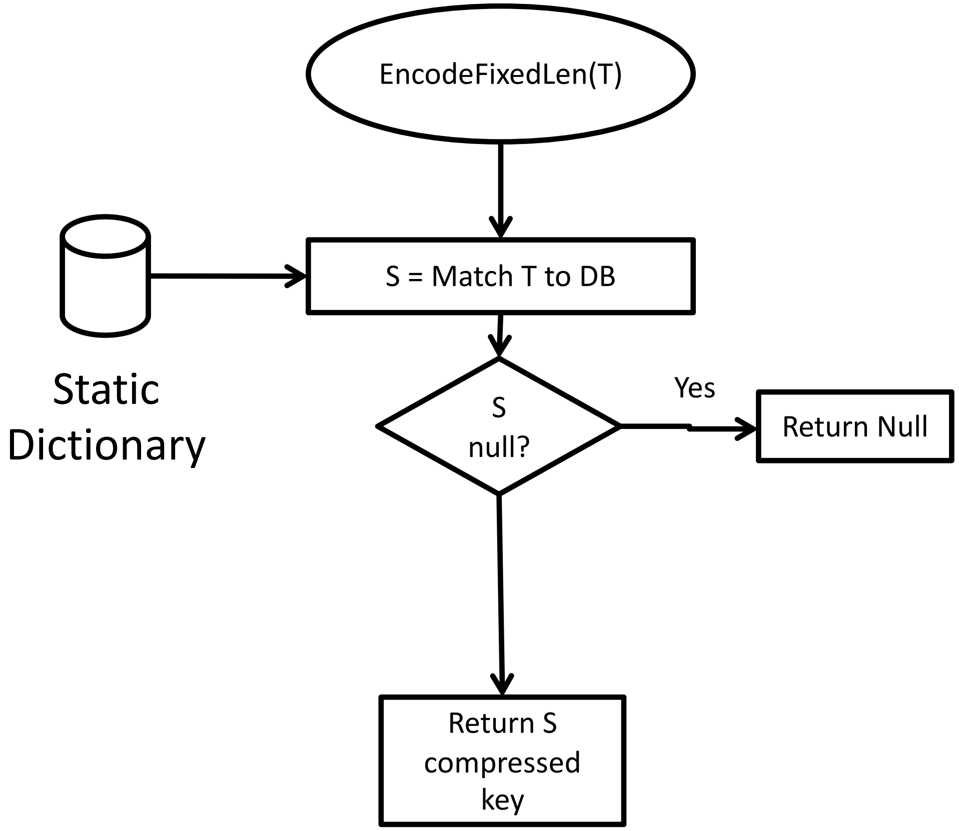

Encode(T)
R = EncodeLearned(T)
R null?
No
R = EncodeFixedLen(T)
R null?
No
Return R
R = EncodeVarLen(T)
R null?
No
R = Compact(T)

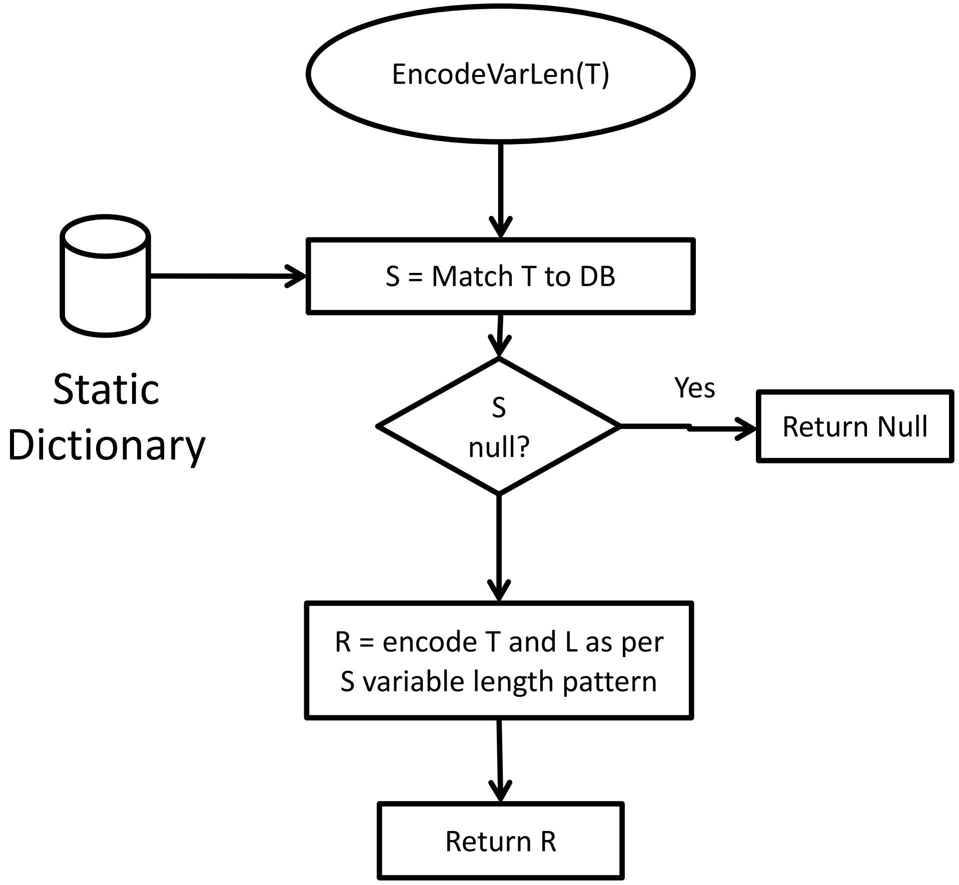
Compression with learning





ACK'd state are those state vectors S queued for transfer that have been acknowledged by the peer.


EncodeFixedLen(T)
S = Match T to DB
Static Dictionary
S null?
Yes
Return Null
Return S compressed key


EncodeVarLen(T)
S = Match T to DB
Static Dictionary
S null?
Yes
Return Null
R = encode T and L as per S variable length pattern
Return R

ANALYSIS

Information Theory Analysis

- Static dictionary
  - Does not require any state exchange.
  - Only analyze it for TL compression, not V.
  - There is no state transfer and is immune to packet loss or synchronization loss.
- Learned dictionary
  - Compacts TL and V
  - Analyze over whole TLV

A typical Interest

T_IntLifetime:	4 + 8 bytes, (4 bits, excluding V)
T_Interest:	4 bytes, (11 bits, assume < 1024 bytes)
T_Name:	4 bytes, (12 bits, assume < 1024 bytes)
T_NameSeg:	6x 4 bytes TL, plus 6x 8 bytes data (average) (6x 5 bits)
T_KeyIdRestr:	4 bytes + 32 bytes (5 bits, excluding V)
T_HashRestr:	4 bytes + 32 bytes (5 bits, excluding V)
T_ValAlg:	4 bytes (0 bits)
T_CRC32C:	4 bytes (2 bits)
T_ValPay:	4 bytes + 4 bytes (0 bits)

Shannon: H = E(# bits per symbol) ➔ H = 4.93 for bit-aligned data

Our coding would use E(L) = 8, so about 1.62x worse *for bit-aligned data*.
This is the price of staying byte-aligned for T and V fields.

(2+2 encoding H = 32, NDN 1/3/5 encoding H = 18.9)

Byte-aligned T and V

If we require the TL encoding be byte aligned (so V is byte aligned), then

Shannon: H = E(# bits per symbol) ➔ H = 8

Our coding would use E(L) = 8, so it is an optimal encoding of the packet.

In terms of overhead (TL) compression:

2+2 H = 32, so we should see 75% reduction in TL overhead

1/3/5 H = 18.9, so we should see 57.6% reduction in TL overhead

Including V fields

Using same Interest as previously, but including bits for V fields

Assume InterestLifetime is a 3-byte counter (encoded as 5 bytes total)
Assume first 5 name components are common prefix (encoded as 3 bytes total)
Assume last name component is chunk # (encoded as counter, 3 bytes total)
All these "predictable" fields have 0 bits of Information.

H = E(# bits per symbol) ➔ H = 8.38 (bit-aligned) or 11.69 (byte-aligned)

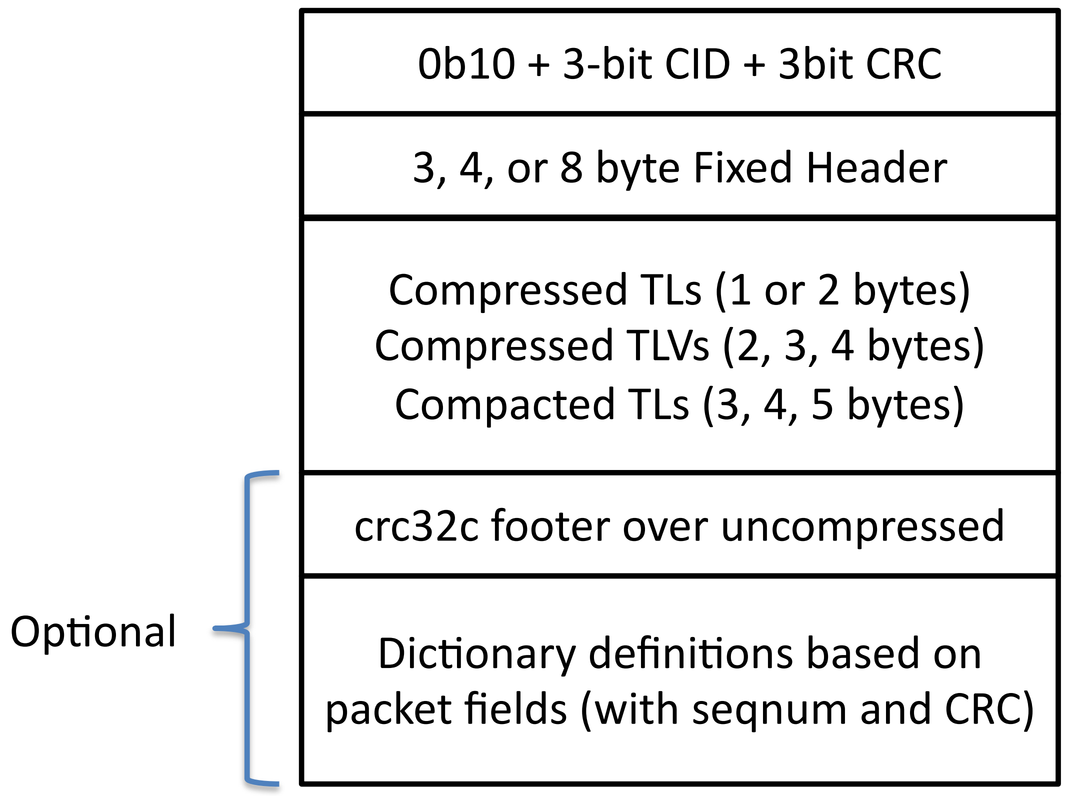
Our encoding: H = 14.77, about 1.26x over the limit (byte-aligned)

Compared to:

  2+2 has H = 88.3, so expect 83% compression
  1/3/5 has H = 55.4, so expect 73% compression

DETAILED BIT FIELDS

Typical compressed packet


0b10 + 3-bit CID + 3bit CRC
3, 4, or 8 byte Fixed Header
Compressed TLs (1 or 2 bytes)
Compressed TLVs (2, 3, 4 bytes)
Compacted TLs (3, 4, 5 bytes)
crc32c footer over uncompressed
Dictionary definitions based on packet fields (with seqnum and CRC)
Optional

Optional fields

- Final CRC32C
  - If the peer validating packet signatures and the packet has a ValidationAlg, can skip this.
  - Covers entire packet from CID to end of compressed body.
- In-band dictionary definitions
  - If new fields are to be learned (e.g. a KeyID), can be done in-line to avoid sending as separate state.
  - Peer must still ACK the definition before use.

FixedHeader Compression

v = version, t = packetType (PT), h = headerLen (HL),
l = packetLen (PL), m = hopLimit (HOP) c = return code (RC),
r = reserved, i = Context ID (CID)

	BYTE	HL	PL	HOP	RC	PT
Uncompressed packet						
`000vvvvr t{8} l{16} m{8} c{8} r{8} h{8}`	8	8	16	8	8	8
Compressed packet						
`10 i{3} crc{3} compressed_fh`						
`110 i{6} crc{7} compressed_fh`						
`111 reserved`						
`001vvvvr t{8} l{16} m{8} c{8} r{8} h{8}`	8	8	16	8	8	8
`010vvvvt ttllllll m{8}`	3	0	6	8	0	3
`011vvvvt tthhhhhl l{8}`	3	5	9	0	0	3
`100vvvvt tthhhhhl l{8} m{8}`	4	5	9	8	0	3

green: full len

Version field reduced to 4 bits in all packets
PacketType greater than 7 must use 8-byte fixed header

CRCs

- As per RFC 4995
  - Calculated over the preamble and CID (e.g. ‘10 i{3}’), so there are no leading 0s.
  - Initialize CRC register to all ‘1’s.
  - crc{3} = 1 + x + x^3
  - crc{7} = 1 + x + x^2 + x^3 + x^6 + x^7
  - The given combinations (i{3} crc{3}, i{6} crc{7}) will detect all bit errors over the 3 or 6 bit field.
- To verify the CRC
  - Zero the CRC bits then calculate over the 1 or 2 bytes

TL Compression

(t = type bit, l = length bit, z = compressor key)

```
Uncompressed Format: ("000" fixed header)
t{16} l{16}                            (16-bit T & 16-bit L)

Compressed Formats: ("1xx" fixed header)
0zzzllll                               ( 3-bit Z &  4-bit L)
10zzzzzz                               ( 6-bit Z &  fixed L)
110zzzzl l{8}                          ( 4-bit Z &  9-bit L)
1110tttt t{8} tttlllll                 (15-bit T &  5-bit L)
11110zzz z{8}                          (learned, next slide)
111110tt t{8} ttttttll l{8}            (16-bit T & 10-bit L)
1111110z z{16}                         (learned, next slide)
11111110 z{24}                         (learned, next slide)
11111111 t{16} l{16}                   (16-bit T & 16-bit L)
```

Formats with a 't' encode dictionary misses.
Formats with a 'z' encode dictionary hits.

Learned Dictionaries

```
Variable length keys for dynamic TL + V dictionaries
11110    z{11} -- 2 bytes (2K entries)
1111110  z{17} -- 3 bytes (128K entries)
11111110 z{24} -- 4 bytes (16M entries)
```

- Used to encode TL + V tokens
  - ‘Token’ type: a fixed TLV string
  - ‘Counter’ type: a base plus an offset
- Token type: e.g. keyid, public keys, and prefix
- Counter type: e.g. times, sequence numbers

Counter Types

- A ‘Z’ value followed by a signed offset
  - $0 <= \text{offset} < 256$: 0bbbbbbb (1 byte)
  - $256 <= \text{offset} < 2^{15}$: 10b{14} (2 bytes)
  - $2^{15} <= \text{offset} < 2^{22}$: 110b{21} (3 bytes)
  - $2^{22} <= \text{offset} < 2^{29}$: 1110b{28} (4 bytes)
  - $2^{29} <= \text{offset} < 2^{36}$: 11110b{35} (5 bytes)
- Sign extended to length of counter

Structure

- TL compressors
  - Will always begin on a ‘T’ and end before a ‘V’.
  - May consume multiple ‘TL’ pairs before first ‘V’, if they are all common values.
- TLV compressors
  - Will always begin on a ‘T’ and end with a ‘V’
  - ‘Token’ type may consume multiple static TLV tuples.
  - ‘Counter’ type one TLV
- Unambiguous
  - Because all code words start on a ‘T’ and all ‘T’s are unambiguous, there is a 1:1 encode/decode.

Examples of TL Compression

```
{0x00,0x03,0x00,0x04, /* validation alg, len= 4 */
 0x00,0x02,0x00,0x00, /* CRC32C */
 0x00,0x04,0x00,0x04,
 (4-byte CRC output) } /* validation payload, len= 4 */
➔ 0b10000100 (4-byte CRC output)
➔ 12 bytes -> 1 byte

{0x00,0x09,0x00,0x20, /* type = keyid, len= 32 */
 (32-byte keyid) }
➔ 0b10000010 (32-byte keyid)
➔ 4 bytes -> 1 byte

{0x00,0x01,0x00,0x05, /* type = NameSeg, len = 5 */
 'h','e','l','l','o'}
➔  0b00010101‘hello’
➔ 4 bytes -> 1 byte
```

Example of TLV Token Compression

In state exchange

```
0b11011100.00100010   // Token Definition (len = 36)
0b11111000.00000000   // z = 0xF800
{0x00,0x09,0x00,0x20, /* type = keyid, len= 32 */
 0x5c,0x23,0x4c,0x28,0x50,0xda,0x20,0x7b,
 0x88,0x25,0x8b,0xf3,0x62,0x61,0x96,0xd8,
 0xf0,0x60,0x76,0x38,0xa2,0xd4,0xe0,0xe2,
 0x49,0xb2,0xa9,0xaf,0xce,0xb8,0x85,0x59}
```

In packet

```
{0x00,0x09,0x00,0x20, /* type = keyid, len= 32 */
 0x5c,0x23,0x4c,0x28,0x50,0xda,0x20,0x7b,
 0x88,0x25,0x8b,0xf3,0x62,0x61,0x96,0xd8,
 0xf0,0x60,0x76,0x38,0xa2,0xd4,0xe0,0xe2,
 0x49,0xb2,0xa9,0xaf,0xce,0xb8,0x85,0x59}
```

➔ 0b11111000.00000000

➔ 36 bytes -> 2 bytes

Example of TLV Counter Compression

In state exchange

```
0b11011110.00001100   // Counter Definition (len = 12)
0b11111000.00000001   // z = 0xF801
{0x00,0x06}           // type 6, 2015-08-19T19:26:51.000Z
{0x00,0x00,0x01,0x4f,0x48,0xee,0x25,0xf8}
```

In packet

```
{0x00,0x06,0x00,0x08, /* type = expiry, len= 8 */
0x00,0x00,0x01,0x4f,0x49,0x25,0x14,0x78}// 2015-08-19T20:26:51.000Z
➔ 0b11111000.00000001
  0b11100000.00110110.11101110.10000000
➔ 12 bytes -> 6 bytes
```

Example state exchange packet

```
11000011.01010000.0100100  // fh: ver=1, pt=5, hl=8, pl=72
0b11001010.00100000        // Dictionary Def (len = 64)
0b00010010                 // seqnum (len = 2)
{0x03,0xc8}                // seqnum
0b11000100.00100110        // Token Definition (len = 38)
0b11111000.00000000        // z = 0xF800
{0x00,0x09,0x00,0x20,      /* type = keyid, len= 32 */
 0x5c,0x23,0x4c,0x28,0x50,0xda,0x20,0x7b,
 0x88,0x25,0x8b,0xf3,0x62,0x61,0x96,0xd8,
 0xf0,0x60,0x76,0x38,0xa2,0xd4,0xe0,0xe2,
 0x49,0xb2,0xa9,0xaf,0xce,0xb8,0x85,0x59}
0b10000100                 // valalg CRC32, valpayload
{4-byte string}            // crc32c value

T_DICT = 0x0005, T_SEQNUM = 0x0001, T_TOKEN = 0x0002
Note: uses normal compression, so lengths are all in
expanded sizes.
```

Example state exchange ACK

```
11000011.01000110.00110000 // fh: ver=1, pt=5, hl=3, pl=13
0b01010011                 // ACK (len = 3)
0b00010010                 // seqnum (len = 2)
{0x03,0xc8}                // seqnum
0b10000100                 // valalg CRC32, valpayload
{0x32,0x4a,0x96,0x13}      // crc32c value

T_ACK = 0x0006, T_SEQNUM = 0x0001, T_SELECTIVE = 0x0002
13 bytes to communicate 2 bytes of data with a 4-byte CRC.
```

In-band example

```
0x0101, 0x0066, 0x2000, 0x0008,      // FixedHeader
0x0001, 0x004F,                      // Interest
0x0000, 0x0025,                      // Name
0x0001, 0x0008, 'parc.com'           // NameSeg
0x0001, 0x0010, 'compression.pptx', // NameSeg
0x0013, 0x0001, {0x01},              // Chunk
0x0002, 0x0020, {32-byte string},    // KeyId restriction
0x0003, 0x0004, 0x0004, 0x0000,      // Validation Alg, CRC32C
0x0004, 0x0004, {4-byte string}      // Validation Payload
0x0005, 0x000F,                      // Dictionary Def
0b00010010, {0x03, 0xc8}             // seqnum (len = 2)
0b00100110                   // Token Definition (len = 12)
0b11111000.00000000          // z = 0xF800
0b00010001, {58}             // offset = 58 bytes back (KeyId)
0b00100001, {36}             // length = 36
0b10000100                   // valalg CRC32, valpayload
{4-byte string}              // crc32c value
T_DICT = 0x0005, T_SEQNUM=0x0001, T_TOKEN=0x0002,
T_OFFSET=0x0001, T_LENGTH = 0x0002
```

Static TL Dictionary

Z	Token	Notes
10000000	0x0002 0x0000	T_CRC32 (0)
10000001	0x0002 0x0004	T_KEYIDRESTR (4)
10000010	0x0002 0x0020	T_KEYIDRESTR (32)
10000011	0x0003 0x0004	T_VALALG (4)
10000100	0x0003 0x0004 0x0002 0x0000 0x0004 0x0004	Validation Alg w/ CRC32-C Validation Payload
10000101	0x0003 0x000C	T_INTFRAG (12)
10000110	0x0003 0x000C 0x0004 0x0008 0x0009 0x0004	Validation Alg w/ HMAC-SHA256, KeyId (4)
10000111	0x0003 0x0012	T_VALALG (18)
10001000	0x0003 0x0014 0x0004 0x0010 0x0009 0x0004	Validation Alg w/ HMAC-SHA256, KeyId (4), SigTime (8)
10001001	0x0003 0x0020	T_OBJHASHRESTR (32)
10001010	0x0003 0x0034 0x0006 0x0030 0x0009 0x0020	Validation Alg w/ RSA-SHA256 KeyId, SigTime (8)
10001011	0x0004 0x0004	T_VALPLD (4)
10001100	0x0004 0x000E	T_HMAC-SHA256
10001101	0x0004 0x0010	T_VALPLD (16)
10001110	0x0004 0x0014	T_OBJFRAG (20)
10001111	0x0005 0x0001	T_PLYTYPE (1)
10010000	0x0006 0x0008	T_EXPIRY (8)
10010001	0x0008 0x0011	T_IPID (17)
10010010	0x0009 0x0004	T_KEYID (4)
10010011	0x0009 0x0010	T_KEYID (16)
10010100	0x0009 0x0020	T_KEYID (32)
10010101	0x000B 0x00A2	T_PUBKEY (162)
10010110	0x000B 0x0126	T_PUBKEY (294)
10010111	0x000B 0x0226	T_PUBKEY (550)
10011000	0x000F 0x0008	T_SIGTIME (8)
10011001	0x0019 0x0001	T_ENDCHUNK (1)
10011010	0x0019 0x0002	T_ENDCHUNK (2)
10011011	0x0019 0x0004	T_ENDCHUNK (4)
10011100	0x0003 0x00CE 0x0006 0x00CA 0x0009 0x0020	ValAlg + RSA-SHA256 + KeyId + PubKey
10011101		

Variable Length Dictionaries

Z	Type	Length
00000000	0x0000	4-bit
00010000	0x0001	4-bit
00100000	0x000A	4-bit
00110000	0x0013	4-bit
01000000		4-bit
01010000		4-bit
01100000		4-bit
01110000		4-bit

Z	Type	Length
11000000	0x0000	9-bit
11000010	0x0001	9-bit
11000100	0x0002	9-bit
11000110	0x0003	9-bit
11001000	0x0004	9-bit
11001010	0x0005	9-bit
11001100	0x0006	9-bit
11001110		9-bit
11010000		9-bit
11010010		9-bit
11010100		9-bit
11010110		9-bit
11011000		9-bit
11011010	Dict ACK	9-bit
11011100	Token Def	9-bit
11011110	Counter Def	9-bit

Dict Act = Dictionary ACK field
Token Def = Token definition field
Counter Def = Counter definition field

Conclusion

- Initialization stage
  - Use static dictionary to compress TLs.
  - Compress fixed header.
  - Can be used as ‘native compressed’ format too.
- Learning stage
  - Use reliable state exchange to compress TLVs.
  - Token type static pattern substitution.
  - Counter type for signed offset from a base.