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ICN Adaptation to LoWPAN Networks (ICN LoWPAN)
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Abstract

This document defines a convergence layer for CCNx and NDN over IEEE 802.15.4 LoWPAN networks. A new frame format is specified to adapt CCNx and NDN packets to the small MTU size of IEEE 802.15.4. For that, syntactic and semantic changes to the TLV-based header formats are described. To support compatibility with other LoWPAN technologies that may coexist on a wireless medium, the dispatching scheme provided by 6LoWPAN is extended to include new dispatch types for CCNx and NDN. Additionally, the link fragmentation component of the 6LoWPAN dispatching framework is applied to ICN chunks. In its second part, the document defines stateless and stateful compression schemes to improve efficiency on constrained links. Stateless compression reduces TLV expressions to static header fields for common use cases. Stateful compression schemes elide state local to the LoWPAN and replace names in data packets by short local identifiers.

This document is a product of the IRTF Information-Centric Networking Research Group (ICNRG).

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1. Introduction

The Internet of Things (IoT) has been identified as a promising deployment area for Information Centric Networks (ICN), as infrastructureless access to content, resilient forwarding, and in-network data replication demonstrated notable advantages over the traditional host-to-host approach on the Internet [NDN-EXP1], [NDN-EXP2]. Recent studies [NDN-MAC] have shown that an appropriate mapping to link layer technologies has a large impact on the practical performance of an ICN. This will be even more relevant in the context of IoT communication where nodes often exchange messages via low-power wireless links under lossy conditions. In this memo, we address the base adaptation of data chunks to such link layers for the ICN flavors NDN [NDN] and CCNx [RFC8569], [RFC8609].

The IEEE 802.15.4 [ieee802.15.4] link layer is used in low-power and lossy networks (see "LLN" in [RFC7228]), in which devices are typically battery-operated and constrained in resources. Characteristics of LLNs include an unreliable environment, low

bandwidth transmissions, and increased latencies. IEEE 802.15.4 admits a maximum physical layer packet size of 127 octets. The maximum frame header size is 25 octets, which leaves 102 octets for the payload. IEEE 802.15.4 security features further reduce this payload length by up to 21 octets, yielding a net of 81 octets for CCNx or NDN packet headers, signatures and content.

6LoWPAN [[RFC4944](#)], [[RFC6282](#)] is a convergence layer that provides frame formats, header compression and link fragmentation for IPv6 packets in IEEE 802.15.4 networks. The 6LoWPAN adaptation introduces a dispatching framework that prepends further information to 6LoWPAN packets, including a protocol identifier for IEEE 802.15.4 payload and meta information about link fragmentation.

Prevalent Type-Length-Value (TLV) based packet formats such as in CCNx and NDN are designed to be generic and extensible. This leads to header verbosity which is inappropriate in constrained environments of IEEE 802.15.4 links. This document presents ICN LoWPAN, a convergence layer for IEEE 802.15.4 motivated by 6LoWPAN. ICN LoWPAN compresses packet headers of CCNx as well as NDN and allows for an increased effective payload size per packet. Additionally, reusing the dispatching framework defined by 6LoWPAN enables compatibility between coexisting wireless networks of competing technologies. This also allows to reuse the link fragmentation scheme specified by 6LoWPAN for ICN LoWPAN.

ICN LoWPAN defines a more space efficient representation of CCNx and NDN packet formats. This syntactic change is described for CCNx and NDN separately, as the header formats and TLV encodings differ notably. For further reductions, default header values suitable for constrained IoT networks are selected in order to elide corresponding TLVs. Experimental evaluations of the ICN LoWPAN header compression schemes in [[ICNLOWPAN](#)] illustrate a reduced message overhead, a shortened message airtime, and an overall decline in power consumption for typical Class 2 devices compared to uncompressed ICN messages.

In a typical IoT scenario (see (Figure 1)), embedded devices are interconnected via a quasi-stationary infrastructure using a border router (BR) that uplinks the constrained LoWPAN network by some Gateway with the public Internet. In ICN based IoT networks, non-local Interest and Data messages transparently travel through the BR up and down between a Gateway and the embedded devices situated in the constrained LoWPAN.

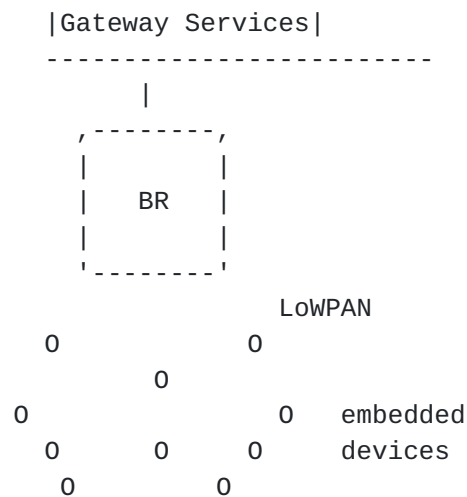


Figure 1: IoT Stub Network

The draft has received fruitful reviews by members of the ICN community and the research group (see Acknowledgments) for a period of two years. It is the consensus of ICNRG that this document should be published in the IRTF Stream of the RFC series. This document does not constitute an IETF standard.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC 2119](#) [RFC2119]. The use of the term, "silently ignore" is not defined in [RFC 2119](#). However, the term is used in this document and can be similarly construed.

This document uses the terminology of [\[RFC7476\]](#), [\[RFC7927\]](#), and [\[RFC7945\]](#) for ICN entities.

The following terms are used in the document and defined as follows:

ICN LoWPAN: Information-Centric Networking over Low-power Wireless Personal Area Network

LLN Low-Power and Lossy Network

CCNx: Content-Centric Networking Architecture

NDN: Named Data Networking Architecture

time-value: a time value measured in seconds

time-code: an 8-bit encoded time-value

3. Overview of ICN LowPAN

3.1. Link-Layer Convergence

ICN LowPAN provides a convergence layer that maps ICN packets onto constrained link-layer technologies. This includes features such as link-layer fragmentation, protocol separation on the link-layer level, and link-layer address mappings. The stack traversal is visualized in Figure 2.

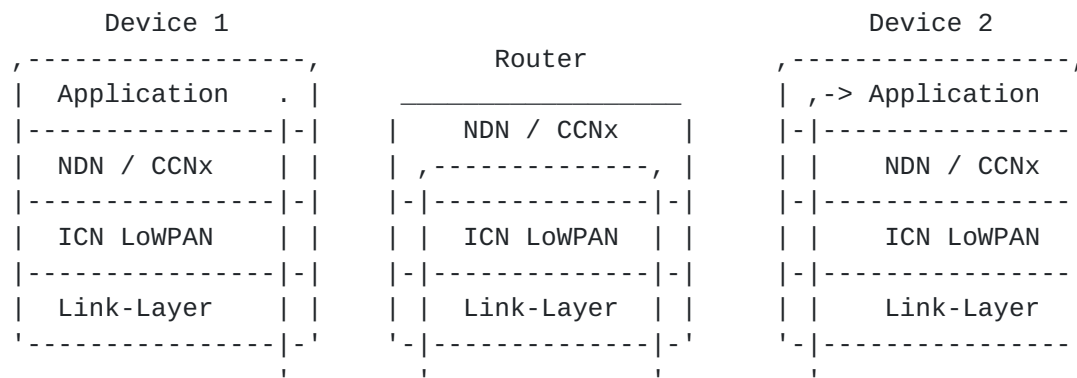


Figure 2: ICN LowPAN convergence layer for IEEE 802.15.4

[Section 4](#) of this document defines the convergence layer for IEEE 802.15.4.

3.2. Stateless Header Compression

ICN LowPAN also defines a stateless header compression scheme with the main purpose of reducing header overhead of ICN packets. This is of particular importance for link-layers with small MTUs. The stateless compression does not require pre-configuration of global state.

The CCNx and NDN header formats are composed of Type-Length-Value (TLV) fields to encode header data. The advantage of TLVs is its native support of variably structured data. The main disadvantage of TLVs is the verbosity that results from storing the type and length of the encoded data.

The stateless header compression scheme makes use of compact bit fields to indicate the presence of optional TLVs in the uncompressed packet. The order of set bits in the bit fields corresponds to the order of each TLV in the packet. Further compression is achieved by

specifying default values and reducing the codomain of certain header fields.

Figure 3 demonstrates the stateless header compression idea. In this example, the first type of the first TLV is removed and the corresponding bit in the bit field is set. The second TLV represents a fixed-length TLV (e.g., the Nonce TLV in NDN), so that the type and the length fields are removed. The third TLV represents a boolean TLV (e.g., the MustBeFresh selector in NDN) for which the type, length and the value fields are elided.

Uncompressed:

Variable-length TLV			Fixed-length TLV			Boolean TLV	
TYP	LEN	VAL	TYP	LEN	VAL	TYP	LEN

Compressed:

1	0	1	0	0	0	0	1	Bit field
								Boolean Value
LEN		VAL		VAL				

Var-len Value Fixed-len Value

Figure 3: Compression using a compact bit field - bits encode the inclusion of TLVs.

Stateless TLV compression for NDN is defined in [Section 5](#). [Section 6](#) defines the stateless TLV compression for CCNx.

The extensibility of this compression is described in [Section 4.1.1](#) and allows future documents to update the compression rules outlined in this manuscript.

[3.3. Stateful Header Compression](#)

ICN LowPAN further employs two orthogonal stateful compression schemes for packet size reductions which are defined in [Section 8](#). These mechanisms rely on shared contexts that are either distributed

and maintained in the entire LoWPAN, or are generated on-demand hop-wise on a particular Interest-data path.

The shared context identification is defined in [Section 8.1](#). The hop-wise name compression "en-route" is specified in [Section 8.2](#).

4. IEEE 802.15.4 Adaptation

4.1. LoWPAN Encapsulation

The IEEE 802.15.4 frame header does not provide a protocol identifier for its payload. This causes problems of misinterpreting frames when several network layers coexist on the same link. To mitigate errors, 6LoWPAN defines dispatches as encapsulation headers for IEEE 802.15.4 frames (see [Section 5 of \[RFC4944\]](#)). Multiple LoWPAN encapsulation headers can prepend the actual payload and each encapsulation header is identified by a dispatch type.

[RFC8025] further specifies dispatch pages to switch between different contexts. When a LoWPAN parser encounters a "Page switch" LoWPAN encapsulation header, then all following encapsulation headers are interpreted by using a dispatch table as specified by the "Page switch" header. Page 0 and page 1 are reserved for 6LoWPAN. This document uses page TBD1 ("1111 TBD1 (0xFTBD1)") for NDN and page TBD2 ("1111 TBD2 (0xFTBD2)") for CCNx.

The base dispatch format (Figure 4) is used and extended by CCNx and NDN in [Section 5](#) and [Section 6](#).

```

      0   1   2   ...
      +---+---+-----
      | C | M |
      +---+---+-----

```

Figure 4: Base dispatch format for ICN LoWPAN

C: Compression

0: The message is uncompressed.

1: The message is compressed.

M: Message Type

0: The payload contains an Interest message.

1: The payload contains a Data message.

ICN LoWPAN frames with compressed CCNx and NDN messages (C=1) use the extended dispatch format in Figure 5.

```

      0   1   2   3   ...
+---+---+---+---+---
| 1 | M |CID|EXT|
+---+---+---+---+---

```

Figure 5: Extended dispatch format for compressed ICN LoWPAN

CID: Context Identifier

- 0: No context identifiers are present.
- 1: Context identifier(s) are present (see [Section 8.1](#)).

EXT: Extension

- 0: No extension octets are present.
- 1: Extension octet(s) are present (see [Section 4.1.1](#)).

The encapsulation format for ICN LoWPAN is displayed in Figure 6.

```

+-----+-----+-----+-----+-----+-----+-----+-----+
| IEEE 802.15.4 | RFC4944 Disp. | Page | ICN LoWPAN Disp. | Payl. /
+-----+-----+-----+-----+-----+-----+-----+-----+

```

Figure 6: LoWPAN Encapsulation with ICN-LoWPAN

IEEE 802.15.4: The IEEE 802.15.4 header.

[RFC4944](#) Disp.: Optional additional dispatches defined in [Section 5.1 of \[RFC4944\]](#)

Page: Page Switch. TBD1 for NDN and TBD2 for CCNx.

ICN LoWPAN: Dispatches as defined in [Section 5](#) and [Section 6](#).

Payload: The actual (un-)compressed CCNx or NDN message.

[4.1.1.1](#). Dispatch Extensions

Extension octets allow for the extensibility of the initial compression rule set. The base format for an extension octet is depicted in Figure 7.

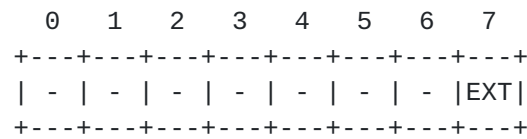


Figure 7: Base format for dispatch extensions.

EXT: Extension

0: No other extension octet follows.

1: A further extension octet follows.

Extension octets are numbered according to their order. Future documents MUST follow the naming scheme "EXT_0, EXT_1, ...", when updating or referring to a specific dispatch extension octet. Amendments that require an exchange of configurational parameters between devices SHOULD use manifests to encode structured data in a well-defined format, as, e.g., outlined in [\[I-D.irtf-icnrg-flic\]](#).

4.2. Link Fragmentation

Small payload sizes in the LoWPAN require fragmentation for various network layers. Therefore, [Section 5.3 of \[RFC4944\]](#) defines a protocol-independent fragmentation dispatch type, a fragmentation header for the first fragment, and a separate fragmentation header for subsequent fragments. ICN LoWPAN adopts this fragmentation handling of [\[RFC4944\]](#).

The Fragmentation LoWPAN header can encapsulate other dispatch headers. The order of dispatch types is defined in [Section 5 of \[RFC4944\]](#). Figure 8 shows the fragmentation scheme. The reassembled ICN LoWPAN frame does not contain any fragmentation headers and is depicted in Figure 9.

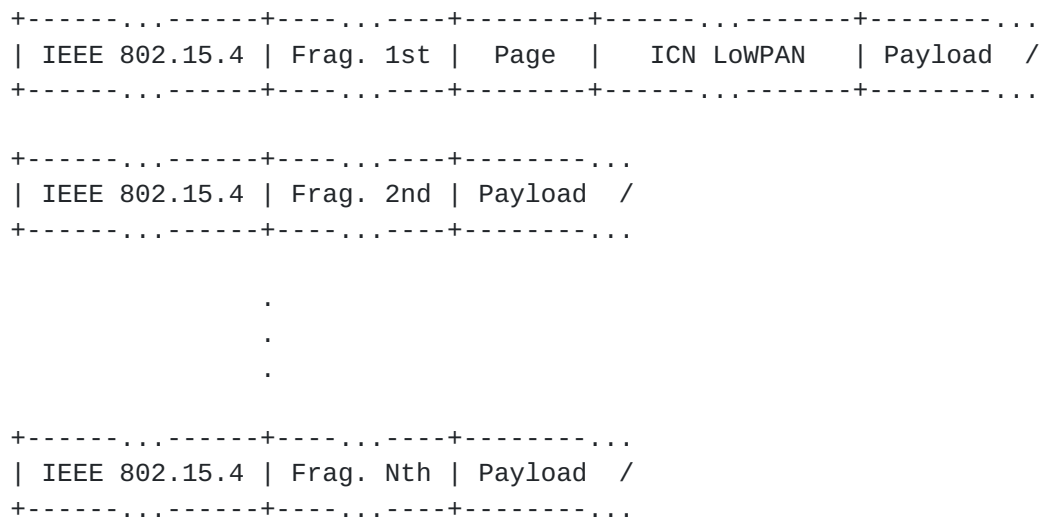


Figure 8: Fragmentation scheme

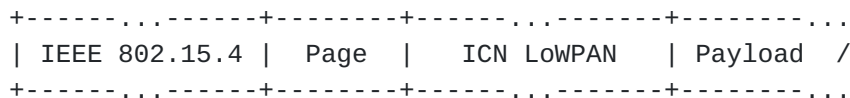


Figure 9: Reassembled ICN LowPAN frame

5. Space-efficient Message Encoding for NDN

5.1. TLV Encoding

The NDN packet format consists of TLV fields using the TLV encoding that is described in [\[NDN-PACKET-SPEC\]](#). Type and length fields are of variable size, where numbers greater than 252 are encoded using multiple octets.

If the type or length number is less than "253", then that number is encoded into the actual type or length field. If the number is greater or equals "253" and fits into 2 octets, then the type or length field is set to "253" and the number is encoded in the next following 2 octets in network byte order, i.e., from the most significant byte (MSB) to the least significant byte (LSB). If the number is greater than 2 octets and fits into 4 octets, then the type or length field is set to "254" and the number is encoded in the subsequent 4 octets in network byte order. For larger numbers, the type or length field is set to "255" and the number is encoded in the subsequent 8 octets in network byte order.

In this specification, compressed NDN TLVs make use of a different TLV encoding scheme that reduces size. Instead of using the first octet as a marker for the number of following octets, the compressed

This Name TLV compression encodes length fields of two consecutive NameComponent TLVs into one octet, using 4 bits each. This process limits the length of a NameComponent TLV to 15 octets. A length of 0 marks the end of the compressed Name TLV. An example for this encoding is presented in Figure 11.

Name: /HAW/Room/481/Humid/99

```

      0          1          2          3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|0 0 1 1|0 1 0 0|          H          |          A          |          W          |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|          R          |          o          |          o          |          m          |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|0 0 1 1|0 1 0 1|          4          |          8          |          1          |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|          H          |          u          |          m          |          i          |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|          d          |0 0 1 0|0 0 0 0|          9          |          9          |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+

```

Figure 11: Name TLV compression for /HAW/Room/481/Humid/99

5.3. Interest Messages

5.3.1. Uncompressed Interest Messages

An uncompressed Interest message uses the base dispatch format (see Figure 4) and sets the C as well as the M flag to "0" (Figure 12). "resv" MUST be set to 0. The Interest message is handed to the NDN network stack without modifications.

```

      0      1      ...      7
+--+--+--+-----+
| 0 | 0 |          resv          |
+--+--+--+-----+

```

Figure 12: Dispatch format for uncompressed NDN Interest messages

5.3.2. Compressed Interest Messages

The compressed Interest message uses the extended dispatch format (Figure 5) and sets the C flag to "1" and the M flag to "0". If an Interest message contains TLVs that are not mentioned in the following compression rules, then this message MUST be sent uncompressed.

This specification assumes that a HopLimit TLV is part of the original Interest message. If such HopLimit TLV is not present, it will be set with a default value of DEFAULT_NDN_HOPLIMIT prior to the compression.

In the default use case, the Interest message is compressed with the following minimal rule set:

1. The "Type" field of the outermost MessageType TLV is removed.
2. The Name TLV is compressed according to [Section 5.2](#). For this, all NameComponents are expected to be of type GenericNameComponent with a length greater than 0. An ImplicitSha256DigestComponent or ParametersSha256DigestComponent MAY appear at the end of the name. In any other case, the message MUST be sent uncompressed.
3. InterestLifetime TLV is moved to the end of the compressed Interest and is encoded as described in [Section 7](#). If a lifetime is not a valid time-value, then the lifetime is rounded up to the nearest valid time-value as specified in [Section 7](#).
4. The Type and Length fields of Nonce TLV, HopLimit TLV and InterestLifetime TLV are elided. The Nonce value has a length of 4 octets and the HopLimit value has a length of 1 octet. The compressed InterestLifetime ([Section 7](#)) has a length of 1 octet. The presence of an InterestLifetime TLV is deduced from the remaining length to parse.

The compressed NDN LoWPAN Interest message is visualized in Figure 13.

T = Type, L = Length, V = Value, Vc = Compressed Value

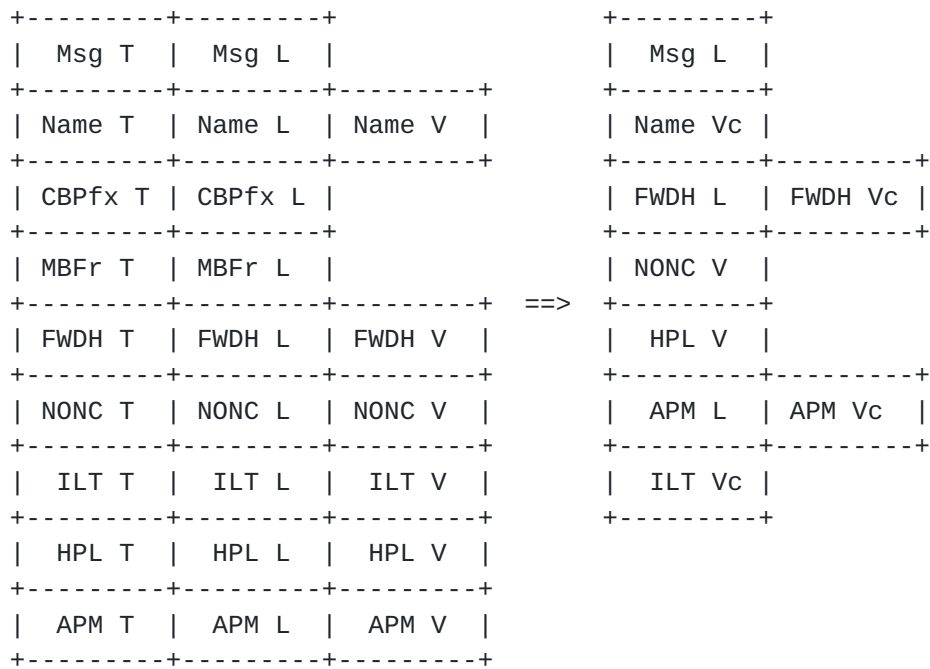


Figure 13: Compression of NDN LowPAN Interest Message

Further TLV compression is indicated by the ICN LowPAN dispatch in Figure 14.

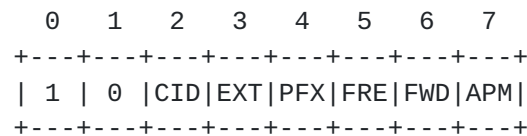


Figure 14: Dispatch format for compressed NDN Interest messages

CID: Context Identifier See Figure 5.

EXT: Extension

0: No extension octet follows.

1: Extension octet "EXT_0" follows immediately. See [Section 5.3.3](#).

PFX: CanBePrefix TLV

0: The uncompressed message does not include a CanBePrefix TLV.

- 1: The uncompressed message does include a CanBePrefix TLV and is removed from the compressed message.

FRE: MustBeFresh TLV

- 0: The uncompressed message does not include a MustBeFresh TLV.
- 1: The uncompressed message does include a MustBeFresh TLV and is removed from the compressed message.

FWD: ForwardingHint TLV

- 0: The uncompressed message does not include a ForwardingHint TLV.
- 1: The uncompressed message does include a ForwardingHint TLV. The Type field is removed from the compressed message. Further, all link delegation types and link preference types are removed. All included names are compressed according to [Section 5.2](#). If any name is not compressible, the message MUST be sent uncompressed.

APM: ApplicationParameters TLV

- 0: The uncompressed message does not include an ApplicationParameters TLV.
- 1: The uncompressed message does include an ApplicationParameters TLV. The Type field is removed from the compressed message.

[5.3.3](#). Dispatch Extension

The "EXT_0" octet follows the description in [Section 4.1.1](#) and is illustrated in Figure 15.

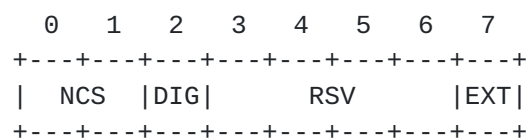


Figure 15: EXT_0 format

NCS: Name Compression Strategy

- 00: Names are compressed with the default name compression strategy (see [Section 5.2](#)).
- 01: Reserved.
- 10: Reserved.
- 11: Reserved.

DIG: ImplicitSha256DigestComponent TLV

- 0: The name does not include an ImplicitSha256DigestComponent as the last TLV. If "EXT_0" is absent, then DIG is treated as 0.
- 1: The name does include an ImplicitSha256DigestComponent as the last TLV. The Type and Length fields are omitted.

RSV: Reserved Must be set to 0.

EXT: Extension

- 0: No extension octet follows.
- 1: A further extension octet follows immediately.

[5.4.](#) Data Messages

[5.4.1.](#) Uncompressed Data Messages

An uncompressed Data message uses the base dispatch format and sets the C flag to "0" and the M flag to "1" (Figure 16). "resv" MUST be set to 0. The Data message is handed to the NDN network stack without modifications.

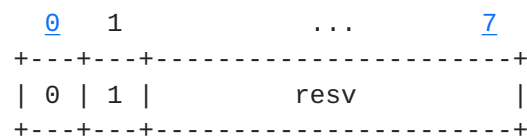


Figure 16: Dispatch format for uncompressed NDN Data messages

[5.4.2.](#) Compressed Data Messages

The compressed Data message uses the extended dispatch format (Figure 5) and sets the C flag as well as the M flag to "1". If a

Data message contains TLVs that are not mentioned in the following compression rules, then this message MUST be sent uncompressed.

By default, the Data message is compressed with the following base rule set:

1. The "Type" field of the outermost MessageType TLV is removed.
2. The Name TLV is compressed according to [Section 5.2](#). For this, all NameComponents are expected to be of type GenericNameComponent and to have a length greater than 0. In any other case, the message MUST be sent uncompressed.
3. The MetaInfo TLV Type and Length fields are elided from the compressed Data message.
4. The FreshnessPeriod TLV MUST be moved to the end of the compressed Data message and the length is set to 1. Type and Length fields are elided and the value is encoded as described in [Section 7](#). If the freshness period is not a valid time-value, then the message MUST be sent uncompressed in order to preserve the security envelope of the Data message. The presence of a FreshnessPeriod TLV is deduced from the remaining length to parse.
5. The Type fields of the SignatureInfo TLV, SignatureType TLV and SignatureValue TLV are removed.

The compressed NDN LowPAN Data message is visualized in Figure 17.

T = Type, L = Length, V = Value, Vc = Compressed Value

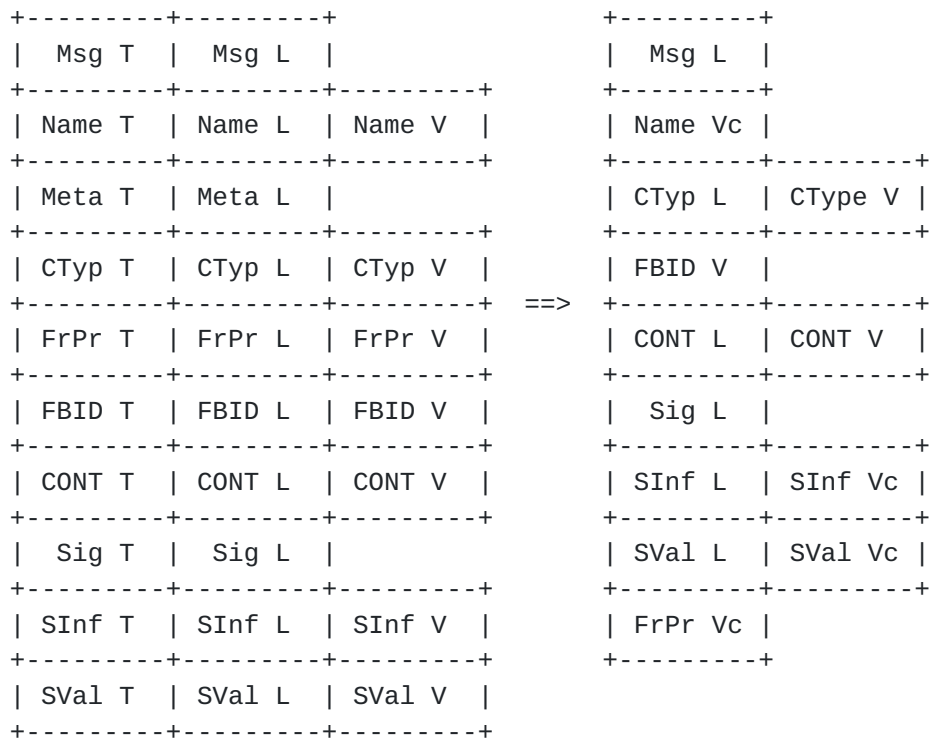


Figure 17: Compression of NDN LowPAN Data Message

Further TLV compression is indicated by the ICN LowPAN dispatch in Figure 18.

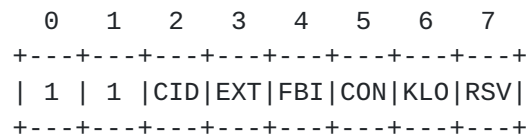


Figure 18: Dispatch format for compressed NDN Data messages

CID: Context Identifier See Figure 5.

EXT: Extension

0: No extension octet follows.

1: Extension octet "EXT_0" follows immediately. See [Section 5.4.3](#).

FBI: FinalBlockId TLV

- 0: The uncompressed message does not include a FinalBlockId TLV.
- 1: The uncompressed message does include a FinalBlockId and it is encoded according to [Section 5.2](#). If the FinalBlockId TLV is not compressible, then the message MUST be sent uncompressed.

CON: ContentType TLV

- 0: The uncompressed message does not include a ContentType TLV.
- 1: The uncompressed message does include a ContentType TLV. The Type field is removed from the compressed message.

KLO: KeyLocator TLV

- 0: If the included SignatureType requires a KeyLocator TLV, then the KeyLocator represents a name and is compressed according to [Section 5.2](#). If the the name is not compressible, then the message MUST be sent uncompressed.
- 1: If the included SignatureType requires a KeyLocator TLV, then the KeyLocator represents a KeyDigest. The Type field of this KeyDigest is removed.

RSV: Reserved Must be set to 0.

[5.4.3. Dispatch Extension](#)

The "EXT_0" octet follows the description in [Section 4.1.1](#) and is illustrated in Figure 19.

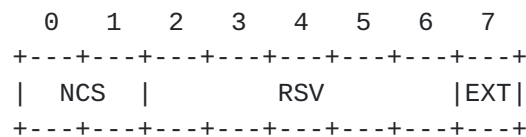


Figure 19: EXT_0 format

NCS: Name Compression Strategy

- 00: Names are compressed with the default name compression strategy (see [Section 5.2](#)).

01: Reserved.

10: Reserved.

11: Reserved.

RSV: Reserved Must be set to 0.

EXT: Extension

0: No extension octet follows.

1: A further extension octet follows immediately.

6. Space-efficient Message Encoding for CCNx

6.1. TLV Encoding

The generic CCNx TLV encoding is described in [RFC8609]. Type and Length fields attain the common fixed length of 2 octets.

The TLV encoding for CCNx LowPAN is changed to the more space efficient encoding described in [Section 5.1](#). Hence NDN and CCNx use the same compressed format for writing TLVs.

6.2. Name TLV Compression

Name TLVs are compressed using the scheme already defined in [Section 5.2](#) for NDN. If a Name TLV contains T_IPID, T_APP, or organizational TLVs, then the name remains uncompressed.

6.3. Interest Messages

6.3.1. Uncompressed Interest Messages

An uncompressed Interest message uses the base dispatch format (see Figure 4) and sets the C as well as the M flag to "0" (Figure 20). "resv" MUST be set to 0. The Interest message is handed to the CCNx network stack without modifications.



Figure 20: Dispatch format for uncompressed CCNx Interest messages

6.3.2. Compressed Interest Messages

The compressed Interest message uses the extended dispatch format (Figure 5) and sets the C flag to "1" and the M flag to "0". If an Interest message contains TLVs that are not mentioned in the following compression rules, then this message MUST be sent uncompressed.

In the default use case, the Interest message is compressed with the following minimal rule set:

1. The Type and Length fields of the CCNx Message TLV are elided and are obtained from the Fixed Header on decompression.

The compressed CCNx LoWPAN Interest message is visualized in Figure 21.

T = Type, L = Length, V = Value

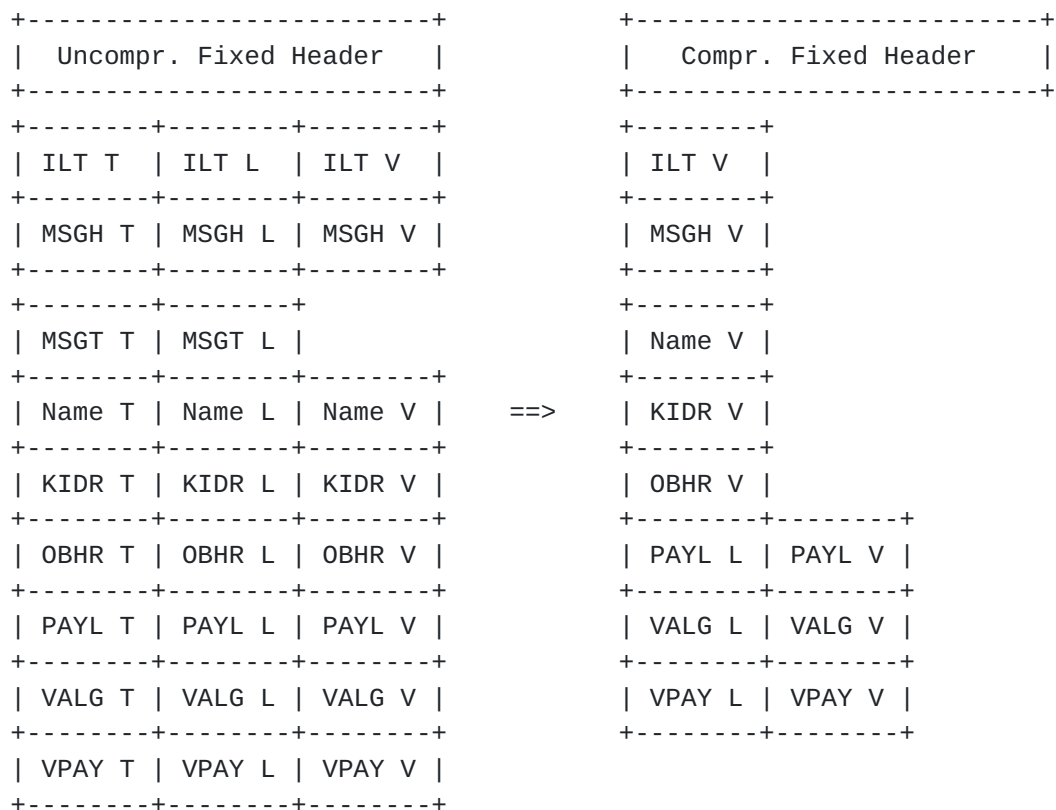


Figure 21: Compression of CCNx LoWPAN Interest Message

Further TLV compression is indicated by the ICN LoWPAN dispatch in Figure 22.

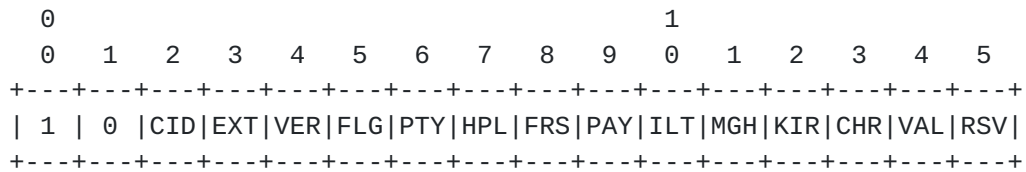


Figure 22: Dispatch format for compressed CCNx Interest messages

CID: Context Identifier See Figure 5.

EXT: Extension

- 0: No extension octet follows.
- 1: Extension octet "EXT_0" follows immediately. See [Section 6.3.3](#).

VER: CCNx protocol version in the fixed header

- 0: The Version field equals 1 and is removed from the fixed header.
- 1: The Version field is carried in-line.

FLG: Flags field in the fixed header

- 0: The Flags field equals 0 and is removed from the Interest message.
- 1: The Flags field is carried in-line.

PTY: PacketType field in the fixed header

- 0: The PacketType field is elided and assumed to be "PT_INTEREST"
- 1: The PacketType field is elided and assumed to be "PT_RETURN"

HPL: HopLimit field in the fixed header

- 0: The HopLimit field is carried in-line
- 1: The HopLimit field is elided and assumed to be "1"

FRS: Reserved field in the fixed header

- 0: The Reserved field is carried in-line

- 1: The Reserved field is elided and assumed to be "0"

PAY: Optional Payload TLV

- 0: The Payload TLV is absent.
- 1: The Payload TLV is present and the type field is elided.

ILT: Optional Hop-By-Hop InterestLifetime TLV

See [Section 6.3.2.1](#) for further details on the ordering of hop-by-hop TLVs.

- 0: No InterestLifetime TLV is present in the Interest message.
- 1: An InterestLifetime TLV is present with a fixed length of 1 octet and is encoded as described in [Section 7](#). The type and length fields are elided. If a lifetime is not a valid time-value, then the lifetime is rounded up to the nearest valid time-value (see [Section 7](#)).

MGH: Optional Hop-By-Hop MessageHash TLV

See [Section 6.3.2.1](#) for further details on the ordering of hop-by-hop TLVs.

This TLV is expected to contain a T_SHA-256 TLV. If another hash is contained, then the Interest MUST be sent uncompressed.

- 0: The MessageHash TLV is absent.
- 1: A T_SHA-256 TLV is present and the type as well as the length fields are removed. The length field is assumed to represent 32 octets. The outer Message Hash TLV is omitted.

KIR: Optional KeyIdRestriction TLV

This TLV is expected to contain a T_SHA-256 TLV. If another hash is contained, then the Interest MUST be sent uncompressed.

- 0: The KeyIdRestriction TLV is absent.
- 1: A T_SHA-256 TLV is present and the type as well as the length fields are removed. The length field is assumed

to represent 32 octets. The outer KeyIdRestriction TLV is omitted.

CHR: Optional ContentObjectHashRestriction TLV

This TLV is expected to contain a T_SHA-256 TLV. If another hash is contained, then the Interest MUST be sent uncompressed.

- 0: The ContentObjectHashRestriction TLV is absent.
- 1: A T_SHA-256 TLV is present and the type as well as the length fields are removed. The length field is assumed to represent 32 octets. The outer ContentObjectHashRestriction TLV is omitted.

VAL: Optional ValidationAlgorithm and ValidationPayload TLVs

- 0: No validation related TLVs are present in the Interest message.
- 1: Validation related TLVs are present in the Interest message. An additional octet follows immediately that handles validation related TLV compressions and is described in [Section 6.3.2.2](#).

RSV: Reserved Must be set to 0.

[6.3.2.1](#). Hop-By-Hop Header TLVs Compression

Hop-By-Hop Header TLVs are unordered. For an Interest message, two optional Hop-By-Hop Header TLVs are defined in [[RFC8609](#)], but several more can be defined in higher level specifications. For the compression specified in the previous section, the Hop-By-Hop TLVs are ordered as follows:

1. Interest Lifetime TLV
2. Message Hash TLV

Note: Other Hop-By-Hop Header TLVs than those two remain uncompressed.

[6.3.2.2](#). Validation

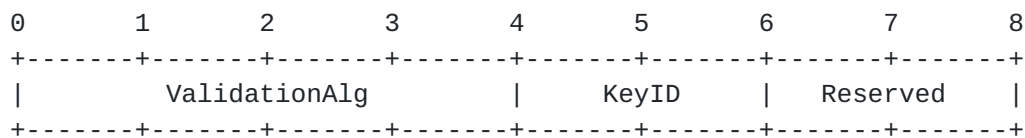


Figure 23: Dispatch for Intersect Validations

ValidationAlg: Optional ValidationAlgorithm TLV

- 0000: An uncompressed ValidationAlgorithm TLV is included.
- 0001: A T_CRC32C ValidationAlgorithm TLV is assumed, but no ValidationAlgorithm TLV is included.
- 0010: A T_CRC32C ValidationAlgorithm TLV is assumed, but no ValidationAlgorithm TLV is included. Additionally, a Sigtime TLV is inlined without a type and a length field.
- 0011: A T_HMAC-SHA256 ValidationAlgorithm TLV is assumed, but no ValidationAlgorithm TLV is included.
- 0100: A T_HMAC-SHA256 ValidationAlgorithm TLV is assumed, but no ValidationAlgorithm TLV is included. Additionally, a Sigtime TLV is inlined without a type and a length field.
- 0101: Reserved.
- 0110: Reserved.
- 0111: Reserved.
- 1000: Reserved.
- 1001: Reserved.
- 1010: Reserved.
- 1011: Reserved.
- 1100: Reserved.
- 1101: Reserved.
- 1110: Reserved.
- 1111: Reserved.

KeyID: Optional KeyID TLV within the ValidationAlgorithm TLV

- 00: The KeyId TLV is absent.
- 01: The KeyId TLV is present and uncompressed.
- 10: A T_SHA-256 TLV is present and the type field as well as the length fields are removed. The length field is assumed to represent 32 octets. The outer KeyId TLV is omitted.
- 11: A T_SHA-512 TLV is present and the type field as well as the length fields are removed. The length field is assumed to represent 64 octets. The outer KeyId TLV is omitted.

The ValidationPayload TLV is present if the ValidationAlgorithm TLV is present. The type field is omitted.

6.3.3. Dispatch Extension

The "EXT_0" octet follows the description in [Section 4.1.1](#) and is illustrated in Figure 24.

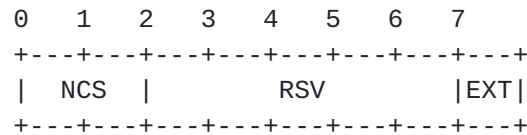


Figure 24: EXT_0 format

NCS: Name Compression Strategy

- 00: Names are compressed with the default name compression strategy (see [Section 5.2](#)).
- 01: Reserved.
- 10: Reserved.
- 11: Reserved.

RSV: Reserved Must be set to 0.

EXT: Extension

- 0: No extension octet follows.
- 1: A further extension octet follows immediately.

6.4. Content Objects

6.4.1. Uncompressed Content Objects

An uncompressed Content object uses the base dispatch format (see Figure 4) and sets the C flag to "0" and the M flag to "1" (Figure 25). "resv" MUST be set to 0. The Content object is handed to the CCNx network stack without modifications.

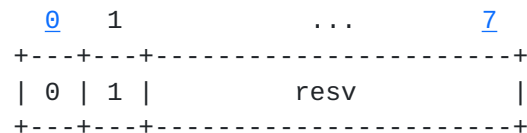


Figure 25: Dispatch format for uncompressed CCNx Content objects

6.4.2. Compressed Content Objects

The compressed Content object uses the extended dispatch format (Figure 5) and sets the C flag as well as the M flag to "1". If a Content object contains TLVs that are not mentioned in the following compression rules, then this message MUST be sent uncompressed.

By default, the Content object is compressed with the following base rule set:

1. The PacketType field is elided from the Fixed Header.
2. The Type and Length fields of the CCNx Message TLV are elided and are obtained from the Fixed Header on decompression.

The compressed CCNx LowPAN Data message is visualized in Figure 26.

T = Type, L = Length, V = Value

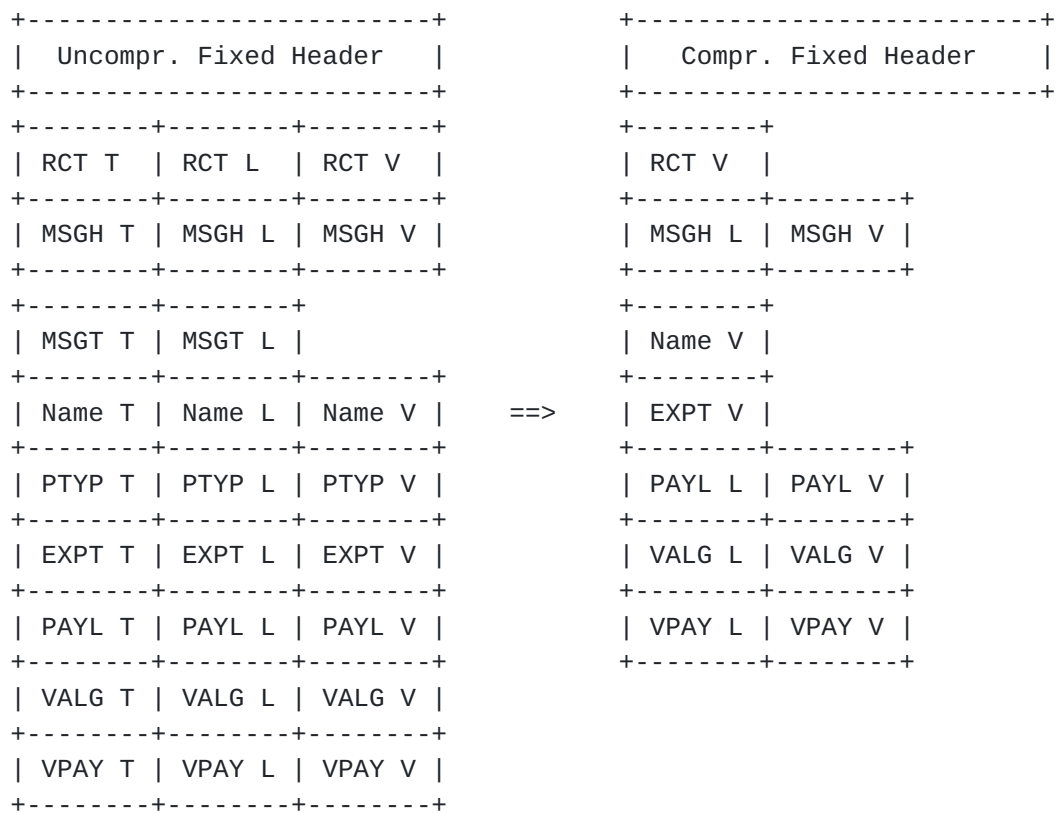


Figure 26: Compression of CCNx LowPAN Data Message

Further TLV compression is indicated by the ICN LowPAN dispatch in Figure 27.

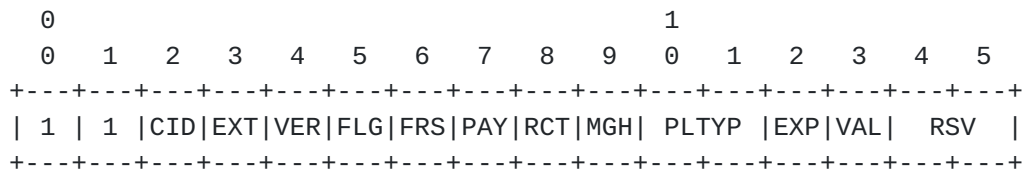


Figure 27: Dispatch format for compressed CCNx Content objects

CID: Context Identifier See Figure 5.

EXT: Extension

0: No extension octet follows.

1: Extension octet "EXT_0" follows immediately. See [Section 6.4.3](#).

VER: CCNx protocol version in the fixed header

- 0: The Version field equals 1 and is removed from the fixed header.
- 1: The Version field is carried in-line.

FLG: Flags field in the fixed header See [Section 6.3.2](#).

FRS: Reserved field in the fixed header See [Section 6.3.2](#).

PAY: Optional Payload TLV See [Section 6.3.2](#).

RCT: Optional Hop-By-Hop RecommendedCacheTime TLV

- 0: The Recommended Cache Time TLV is absent.
- 1: The Recommended Cache Time TLV is present and the type as well as the length fields are elided.

MGH: Optional Hop-By-Hop MessageHash TLV

See [Section 6.4.2.1](#) for further details on the ordering of hop-by-hop TLVs.

This TLV is expected to contain a T_SHA-256 TLV. If another hash is contained, then the Content Object MUST be sent uncompressed.

- 0: The MessageHash TLV is absent.
- 1: A T_SHA-256 TLV is present and the type as well as the length fields are removed. The length field is assumed to represent 32 octets. The outer Message Hash TLV is omitted.

PLTYP: Optional PayloadType TLV

- 00: The PayloadType TLV is absent.
- 01: The PayloadType TLV is absent and T_PAYLOADTYPE_DATA is assumed.
- 10: The PayloadType TLV is absent and T_PAYLOADTYPE_KEY is assumed.

11: The PayloadType TLV is present and uncompressed.

EXP: Optional ExpiryTime TLV

0: The ExpiryTime TLV is absent.

1: The ExpiryTime TLV is present and the type as well as the length fields are elided.

RSV: Reserved Must be set to 0.

VAL: Optional ValidationAlgorithm and ValidationPayload TLVs See Section 6.3.2.

6.4.2.1. Hop-By-Hop Header TLVs Compression

Hop-By-Hop Header TLVs are unordered. For a Content Object message, two optional Hop-By-Hop Header TLVs are defined in [RFC8609], but several more can be defined in higher level specifications. For the compression specified in the previous section, the Hop-By-Hop TLVs are ordered as follows:

1. Recommended Cache Time TLV
2. Message Hash TLV

Note: Other Hop-By-Hop Header TLVs than those two remain uncompressed.

6.4.3. Dispatch Extension

The "EXT_0" octet follows the description in [Section 4.1.1](#) and is illustrated in Figure 28.

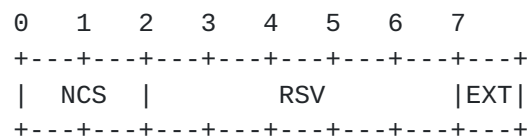


Figure 28: EXT_0 format

NCS: Name Compression Strategy

00: Names are compressed with the default name compression strategy (see [Section 5.2](#)).

01: Reserved.

10: Reserved.

11: Reserved.

RSV: Reserved Must be set to 0.

EXT: Extension

0: No extension octet follows.

1: A further extension octet follows immediately.

7. Compressed Time Encoding

This document adopts the compact time representation [[I-D.gundogan-icnrg-ccnx-timetlv](#)] for relative time values. Exponent (e) and mantissa (m) values are encoded in a 1-octet wide representation as depicted in Figure 29.

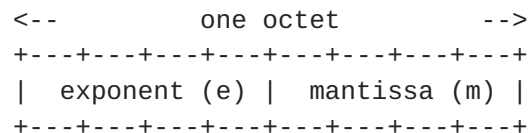


Figure 29: A time-code with exponent and mantissa to encode a logarithmic range time representation.

The mantissa size is set to 3 bits, the exponent size to 5 bits, and a bias of -5 is applied. This allows for a time representation that ranges from milliseconds with high precision to days with low precision. The base unit for time values are seconds. A time-value is calculated using the following formula, where (e) represents the exponent, (m) the mantissa, ($m_{\max} = 8$) the maximum mantissa value, and (b) the bias.

Subnormal ($e == 0$): $(0 + m/m_{\max}) * 2^{(1+b)}$

Normalized ($e > 0$): $(1 + m/m_{\max}) * 2^{(e+b)}$

The subnormal form provides a gradual underflow from the smallest normalized number towards zero.

This configuration allows for the following ranges:

- o Minimum subnormal number: 0 seconds
- o Maximum subnormal number: ~0.054688 seconds

- o Minimum normalized number: ~0.062500 seconds
- o Maximum normalized number: ~3.987284 years

Valid time-values are always positive numbers. An invalid time-value (t , in seconds) MUST be rounded down to the nearest valid time-value using this algorithm, where (e) represents the number of bits for the exponent, (m) the number of bits for the mantissa, and ($m_{\text{max}} = 8$) the maximum mantissa value. The bias (b) is set to -5 as before.

- o $e := \text{floor}(\log_2(t/(2^{-b})))$
- o $m := \text{floor}(8 * (t / 2^{(e+b)} - 1))$

8. Stateful Header Compression

Stateful header compression in ICN LowPAN enables packet size reductions in two ways. First, common information that is shared throughout the local LowPAN may be memorized in context state at all nodes and omitted from communication. Second, redundancy in a single Interest-data exchange may be removed from ICN stateful forwarding on a hop-by-hop bases and memorized in en-route state tables.

8.1. LowPAN-local State

A context identifier (CID) is an octet that refers to a particular conceptual context between network devices and MAY be used to replace frequently appearing information, such as name prefixes, suffixes, or meta information, such as Interest lifetime.

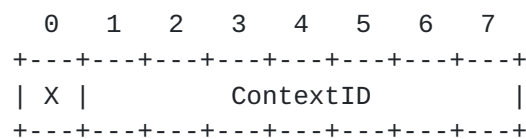


Figure 30: Context Identifier.

The ContextID refers to a locally-scoped unique identifier that represents contextual state shared between sender and receiver of the corresponding frame (see Figure 30).

Such state shared between senders and receivers is removed from the compressed packet prior to sending, and reinserted after reception prior to passing to the upper stack.

The initial distribution and maintenance of shared context is out of scope of this document. Frames containing unknown or invalid CIDs MUST be silently discarded.

8.2. En-route State

In CCNx and NDN, Name TLVs are included in Interest messages, and they return in data messages. Returning Name TLVs either equal the original Name TLV, or they contain the original Name TLV as a prefix. ICN LoWPAN reduces this redundancy in responses by replacing Name TLVs with single octets that represent link-local HopIDs. HopIDs are carried as Context Identifiers of link-local scope as shown in Figure 31.

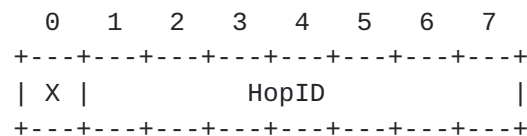


Figure 31: Context Identifier as HopID.

A HopID is valid, if not all ID bits are set to zero and invalid otherwise. This yields 127 distinct HopIDs. If this range (1...127) is exhausted, the messages MUST be sent without en-route state compression until new HopIDs are available. An ICN LoWPAN node that forwards without replacing the name by a HopID (without en-route compression) MUST invalidate the HopID by setting all ID-bits to zero.

While an Interest is traversing, a forwarder generates an ephemeral HopID that is tied to a PIT entry. Each HopID MUST be unique within the local PIT and only exists during the lifetime of a PIT entry. To maintain HopIDs, the local PIT is extended by two new columns: HIDi (inbound HopIDs) and HIDO (outbound HopIDs).

HopIDs are included in Interests and stored on the next hop with the resulting PIT entry in the HIDi column. The HopID is replaced with a newly generated local HopID before the Interest is forwarded. This new HopID is stored in the HIDO column of the local PIT (see Figure 32).

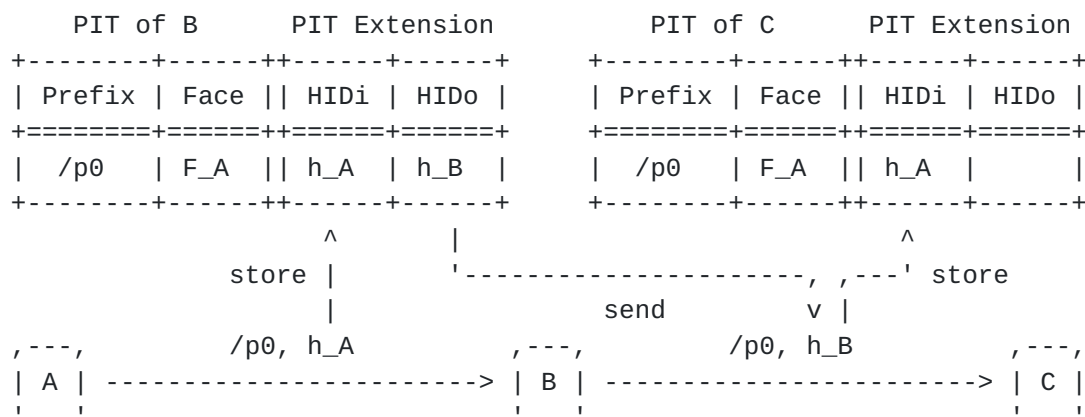


Figure 32: Setting compression state en-route (Interest).

Responses include HopIDs that were obtained from Interests. If the returning Name TLV equals the original Name TLV, then the name is entirely elided. Otherwise, the distinct suffix is included along with the HopID. When a response is forwarded, the contained HopID is extracted and used to match against the correct PIT entry by performing a lookup on the HIDo column. The HopID is then replaced with the corresponding HopID from the HIDi column prior to forwarding the response (Figure 33).

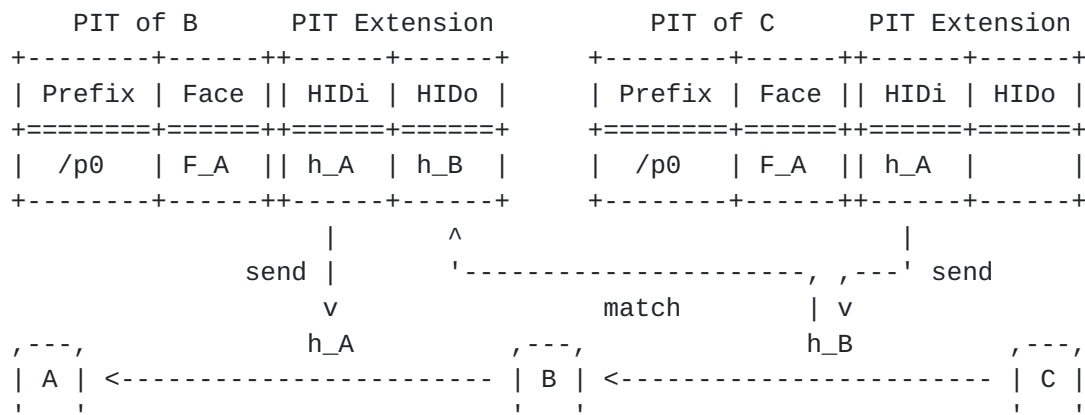


Figure 33: Eliding Name TLVs using en-route state (data).

It should be noted that each forwarder of an Interest in an ICN LowPAN network can individually decide whether to participate in en-route compression or not. However, an ICN LowPAN node SHOULD use en-route compression whenever the stateful compression mechanism is activated.

Note also that the extensions of the PIT data structure are required only at ICN LowPAN nodes, while regular NDN/CCNx forwarders outside of an ICN LowPAN domain do not need to implement these extensions.

8.3. Integrating Stateful Header Compression

A CID appears whenever the CID flag is set (see Figure 5). The CID is appended to the last ICN LowPAN dispatch octet as shown in Figure 34.

```

...-----+-----+-----+-----+-----+-----+
/  ...      | Page  | ICN LowPAN Disp. | CIDs | Payload /
...-----+-----+-----+-----+-----+-----+

```

Figure 34: LowPAN Encapsulation with ICN LowPAN and CIDs

Multiple CIDs are chained together, with the most significant bit indicating the presence of a subsequent CID (Figure 35).

```

+-+--+--+--+--+--+--+--+--+  +-+--+--+--+--+--+--+--+--+  +-+--+--+--+--+--+--+--+--+
|1|      CID      | --> |1|      CID      | --> |0|      CID      |
+-+--+--+--+--+--+--+--+--+  +-+--+--+--+--+--+--+--+--+  +-+--+--+--+--+--+--+--+--+

```

Figure 35: Chaining of context identifiers.

The HopID is always included as the very first CID.

9. ICN LowPAN Constants and Variables

This is a summary of all ICN LowPAN constants and variables.

DEFAULT_NDN_HOPLIMIT: 255

10. Implementation Report and Guidance

The ICN LowPAN scheme defined in this document has been implemented as an extension of the NDN/CCNx software stack [[CCN-LITE](#)] in its IoT version on RIOT [[RIOT](#)]. An experimental evaluation for NDN over ICN LowPAN with varying configurations has been performed in [[ICNLOWPAN](#)]. Energy profilings and processing time measurements indicate significant energy savings, while amortized costs for processing show no penalties.

10.1. Preferred Configuration

The header compression performance depends on certain aspects and configurations. It works best for the following cases:

- o Each name component is of GenericNameComponent type and is limited to a length of 15 bytes.
- o Relative time values use a compressed encoding as per [Section 7](#).

- o Contextual state (e.g., prefixes) is distributed, such that long names can be elided from Interest and data messages.

10.2. Further Experimental Deployments

An investigation of ICN LowPAN in large-scale deployments with varying traffic patterns using larger samples of the different board types available remains as future work. Especially for the stateful en-route compression and link fragmentation, complex deployment scenarios may provide a better insight regarding compression parameters. Multiple implementations that generate and deploy the compression options of this memo in different ways will also add to the experience and understanding of the benefits and limitations of the proposed schemes.

11. Security Considerations

Main memory is typically a scarce resource of constrained networked devices. Fragmentation as described in this memo preserves fragments and purges them only after a packet is reassembled, which requires a buffering of all fragments. This scheme is able to handle fragments for distinctive packets simultaneously, which can lead to overflowing packet buffers that cannot hold all necessary fragments for packet reassembly. Implementers are thus urged to make use of appropriate buffer replacement strategies for fragments.

The stateful header compression generates ephemeral HopIDs for incoming and outgoing Interests and consumes them on returning Data packets. Forged Interests can deplete the number of available HopIDs, thus leading to a denial of compression service for subsequent content requests.

To further alleviate the problems caused by forged fragments or Interest initiations, proper protective mechanisms for accessing the link-layer should be deployed.

12. IANA Considerations

12.1. Reserving Space in the 6LowPAN Dispatch Type Field Registry

IANA has assigned dispatch values of the "6LowPAN Dispatch Type Field" registry [[RFC4944](#)][RFC8025] with Page TBD1 for NDN and values with Page TBD2 for CCNx. Table 1 represents updates to the registry.

Bit Pattern	Page	Header Type
00 xxxxxx	TBD1	Uncompressed NDN Interest messages
01 xxxxxx	TBD1	Uncompressed NDN Data messages
10 xxxxxx	TBD1	Compressed NDN Interest messages
11 xxxxxx	TBD1	Compressed NDN Data messages
00 xxxxxx	TBD2	Uncompressed CCNx Interest messages
01 xxxxxx	TBD2	Uncompressed CCNx Content Object messages
10 xxxxxx	TBD2	Compressed CCNx Interest messages
11 xxxxxx	TBD2	Compressed CCNx Content Object messages

Table 1: Dispatch types for NDN and CCNx with pages TBD1 and TBD2.

13. References

13.1. Normative References

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<https://www.rfc-editor.org/info/rfc2119>.
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<https://www.rfc-editor.org/info/rfc4944>.
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13.2. Informative References

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 "CCN-lite: A lightweight CCNx and NDN implementation",
<http://ccn-lite.net/>.

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[NDN-EXP1]

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[NDN-EXP2]

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[NDN-MAC]

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Appendix A. Estimated Size Reduction

In the following a theoretical evaluation is given to estimate the gains of ICN LowPAN compared to uncompressed CCNx and NDN messages.

We assume that "n" is the number of name components, "comps_n" denotes the sum of n name component lengths. We also assume that the length of each name component is lower than 16 bytes. The length of the content is given by "clen". The lengths of TLV components is specific to the CCNx or NDN encoding and outlined below.

A.1. NDN

The NDN TLV encoding has variable-sized TLV fields. For simplicity, the 1 octet form of each TLV component is assumed. A typical TLV component therefore is of size 2 (type field + length field) + the actual value.

A.1.1. Interest

Figure 36 depicts the size requirements for a basic, uncompressed NDN Interest containing a CanBePrefix TLV, a MustBeFresh TLV, a InterestLifetime TLV set to 4 seconds and a HopLimit TLV set to 6. Numbers below represent the amount of octets.

-----	,	
Interest TLV	= 2	
-----	,	
Name	2 +	
NameComponents	= 2n +	
	comps_n	
-----	'	= 21 + 2n + comps_n
CanBePrefix	= 2	
MustBeFresh	= 2	
Nonce	= 6	
InterestLifetime	= 4	
HopLimit	= 3	
-----	'	

Figure 36: Estimated size of an uncompressed NDN Interest

Figure 37 depicts the size requirements after compression.

-----	,	
Dispatch Page Switch	= 1	
NDN Interest Dispatch	= 1	
Interest TLV	= 1	
-----	,	
Name		= 9 + n/2 + comps_n
NameComponents	= n/2 +	
	comps_n	
-----	,	
Nonce	= 4	
HopLimit	= 1	
InterestLifetime	= 1	
-----	,	

Figure 37: Estimated size of a compressed NDN Interest

The size difference is:
 $12 + 1.5n$ octets.

For the name "/DE/HH/HAW/BT7", the total size gain is 18 octets,
 which is 46% of the uncompressed packet.

[A.1.2.](#) Data

Figure 38 depicts the size requirements for a basic, uncompressed NDN Data containing a FreshnessPeriod as MetaInfo. A FreshnessPeriod of 1 minute is assumed and the value is encoded using 1 octet. An HMACWithSha256 is assumed as signature. The key locator is assumed to contain a Name TLV of length klen.

Data TLV	= 2	
Name	2 +	
NameComponents	= 2n +	
	comps_n	
MetaInfo		
FreshnessPeriod	= 6	= 53 + 2n + comps_n +
		clen + klen
Content	= 2 + clen	
SignatureInfo		
SignatureType		
KeyLocator	= 41 + klen	
SignatureValue		
DigestSha256		

Figure 38: Estimated size of an uncompressed NDN Data

Figure 39 depicts the size requirements for the compressed version of the above Data packet.

Dispatch Page Switch	= 1	
NDN Data Dispatch	= 1	
Name		= 37 + n/2 + comps_n +
NameComponents	= n/2 +	clen + klen
	comps_n	
Content	= 1 + clen	
KeyLocator	= 1 + klen	
DigestSha256	= 32	
FreshnessPeriod	= 1	

Figure 39: Estimated size of a compressed NDN Data

The size difference is:
16 + 1.5n octets.

For the name "/DE/HH/HAW/BT7", the total size gain is 22 octets.

A.2. CCNx

The CCNx TLV encoding defines a 2-octet encoding for type and length fields, summing up to 4 octets in total without a value.

A.2.1. Interest

Figure 40 depicts the size requirements for a basic, uncompressed CCNx Interest. No Hop-By-Hop TLVs are included, the protocol version is assumed to be 1 and the reserved field is assumed to be 0. A KeyIdRestriction TLV with T_SHA-256 is included to limit the responses to Content Objects containing the specific key.

-----	,	
Fixed Header	= 8	
Message	= 4	
-----	,	
Name	4 +	= 56 + 4n + comps_n
NameSegments	= 4n +	
-----	comps_n	
-----	'	
KeyIdRestriction	= 40	
-----	'	

Figure 40: Estimated size of an uncompressed CCNx Interest

Figure 41 depicts the size requirements after compression.

-----	,	
Dispatch Page Switch	= 1	
CCNx Interest Dispatch	= 2	
Fixed Header	= 3	
-----	,	
Name		= 38 + n/2 + comps_n
NameSegments	= n/2 +	
-----	comps_n	
-----	'	
T_SHA-256	= 32	
-----	'	

Figure 41: Estimated size of a compressed CCNx Interest

The size difference is:
 $18 + 3.5n$ octets.

For the name "/DE/HH/HAW/BT7", the size is reduced by 53 octets, which is 53% of the uncompressed packet.

A.2.2. Content Object

Figure 42 depicts the size requirements for a basic, uncompressed CCNx Content Object containing an ExpiryTime Message TLV, an HMAC_SHA-256 signature, the signature time and a hash of the shared secret key. In the fixed header, the protocol version is assumed to be 1 and the reserved field is assumed to be 0

Fixed Header	= 8	
Message	= 4	
-----,		
Name	4 +	
NameSegments	= 4n +	
	comps_n	
-----,		
ExpiryTime	= 12	= 124 + 4n + comps_n + clen
Payload	= 4 + clen	
-----,		
ValidationAlgorithm		
T_HMAC-256	= 56	
KeyId		
SignatureTime		
-----,		
ValidationPayload	= 36	
-----,		

Figure 42: Estimated size of an uncompressed CCNx Content Object

Figure 43 depicts the size requirements for a basic, compressed CCNx Data.

-----	,	
Dispatch Page Switch	= 1	
CCNx Content Dispatch	= 3	
Fixed Header	= 2	
-----	,	
Name		
NameSegments	= n/2 +	
	comps_n	= 89 + n/2 + comps_n + clen
-----	'	
ExpiryTime	= 8	
Payload	= 1 + clen	
T_HMAC-SHA256	= 32	
SignatureTime	= 8	
ValidationPayload	= 34	
-----	'	

Figure 43: Estimated size of a compressed CCNx Data Object

The size difference is:
 $35 + 3.5n$ octets.

For the name `"/DE/HH/HAW/BT7"`, the size is reduced by 70 octets,
 which is 40% of the uncompressed packet containing a 4-octet payload.

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