

# Binary Representation of Device Descriptions: CBOR versus RDF HDT

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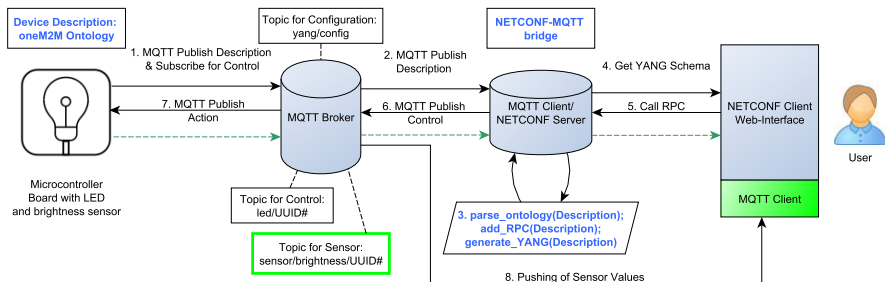


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# Extended System-Architecture with NETCONF-MQTT bridge



# Challenge

Ontology-based Device Description  
has a file size of ca. 19 kB using JSON-LD syntax.



# Ontology for Device Descriptions

Example of ontology in JSON-LD Syntax

---

```
1 "@id" :
2     "https://www.cs.uni-potsdam.de/bs/research
      /myno#myDevice",
3 "@type" :
4     ["http://www.w3.org/2002/07/owl#
      NamedIndividual",
5     "http://www.onem2m.org/ontology/
      Base_Ontology/base_ontology#Device"],
6     "http://www.onem2m.org/ontology/
      Base_Ontology/base_ontology#
      hasFunctionality" :
7     [ { "@id" : "https://www.cs.uni-potsdam.de
      /bs/research/myno#switchOff" } ],
```

---



# Ontology for Device Descriptions

Example of ontology in JSON-LD Syntax, optimized

```
1 { "@context": {
2   "oneM2M": "http://www.onem2m.org/ontology/
   Base_Ontology/base_ontology#",
3   "myno": "https://www.cs.uni-potsdam.de/bs/
   research/myno#" },
4 "@graph": [
5 {   "@id": "myno:myDevice",   ...  },
6   "@type": [
7     "owl:NamedIndividual",
8     "base:Device" ],
9   "oneM2M:hasFunctionality": [
10    { "@id": "myno:funcSwitchOff" },   ...
```



# Requirements for compression of ontology file

- small file size regarding 32 kiB RAM (and 512 kiB Flash memory)
- ontology data structures, particularly strings and structural elements like curly and square braces, should be compressed efficiently
- possibility to edit the file on a constrained device e.g. to change the UUID



# Evaluation of binary compression

Two obvious candidates

- CBOR
- RDF HDT



# Concise Binary Object Representation (CBOR)

RFC 7049 [BH13] in 2013

Each byte is encoded as a major type (the high-order 3 bits) and additional information (the low-order 5 bits).

X X X		X X X X X
major type		additional information





# CBOR Major Types

	Major Type
0	unsigned integer
1	negative integer
2	byte string
3	text string
4	array of data items
5	map of pairs of data items
6	optional semantic tagging of other major types
7	floating-point numbers and simple data types



# CBOR Encoding Examples

datatype	value	major type	add. info.	hex	binary
integer	20	0	20	0x14	000 10100
string	CBOR	3	4 (str. length)	0x6443424F52	*

\*011 00100 01000011 01000010 01001111 01010010



# CBOR Evaluation Results

Better result was achieved through JSON-LD optimization

- introduce context prefix for namespaces
- remove unnecessary white spaces and tabs

Ontology file size in Bytes for JSON-LD and CBOR

JSON-LD	19,771	18.43% space savings
CBOR	16,126	

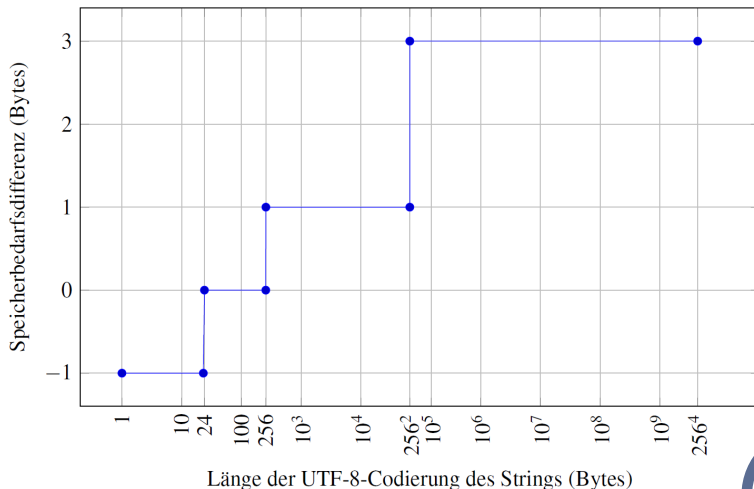
Ontology file size in Bytes for JSON-LD (opt.) and CBOR

JSON-LD (opt.)	7,640	14.65% space savings
CBOR	<b>6,520</b>	



# String Encoding in CBOR comparing to JSON [Hof18]

Additional storage consumption for encoding of strings in CBOR comparing to JSON



# Possibility to replace the UUID using placeholders

```

ch@context;dbase;xhttp://www.onem2m.org/ontology/Base_Ontologyv/base_ontologyv:cowlxRS
http://www.w3.org/2002/07/owl#rdfs:Class;http://www.w3.org/1999/02/22-rdf-syntax-ns#rdfs:Class;http://www.w3.org/2000/01/rdf-schema#
xsd:integer;http://www.w3.org/2001/XMLSchema#boolean;http://yang-netconf-mqtt#graph
*cc@idbase:Commande@typeowl:Class*cc@idbase:ControllingFunctionality@typeowl:Class*cc@idbase:Devicee@typeowl:Class*
cc@idbase:MeasuringFunctionality@typeowl:Class*cc@idbase:Operation@typeowl:Class*cc@idbase:OperationInpute@typeowl:Class*
cc@idbase:OperationOutput@typeowl:Class*cc@idbase:OperationStatee@typeowl:Class*cc@idbase:OutputDataPointe@typeowl:Class*
cc@idbase:Servicee@typeowl:Class*cc@idbase:ThingProperty@typeowl:Class*cc@idbase:exposesCommande@typeowl:ObjectPro
perty*cc@idbase:exposesFunctionality@typeowl:AnnotationProperty*cc@idbase:hasCommande@typeowl:ObjectProperty*cc@idbase:US
base:hasDataRestriction_patterne@typeowl:DatatypeProperty*cc@idbase:hasFunctionality@typeowl:AnnotationProperty*cc@idbase:h
asInpute@typeowl:ObjectProperty;rdfs:range;cc@idbase:ThingProperty*cc@idbase:hasOperatione@typeowl:ObjectProperty*cc@idbase
:hasOperationStatee@typeowl:ObjectProperty*cc@idbase:hasOutpute@typeowl:ObjectProperty*cc@idbase:hasOutputDataPointe@type
owl:ObjectProperty*cc@idbase:hasServicee@typeowl:ObjectProperty*cc@idbase:hasSubServicee@typeowl:ObjectProperty*cc@idbase
:hasThingProperty@typeowl:ObjectProperty*cc@idbase:hasValuee@typeowl:DatatypeProperty*cc@idbase:
http://yang-netconf-mqtt#typeowl:Ontologykowl:import;cc
idx#http://www.onem2m.org/ontology/Base_Ontologyv/base_ontologyv-v0_9_0
cc@idynm:YangDescriptione@typeowl:Class;rdfs:subClassOf;cc@idbase:ThingProperty*cc@idynm:cmdGreene@type,owl:NamedIndividu
albase:Commandbase:hasInput;cc@idynm:uidInput*cc@idynm:cmdOffe@type,owl:NamedIndividualbase:Commandbase:hasInput;cc@idm
ynm:uidInput*cc@idynm:cmdOne@type,owl:NamedIndividualbase:Commandbase:hasInput;cc@idynm:uidInput*cc@idynm:cmdSetColore@
type,owl:NamedIndividualbase:Commandbase:hasInput;cc@idynm:colorInput;cc@idynm:uidInput*cc@idynm:colorInpute@type,owl:
NamedIndividualbase:OperationInput*USbase:hasDataRestriction_pattern_callegreenforangedredyellowbase:hasThingProperty;cc@
idynm:colorYangDesc*cc@idynm:colorYangDesc@type,owl:NamedIndividualbase:YangDescriptionbase:hasValuecolor
parameter*cc@idynm:deviceCategorye@type,owl:NamedIndividualbase:ThingPropertybase:hasValueLED-LAMP*cc@idynm:deviceDesc@
type,owl:NamedIndividualbase:YangDescriptionbase:hasValue*cc@idynm:MQTT-Device identified by
UUID*cc@idynm:deviceUide@type,owl:NamedIndividualbase:ThingPropertybase:hasValue*F97DF79-8A12-4F4F-8F69-6B8F3C2E78DDE*cc@
idynm:funcDescBrighte@type,owl:NamedIndividualbase:YangDescriptionbase:hasValue*cc@idynm:request brightness
value*cc@idynm:funcDescColore@type,owl:NamedIndividualbase:YangDescriptionbase:hasValue*cc@idynm:arbitrary LED
color*cc@idynm:funcDescGreene@type,owl:NamedIndividualbase:YangDescriptionbase:hasValue*cc@idynm:Set the led color to
green*cc@idynm:funcDescSwitchOffe@type,owl:NamedIndividualbase:YangDescriptionbase:hasValue*cc@idynm:Switches the led
off*cc@idynm:funcDescSwitchOne@type,owl:NamedIndividualbase:YangDescriptionbase:hasValue*cc@idynm:Switches the led
on*cc@idynm:funcGetBrighte@type,owl:NamedIndividualbase:MeasuringFunctionalitybase:hasThingProperty;cc@idynm:
Bright*cc@idynm:funcSetColore@type,owl:NamedIndividualbase:ControllingFunctionalitybase:hasCommand;cc@idynm:
rbase:hasThingProperty;cc@idynm:funcDescColor*cc@idynm:funcSetGreene@type,owl:NamedIndividualbase:Controlling
Functionalitybase:hasCommand;cc@idynm:cmdGreenbase:hasThingProperty;cc@idynm:funcDescGreen*cc@idynm:funcSwitchOffe@type
owl:NamedIndividualbase:ControllingFunctionalitybase:hasCommand;cc@idynm:cmdOffbase:hasThingProperty;cc@idynm:funcDe
c@idynm:funcSwitchOne@type,owl:NamedIndividualbase:ControllingFunctionalitybase:hasCommand;cc@idynm:cmdOn

```



# Ontology Structure

The ontology defines so-called *Triples*:

***Subject*** → ***Predicate*** → ***Object*** (***SPO***)

An example for an *SPO triple* within IoT:

***myDevice*** → ***hasFunctionality*** → ***funcSwitchOff***



# RDF HDT

W3C Member Submission [FMPGP11] from 2011

HDT splits ontology file in three logical components:  
Header, Dictionary and Triples

- Header holds meta data about the file using a plain RDF structure.
- The Dictionary is a catalog of triples for the used terms based on Front-Coding which is again based on words with similar prefix. Subjects, Predicates and Objects are subsumed in sections to avoid repeating. Each section is sorted lexicographically and then IDs are assigned to each term.
- RDF Triples are now tuples of three IDs.



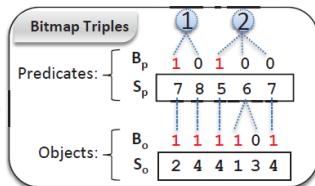
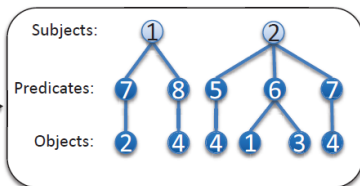
# RDF HDT

HDT proposes an encoding of Triples called Bitmap Triples (BT)

## ID-triples

```

1 7 2 .
1 8 4 .
2 5 4 .
2 6 1 .
2 6 3 .
2 7 4 .
  
```





# RDF HDT File Example

## Header with Meta Data

```
$HDT.<http://purl.org/HDT/hdt#HDTv1>..v5$HDT.ntriples.length=1834;Âr<file://mqt-cap-json-v5-2-turtle-opt.owl>
<http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://purl.org/HDT/hdt#Dataset>
..<file://mqt-cap-json-v5-2-turtle-opt.owl> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type>
<http://rdfs.org/ns/void#Dataset> ..<file://mqt-cap-json-v5-2-turtle-opt.owl> <http://rdfs.org/ns/void#triples> "179"
..<file://mqt-cap-json-v5-2-turtle-opt.owl> <http://rdfs.org/ns/void#properties> "19"
..<file://mqt-cap-json-v5-2-turtle-opt.owl> <http://rdfs.org/ns/void#distinctSubjects> "61"
..<file://mqt-cap-json-v5-2-turtle-opt.owl> <http://rdfs.org/ns/void#distinctObjects> "76"
..<file://mqt-cap-json-v5-2-turtle-opt.owl> <http://purl.org/HDT/hdt#statisticalInformation> _:statistics
..<file://mqt-cap-json-v5-2-turtle-opt.owl> <http://purl.org/HDT/hdt#publicationInformation> _:publicationInformation
..<file://mqt-cap-json-v5-2-turtle-opt.owl> <http://purl.org/HDT/hdt#formatInformation> _:format .._:format
<http://purl.org/HDT/hdt#dictionary> _:dictionary .._:format <http://purl.org/HDT/hdt#triples> _:triples .._:dictionary
<http://purl.org/dc/terms/format> <http://purl.org/HDT/hdt#dictionaryFour> .._:dictionary
<http://purl.org/HDT/hdt#dictionarynumSharedSubjectObject> "41" .._:dictionary <http://purl.org/HDT/hdt#dictionarymapping>
"1" .._:dictionary <http://purl.org/HDT/hdt#dictionarysizeStrings> "3750" .._:dictionary
<http://purl.org/HDT/hdt#dictionaryblockSize> "16" .._:triples <http://purl.org/dc/terms/format>
<http://purl.org/HDT/hdt#triplesBitmap> .._:triples <http://purl.org/HDT/hdt#triplesnumTriples> "179" .._:triples
<http://purl.org/HDT/hdt#triplesOrder> "SPO" .._:statistics <http://purl.org/HDT/hdt#originalSize> "9992" .._:statistics
<http://purl.org/HDT/hdt#hdtSize> "4279" .._:publicationInformation <http://purl.org/dc/terms/issued>
"2018-06-14T09:10:46+02:00"..
```



# RDF HDT File Example

## Dictionary

```

$HDT.<http://purl.org/HDT/hdt#dictionaryFour>.mapping=1;sizeStrings=6234;..ä.@"..).].].d0šší["http://www.onem2m.org/ontology/
Base_Ontology/base_ontology#Command.&ntrollingFunctionality.>Device.>MeasuringFunctionality.>Operation.&Input.&State.&outputDat
aPoint.>Service.>ThingProperty.&yang-netconf-mqtt#YangDescription.&cmdGreen.&Off..n.&SetColor.&olorInput.http://yang-netconf-m
qtt#colorYangDesc.&deviceCategory.&Desc.&YUID.&funcDescBright.;Color.;Green.;SwitchOff..n.&GetBright..SetColor..Green.&witchOf
f.&n.&opDescState.&MqttGreen.http://yang-netconf-mqtt#opMqttOff..n.&YSetColor.>State.&utDpBrightness.&servBrightness..Netconf.&
uidInput..YangDesc.-Û
."I,...fV..&.4w]Íhttp://www.onem2m.org/ontology/Base_Ontology/base_ontology#OperationOutput.>exposesCommand.&Functionality.&h
asCommand.&DataRestriction_pattern.&Functionality.&Input.&Operation.&State.&output.&DataPoint.&Service.&ubService.&ThingPropert
y.&Value.&yang-netconf-mqtt.http://yang-netconf-mqtt#mqttMethod..Topic.&yDevice.&paramYangDesc.,š0x."w,.4..fV.XP.&ÄÈ=http://ww
w.onem2m.org/ontology/Base_Ontology/base_ontology#exposesCommand.&Functionality.>hasCommand.&DataRestriction_pattern.&Function
ality.&Input.&Operation.&State.&outputDataPoint.&Service.&ubService.&ThingProperty.&Value.<w3.org/1999/02/22-rdf-syntax-ns#type
.&'2000/01/rdf-schema#range.&subclassOf.http://www.w3.org/2002/07/owl#imports.&yang-netconf-mqtt#mqttMethod..Topic.k*Ei.f.Ž.Ě..
.&1.°.-2./W"ERROR"^^<http://www.w3.org/2001/XMLSchema#string>..F9DF79-8A12-4F4F-8F69-6B8F3C2E78DD"^^<http://www.w3.org/2001/X
MLSchema#string>..GREEN"^^<http://www.w3.org/2001/XMLSchema#string>..LED=LAMP"^^<http://www.w3.org/2001/XMLSchema#string>..MQT
T=Device identified by
UUID"^^<http://www.w3.org/2001/XMLSchema#string>..NOOP"^^<http://www.w3.org/2001/XMLSchema#string>..OFF"^^<http://www.w3.org/2
001/XMLSchema#string>.,K"^^<http://www.w3.org/2001/XMLSchema#string>.,N"^^<http://www.w3.org/2001/XMLSchema#string>..Set the
led color to green"^^<http://www.w3.org/2001/XMLSchema#string>.,witches the led
off"^^<http://www.w3.org/2001/XMLSchema#string>..n"^^<http://www.w3.org/2001/XMLSchema#string>..Target UUID for
request"^^<http://www.w3.org/2001/XMLSchema#string>..all"^^<http://www.w3.org/2001/XMLSchema#string>..color
parameter"^^<http://www.w3.org/2001/XMLSchema#string>..t"^^<http://www.w3.org/2001/XMLSchema#string>..error"^^<http://www.w3.or
g/2001/XMLSchema#string>..green"^^<http://www.w3.org/2001/XMLSchema#string>..led"^^<http://www.w3.org/2001/XMLSchema#string>..
nothing to do"^^<http://www.w3.org/2001/XMLSchema#string>..orange"^^<http://www.w3.org/2001/XMLSchema#string>..parameter
value"^^<http://www.w3.org/2001/XMLSchema#string>..red"^^<http://www.w3.org/2001/XMLSchema#string>..fquest brightness
value"^^<http://www.w3.org/2001/XMLSchema#string>..sensor/brightness/led01"^^<http://www.w3.org/2001/XMLSchema#string>..ft
arbitrary LED
color"^^<http://www.w3.org/2001/XMLSchema#string>.,successful"^^<http://www.w3.org/2001/XMLSchema#string>..yellow"^^<ht
p://www.w3.org/2001/XMLSchema#string>.&http://www.onem2m.org/ontology/Base_Ontology/base_ontology-v0_9_0.<w3.org/2002/07/c
onProperty.&Class.&DatatypeProperty.http://www.w3.org/2002/07/owl#NamedIndividual.&ObjectProperty.&ntology./#0.

```



# RDF HDT File Example

## Triples with IDs

```
$HDT.<http://purl.org/HDT/hdt#triplesBitmap>.order=1;.Yé.ú1ÿ«JUUSIA..) 'pb;._«-Ñ.3.#ÿšVaŮq̄mŮÝ|z¿šŮY/Änyÿ.!.5ÿ-x..úšf9çæsi9hæqZ.
GK@'æšk@'æškž'ÄŮ`n07#...ää..99fANÍ`.""0ç!HNæÁ.sÍ9çæsi9çæsi'è\QI5.±.¶6..3..HHHHHHHHHHH.(J(J(J.(J7;>@E..J8.J-.J..J+.JA.JC.J3.
J4.J5.J..J...J...J...J:=D.J.($.J,<.($.J0<.($.J2<..($.J9<*/1..J.JB.%.J....
!"#$.J.) .J6.JHRGKIGK.KKKKKKKILFII.....'.....J?.J]`8U
```



# RDF HDT Evaluation Results

Optimization through redundancy avoidance in RDF HDT

Ontology file size in Bytes for Turtle and RDF HDT

Turtle	20,385
HDT	5,568

72.68% space savings

Ontology file size in Bytes for Turtle (opt.) and RDF HDT

Turtle (opt.)	9,992
HDT	5,513

44.82% space savings



# RDF HDT Evaluation Results

Better string syntax in N-Triples through elimination of the data type  
`http://www.w3.org/2001/XMLSchema#string` at every string

Ontology file size in Bytes for N-Triples

N-Triples	27,025
HDT	<b>4,307</b>

84.06% space savings



# Conclusion

Ontology file size in Bytes for JSON-LD (opt.) and CBOR

JSON-LD (opt.)	7,640
CBOR	<b>6,520</b>

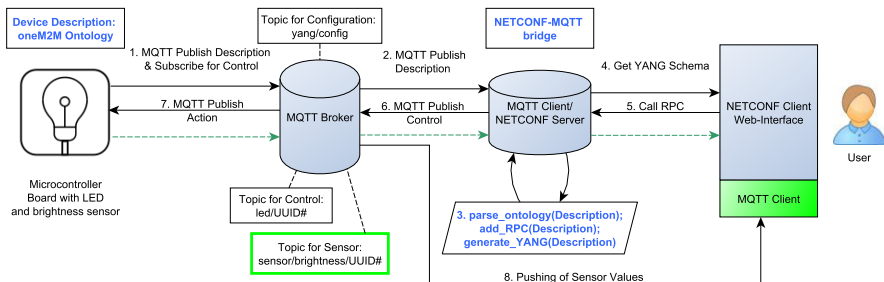
Ontology file size in Bytes for N-Triples and RDF HDT

N-Triples	27,025
HDT	<b>4,307</b>

- possible to edit the files on constrained devices e.g. to change the UUID
- RDF HDT shows better results for our use case
- CBOR is still suitable for sensor data (integer values etc.)



# Demo: An Ontology-based NETCONF-MQTT Bridge for Sensor Devices in the IoT



# Contact

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# Literatur



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