HDC Protocol Specification

Specification of HDC 1.0.0-alpha.9

About this document

WARNING: This document is currently still being drafted!

The "*HDC Protocol Specification*", or “HDC-spec”, for shorthand, is the formal definition of the Host Device Communication protocol, and its purpose is to ensure the interoperability of its implementations over a wide variety of platforms. The HDC protocol aims to become an *open standard* for which this HDC-spec is intended to be the *single source of truth* of its specification.

Intended audience

This document is a riguros specification of HDC concepts and its ***internals***. It will therefore be of little use for anybody who only needs to use the API of a library that readily implements all of that. Please refer to the specific documentation of ready-to-use libraries for your language of choice: hdcproto for Python, or the STM32 HAL driver for C. (More to come, once a stable HDC-spec is released).
The chapters of this document, however, are sorted from high-level to low-level concepts, so it’s

Contributing to this document

This document is being authored collectively on Google Docs, where everybody is invited to contribute their feedback. Alternatively it can be reported via the issue tracker.
The most recent snapshot of HDC-spec is published as a PDF document in the official repository.

License of the HDC Protocol Specification

About the license

- The license shown above **only** applies to this document, but the source-code published in the https://github.com/kiksotik/hdc repository is licensed under the “MIT License”, instead.

- Standards don't work well if everybody cooks its own variant.
  I’ve nevertheless chosen a permissive license, because “*the crowd”* is sometimes better at consolidating a standard, than a single individual is.

- It would be greatly appreciated if any derivative work that modifies any of the conventions defined herein would also change the name of their protocol, as to avoid any potential confusion.

Table of Contents

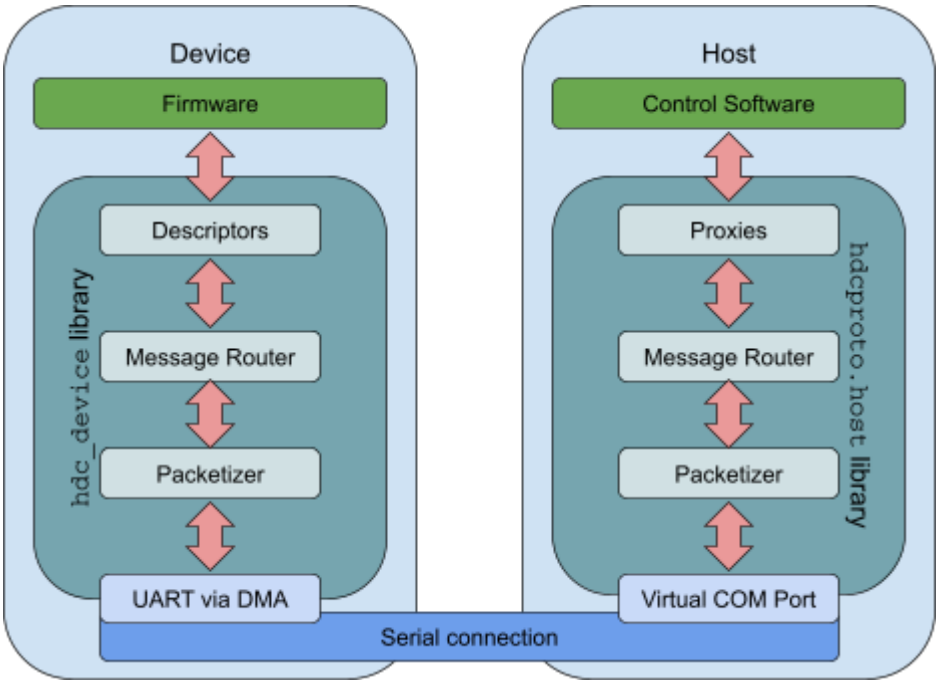
Summary and terminology

The following, highlighted terms have specific meanings in the context of the HDC protocol:

> The HDC protocol defines a ***device*** as being a ***serve***r, which ***replies*** to ***requests*** sent by a ***host***.
>
> At the highest level of abstraction, the capabilities of a device are grouped into ***features***, each exposing a set of ***properties***, ***commands*** and ***events***. A host can use ***introspection*** to discover all of these things and obtain further details about each of them.
>
> At the lowest level of abstraction, HDC specifies how the above is implemented by means of ***messages*** and how those are ***packetized*** for transmission over a ***serial connection***.

Architecture (and more terminology)

The high-level concepts defined by the HDC protocol are essentially an object-oriented API, which unburdens users from having to care about the actual communication protocol that is implemented by an HDC library.
The ***firmware*** of a device declares its capabilities by means of ***descriptors*** that carry some callbacks and all meta-data necessary to fully describe and document each capability.
The ***control software*** of the host interacts with ***proxy-classes*** that mirror the capabilities actually implemented on the device.



Devices

A device is essentially a server whose only client is the host.
All replies sent by a device must have been requested by the host, with exception of events, which a device can raise autonomously.

The HDC protocol is optimized for devices with very limited computing resources; typically microcontrollers with only a few kilobytes of RAM and FLASH memory, executing firmware written in C or C++.

Hosts

The host runs the software which operates/controls/monitors the device.
A host can be connected to multiple devices, each via a dedicated serial connection.
Typically this is a laptop, desktop or embedded PC, capable of executing software written in high level languages like Python, Java, C#, …

Features

The term ***feature*** is intentionally ambiguous, because HDC handles all features in exactly the same manner, regardless of their nature and purpose.
It's therefore only for the sake of comprehension, that features can be categorized as follows:

- Hardware-Features
    - Represent a device's hardware module.
    - e.g.: a thermostat module, a linear axis, an optics-module, …
- Activity-Features
    - Represent a device's ability to perform a certain operation.
    - e.g.: a measurement operation that acquires data.
- … and it's ultimately up to the implementation of each particular device to define what the nature of a feature may be.

Facts about HDC-features:

- The feature abstraction in HDC is meant to match the object-oriented abstraction of the device's implementation, which as a consequence can easily be projected as an equivalent proxy object on the host.
    - If the firmware of the device organizes for example all temperature control related capabilities in a Thermostat object/module, it will likely also make sense for its HDC interface to expose an equivalent Thermostat-feature, which in turn can be handled with a Thermostat-proxy on the host.
    - Note how the HDC features, commands, properties and events map quite naturally into the objects, methods, properties and events of object-oriented languages.
    - Feature implementations are consequently easy to reuse across multiple device implementations. ("Code reusability" and modularity of source-code)
- All commands, properties and events must be implemented in the context of a feature.
    - Except for the `EchoMessage` described further below.
- Features of a device are identified by means of a unique UINT8 value named `FeatureID`.
    - A device can therefore implement a maximum of 256 features.
    - Features cannot be nested into sub-features.
    - `FeatureID` values may not be sequential.
        - e.g.: a device may implement `FeatureIDs` 0x00, 0x42, 0xD7
    - A `FeatureID` is only used for addressing purposes and only `FeatureID=0x00` is hard-coded for a particular purpose, while all other `FeatureIDs` may be assigned differently on different device implementations, e.g:
        - A Thermostat-feature may be `FeatureID=0x01` on one revision of a device and `FeatureID=0x44` on another.
        - It's up to the host's implementation to either hard-code `FeatureID` values for a specific device revision or to use introspection to infer the `FeatureID` of a certain feature.

The mandatory Core-Feature

A device must implement a Core-Feature with `FeatureID=0x00`, which besides implementing all mandatory properties of any feature, also must implement the following additional ones:

PropertyID	PropertyName	DataType	Description
0xFA	AvailableFeatures	BLOB	List of IDs of features available on the device.
0xFB	MaxReqMsgSize	UINT16	Maximum number of bytes of a request message that the device can cope with.

The Core-Feature may implement whatever further commands, properties and events are appropriate for the ***core*** of a particular device implementation.
Some examples of what a device's core-feature may typically implement:

- A read-only property to expose the serial-number of a device.
- A read-writable string property to store information about the most recent maintenance

A command to switch into the bootloader mode.

Feature state

Each feature can implement its own state-machine via the mandatory `FeatureState` property and notifying any state-transition by means of the mandatory `FeatureStateTransition` event.

Recommendations:

- Document all possible values of the FeatureState property via its property-description string expressed in python dictionary curly brace syntax, like for example:
  `"{0:'Initializing', 1:'NotReady', 2:'Ready', 3:'Acquiring', 0xFF:'Error'}"`
- Naming recommendations for typical states:
  - Off
  - Initializing
  - NotReady
  - Ready
  - Preparing
  - Acquiring
  - Error

Feature logger

Each feature can implement its own logger by means of the mandatory `Log` event and also allow tuning its verbosity by means of the mandatory `LogEventThreshold` property whose UINT8 values mimic the logging levels of the python logging module:

UINT8 value of `LogEventThreshold`	Name	Description
`10`	DEBUG	Most detailed information, which might be useful when proactively debugging a certain issue.
`20`	INFO	Useful information to confirm that everything is working as it should.
`30`	WARNING	Something unexpected has happened or some problem is about to happen in the near future.
`40`	ERROR	An error has occurred. The software was unable to perform some function.
`50`	CRITICAL	A serious error has occurred. Device itself may not be able to continue running properly, i.e. entered a safe-state or even shut itself down.

Other logging levels are not supported.

It's up to each device's implementation to decide to which level the `LogEventThreshold` gets initialized, but a device must not change this value afterwards, because the host caches this value and does not expect a device to change it dynamically.

Feature introspection

A host can obtain a list of `FeatureID` values implemented on a device, via the mandatory property:

- `CoreFeature.AvailableFeatures`

It can then obtain further details about each feature, via the mandatory properties implemented on every feature:

- `FeatureName`
  - A UTF8 string, unique among all features implemented on a device.
  - Typically a human-readable name in camel-case without any whitespace.
  - Example values:
    - Core
    - Thermostat
    - AxisX

- `FeatureTypeName`
  - A UTF8 string, ideally unique among all existing feature implementations.
  - TBD: Namespace dot syntax?

- `FeatureTypeRevision`
  - A UINT8 number, to be incremented whenever a feature's implementation changes, without significantly affecting the HDC-interface of the feature. More disrupting changes should preferably be documented by using a different `FeatureTypeName`.

- `FeatureDescription`
  - A UTF8 string, that may be empty.
  - May contain multiple lines of text, which must be delimited with newlines (`\n`) only.

- `FeatureTags`
  - A UTF8 string containing a semi-colon delimited list of tags.
  - Tags allow for the flexible categorization of features and the implementation of future hacks and workarounds.
    Some ideas for tags:
    - Types of features: Hardware-feature, Activity-feature, State-feature, …
    - Declaration of more granular interfaces implemented by a feature.
      - E.g.: `ImplementsStateMachine`
    - Injection of further meta-data by means of a key=value syntax
      - E.g.: `ReleaseDate=2028-Nov-24`
  - TBD: Rough guidelines for the tagging system.

Commands

`Commands` are essentially “remote procedure calls” of procedures implemented on a specific feature of a device. The host sends a ***request*** message to the device, which will acknowledge completion to the host by sending a ***reply*** message.

The structure of a `CommandMessage` ***request*** is:

Message[0]	**Message[1]**	**Message[2]**	***remainder***
`MessageTypeID =0xF2`	`FeatureID`	`CommandID`	Command arguments, if any.

The structure of a `Command` ***reply*** message of a ***successful*** command execution is:

Message[0]	**Message[1]**	**Message[2]**	**Message[3]**	***remainder***
`MessageTypeID =0xF2`	`FeatureID`	`CommandID`	`CmdErrorCode =0x00`	Return values, if any.

Whenever the `CommandErrorCode` is not 0x00, it indicates a failure, and the reply message must omit the usual return value(s) and may instead send a UTF8 string of a human-readable error message explaining the failure.

The structure of a `Command` ***reply*** message of a ***failed*** command execution is:

Message[0]	**Message[1]**	**Message[2]**	**Message[3]**	***remainder***
`MessageTypeID =0xF2`	`FeatureID`	`CommandID`	`CmdErrorCode >0x00`	Typically none, but may be a human-readable, UTF8 encoded error message string

Facts about `Commands`:

- The request may contain ***arguments*** and the reply may contain ***return values***, depending on the specific command implementation.
- A host must wait for the reply to the previous request, before sending the next request.
    - Commands that take longer than a few milliseconds to execute should preferably be refactored into a non-blocking command and use events or a proper state-machine to notify completion.
- Request messages must not exceed the maximum size specified by the `CoreFeature.MaxReqMsgSize` property.
- Every feature must implement all mandatory commands.
- Each feature may implement up to 240 custom commands

Mandatory Commands

Every feature must implement the following commands:

CommandID	CommandName	Arguments	Reply
0x00→0xEF	Available for custom use		
0xF0	GetPropertyName	UINT8: PropertyID	UTF8
0xF1	GetPropertyType	UINT8: PropertyID	UTF8
0xF2	GetPropertyReadonly	UINT8: PropertyID	BOOL
0xF3	GetPropertyValue	UINT8: PropertyID	according to PropertyType
0xF4	SetPropertyValue	UINT8: PropertyID	according to PropertyType
0xF5	GetPropertyDescription	UINT8: PropertyID	UTF8
0xF6	GetCommandName	UINT8: CommandID	UTF8
0xF7	GetCommandDescription	UINT8: CommandID	UTF8
0xF8	GetEventName	UINT8: EventID	UTF8
0xF9	GetEventDescription	UINT8: EventID	UTF8
0xFA→0xFF	Reserved for future use		

Developers usually don't need to bother about any of these, as explained further below.

Command introspection

A host can query a feature for details about the commands it implements, via:

- the mandatory property
  - `AvailableCommands`
    - A BLOB listing all the `CommandID` values implemented on the feature.
- … and the mandatory commands:
  - `GetCommandName(UINT8 CommandID)` → UTF8
    - Takes the CommandID as an argument.
    - Returns a UTF8 string: the name of the corresponding command, which will be unique among all commands implemented on a feature.
    - Typically a human-readable name in camel-case without any whitespace, like this: `MyCustomCommand`
  - `GetCommandDescription(UINT8 CommandID)` → UTF8
    - Takes the CommandID as an argument
    - Returns UTF8 string, that may be empty.
    - May contain multiple lines of text, which must be delimited with newlines (`\n`) only.
    - First line of text may describe the signature of arguments and return values like this:

      ```
      (UINT8 FirstArg, INT32 SecondArg) -> UINT16 FirstRetVal, UINT32 SecondRetVal
      ```

CommandErrorCodes

Each `Command` implementation may define its own CommandErrorCodes as long as they do not collide with the following reserved codes and meanings:

Command Error Code	Meaning	Context
0x00	No error	All commands
0x01→0xEF	Available for custom use	
0xF0	Unknown feature	Any command addressed to a non-existent feature
0xF1	Unknown command	Any command not implemented on the given feature, or when attempting to introspect about thereof.
0xF2	Unknown property	GetPropertyName GetPropertyType GetPropertyReadOnly GetPropertyValue SetPropertyValue
0xF3	Unknown event	GetEventName GetEventDescription
0xF4	Incorrect command arguments	All commands
0xF5	Command not allowed now	All commands
0xF6	Command failed	All commands
0xF7	Invalid property value	SetPropertyValue
0xF8	Property is read-only	SetPropertyValue
0xFA→0xFF	Reserved for future use	

CommandErrorCodes are kept intentionally simple, because more sophisticated error scenarios can resort to Log-events to convey more detailed information about the situation. Note that it's allowed to send events while the host is awaiting for the reply to a command.

Some kinds of errors can't be reported via reply messages and will instead be notified via Log-events. This is especially the case for reading-frame errors and errors that can't be differentiated thereof, like "`Unknown MessageTypeID`", or requests that are larger than allowed by the `CoreFeature.MaxReqMsgSize` property.

Properties

Properties are implemented by means of the following, mandatory `Commands`:

- `GetPropertyValue(UINT8 PropertyID) → PropType`
    - Takes the `PropertyID` as an argument
    - Returns a value of the data-type of the property.
- `SetPropertyValue(UINT8 PropertyID, PropType NewValue) → PropType`
    - Takes the `PropertyID` and the `NewValue` as arguments.
    - Returns a value of the data-type of the property.
    - The returned value may differ from the given `NewValue` argument and reports the actual value of the property, according to any trimming or discretization that the property-setter might consider appropriate.
        - e.g.: Attempting to set a value of 3.567% might be discretized into 3.6%

Properties may serve a wide range of purposes:

- Expose immutable meta-data/capabilities of a feature, as for example:
    - `CoreFeature.SerialNumber`
    - `AxisX.MaxPos`
    - `Thermostat.MaxTargetTemp`
- Expose mutable configuration parameters, as for example:
    - `Axis.MaxAccel`
    - Warning: Avoid abusing properties as a replacement for `Command` arguments!
- Expose the internal state of a feature as read-only properties, as for example:
    - `*.FeatureState`
    - `Thermostat.Setpoint`
- Expose sensor data that might be acquired on request, as for example:
    - `Thermostat.ObjectTemperature`
        - Beware of sensor latency issues!

Mandatory properties

Every feature must implement the following mandatory properties:

PropertyID	PropertyName	DataType	Readonly	Immutable
0x01→0xEF	Available for custom use			
0xF0	FeatureName	UTF8	Yes	Yes
0xF1	FeatureTypeName	UTF8	Yes	Yes
0xF2	FeatureTypeRevision	UINT8	Yes	Yes
0xF3	FeatureDescription	UTF8	Yes	Yes
0xF4	FeatureTags	UTF8	Yes	Yes
0xF5	AvailableCommands	BLOB	Yes	Yes
0xF6	AvailableEvents	BLOB	Yes	Yes
0xF7	AvailableProperties	BLOB	Yes	Yes
0xF8	FeatureState	UINT8	Yes	No
0xF9	LogEventThreshold	UINT8	No	No
0xFA→0xFF	Reserved for future use			

Note how the Core-feature has some additional mandatory properties.

Developers usually don’t need to bother about any of these, as explained further below.

Property introspection

A host can query a feature for details about the properties it implements, via:

- the mandatory property
  - `AvailableProperties`
    - A BLOB listing all the `PropertyID` values implemented on the feature.
- … and the mandatory commands:
  - `GetPropertyName(UINT8 PropertyID) → UTF8`
    - Takes the `PropertyID` as an argument.
    - Returns a UTF8 string: the name of the corresponding property, which will be unique among all properties implemented on a feature.
    - Typically a human-readable name in camel-case without any whitespace.
      - E.g.: `MyCustomProperty`
  - `GetPropertyType(UINT8 PropertyID) → UINT8`
    - Takes the `PropertyID` as an argument.
    - Returns the UINT8 code for the data-type.
  - `GetPropertyReadonly(UINT8 PropertyID) → BOOL`
    - Takes the `PropertyID` as an argument.
    - Returns a BOOL:
      - A value of TRUE means the property is read-only and any attempt to change its value will produce a CommandErrorCode=0x07.
      - A value of FALSE means the host is allowed to modify the value of the property.
  - `GetPropertyDescription(UINT8 PropertyID) → UTF8`
    - Takes the `PropertyID` as an argument
    - Returns a UTF8 string that may be empty.
    - May contain multiple lines of text, which must be delimited with newlines (`\n`) only.
    - First line of text may describe the units and meaning like this:
      - `[°C] Current heat-sink temperature.`

Events

An `Event`, is a kind of message that is sent autonomously by a device's feature, without having been explicitly requested by the host. Besides the `FeatureID` of the emitting feature, it also includes an `EventID`, which enables each feature to emit multiple types of events.

Events may serve a diverse range of purposes, like:

- Notify the host about state-machine transitions of the Core or any other HDC-feature.
- Transfer a stream of data acquired by an ongoing measurement-activity-feature, by sending each tuple of data as the payload of an event message. Note how a single feature may transmit multiple data-streams concurrently, by using different EventIDs for each stream.
- Enable the firmware of a device to send log messages to the host (infos, warnings, errors, …)

The structure of a `Event` message is as follows:

Message[0]	**Message[1]**	**Message[2]**	***remainder***
`MessageTypeID` = `0xF3`	`FeatureID`	`EventID`	Payload of an event

Mandatory events

(Strictly speaking an event cannot be mandatory, but that's too philosophical and beyond scope.)

Any feature requiring any of the following functionality, must implement it as follows:

EventID	**EventName**	**Payload**	**Description**
0x01→0xEF	Available for custom use		
0xF0	Log	[0]: UINT8 LogLevel [remainder]: UTF8 LogMessage	See Feature logger
0xF1	FeatureStateTransition	[0]: UINT8 PreviousStateID [1]: UINT8 NewStateID	See Feature state
0xFA→0xFF	Reserved for future use		

Developers usually don't need to bother about any of these, as explained further below.

Data types

Property introspection uses the following `DataTypeCode`s:

DataTypeCode	DataType
`0x01`	UINT8
`0x02`	UINT16
`0x04`	UINT32
`0x11`	INT8
`0x12`	INT16
`0x14`	INT32
`0x24`	FLOAT
`0x28`	DOUBLE
`0xB0`	BOOL
`0xBF`	BLOB
`0xFF`	UTF8

The ID values of each DataType can be interpreted as follows:

- Upper Nibble: Kind of DataType
  - 0x0_ --> Unsigned integer
  - 0x1_ --> Signed integer
  - 0x2_ --> Floating point number
  - 0xB_ --> Binary data (Either variable size 0xBF, or boolean 0xB0)
  - 0xF_ --> UTF-8 string (Always variable size 0xFF, without zero-termination)
- Lower Nibble: Size of DataType, given in number of bytes.
  - i.e. 0x14 --> INT32, whose size is 4 bytes
    - Exception to the rule: 0x_F denotes a variable size DataType.
    - Exception to the rule: 0xB0 --> BOOL, whose size is 1 byte.

Endianness

Numeric values are serialized in little-endian order when being transmitted in messages.

For example the UINT32 value `0xAABBCCDD` will be serialized in a message like this:

Message[n-1]	Message[n+0]	Message[n+1]	Message[n+2]	Message[n+3]	Message[n+4]
…	`0xDD`	`0xCC`	`0xBB`	`0xAA`	…

The reason being that the firmware will most likely run on little-endian processors (e.g. STM32 microcontrollers) and the pointer arithmetics can be kept less cryptic and more performant when sending numeric values in the same endianness.
Note how also most hosts will run on little-endian processors (e.g. Intel Core)

Messages

ToDo: Explain Message-layer, e.g. in form of a summary with glossary.

Overview of MessageTypeID values

The first byte of any message is its `MessageTypeID`, which roughly specifies its purpose:

MessageTypeID	Name
`0x00 .. 0xEF`	Available for custom use. e.g. Tunneling of other protocols
`0xF0`	HdcVersionMessage
`0xF1`	EchoMessage
`0xF2`	CommandMessage
`0xF3`	EventMessage
`0xF4 .. 0xFF`	Reserved by HDC for future use

Any other MessageTypeID is reserved for future use and must be treated as a reading-frame-error when deserializing messages.

ToDo:

- Specify how request messages that expect a reply must be blocking on the HDC-host!
- Specify how to deal with time-outs while waiting for a reply.
- Explain MaxReqMsgSize.
- Remove related remarks that are scattered in the wrong chapters, i.e. Commands, because it is easier to specify all this at the message-layer.

HdcVersionMessage

The purpose of this type of message is to allow for hosts to infer the HDC-spec version implemented by a device, so that they may decide very early on how to communicate with a given device.

The structure of a `VersionMessage` ***request*** is as follows:

Message[0]	**Message[1...]**
MessageTypeID = 0xF0	Any message payload will be ignored silently.

The structure of a `VersionMessage` ***reply*** is as follows:

Message[0]	**Message[1...7]**
MessageTypeID = 0xF0	"`HDC 1.0.0`" (UTF-8 encoded string. Without the quotes)

Facts about `VersionMessages`:

- Must be implemented by all HDC-devices, including those implementing future HDC-spec versions.
- Syntax and meaning of the version number are those defined by Semantic Versioning 2.0.0.
    - A device compliant with HDC-spec 1.0.0 will return: `HDC 1.0.0`
    - An alpha version firmware might reply: `HDC 1.0.0-alpha.42`
    - Forks of HDC may reply with a different prefix: `HDC++ 1.0.0`
- Note how this resembles a `Property`, but it isn't, because it is not associated with any Feature. It is intentionally implemented at the lower "message layer", instead, to ensure forward-compatibility with future HDC-spec versions that might need to redefine conventions about how `Features` and `Properties` are handled.

EchoMessage

Messages starting with the `MessageTypeID=0xF1` will immediately be echoed back to the host, regardless of their content.

The structure of a `EchoMessage` ***request*** is as follows:

Message[0]	***remainder***
MessageTypeID = 0xF1	Whatever, as long as the size of the message does not exceed `CoreFeature.MaxReqMsgSize`

→ Device must ***reply*** with an identical message.

Facts about `EchoMessages`:

- Since this resembles the request/reply pattern of the more usual commands, this is named `EchoMessage`, but it's otherwise a quite atypical command, because it's unrelated to any feature and its content is discretionary, except for the first `MessageTypeID` byte and that the message size may not exceed `CoreFeature.MaxReqMsgSize`.
- All devices must handle the `EchoMessage`.
- Hosts may use the `EchoMessage` to:
    - Test that the serial communication connection is working.
    - Test that the firmware of a device is responsive.
    - Benchmark the bandwidth and latency of the serial communication.
    - Stress-test the bandwidth while other messages are being sent.
- A host must wait for the reply to the previous request, before sending the next request.
    - This requirement applies to both: `Command`s and `EchoMessage`s.
- There's no introspection on the `EchoMessage`.
    - Hosts can simply count on it being implemented on any device.

CommandMessage

See Commands
ToDo: Move CommandMessage syntax into this chapter, to make the high-level explanation of Commands less confusing to readers who actually do not care about the message-layer.

EventMessage

See Events
ToDo: Move EventMessage syntax into this chapter, to make the high-level explanation of Events less confusing to readers who actually do not care about the message-layer.

Cheat-sheet of message syntax

The following table describes the syntax of messages in terms of bytes:

		Message[0]	Message[1]	Message[2]	Message[3]	Message[...]
Command (request)	H→D	MessageTypeID = 0xF2	FeatureID	CommandID	*Command arguments*	
Property-getter (request)	H→D	MessageTypeID = 0xF2	FeatureID	CommandID = 0xF4	PropertyID	
Property-getter (reply)	D→H	MessageTypeID = 0xF2	FeatureID	CommandID = 0xF4	CmdErrorCode	*Property value*
Property-setter (request)	H→D	MessageTypeID = 0xF2	FeatureID	CommandID = 0xF5	PropertyID	*New value*
Property-setter (reply)	D→H	MessageTypeID = 0xF2	FeatureID	CommandID = 0xF5	CmdErrorCode	*Actual new value (May differ!)*
Event (unrequested reply)	D→H	MessageTypeID = 0xF3	FeatureID	EventID	*Event payload*	
LogEvent	D→H	MessageTypeID = 0xF3	FeatureID	EventID = 0xF0	LogLevel	*Log message*
FeatureState TransitionEvent	D→H	MessageTypeID = 0xF3	FeatureID	EventID = 0xF1	StateID *(before)*	StateID *(after)*
EchoMessage (request & reply)	H→D D→H	MessageTypeID = 0xF1	*Echo payload*			

Custom MessageTypeID values

Note how only `MessageTypeID` values `0xF0` to `0xFF` are reserved for HDC protocol purposes.
The remaining range of values is freely available for any custom purpose, like for example:

- Encapsulation for the tunneling of whatever other communication protocol or raw data stream needs to be transmitted through the HDC connection.
- Note how tunneling of one HDC-connection through another HDC-connection can be implemented more elegantly by the sender mapping the MessageTypeID into the range of custom IDs and the receiver restoring the original ID before forwarding said message to the intended sub-system. Similar to how NAT works.
  This technique is preferable to encapsulation, because it does not incur any additional transmission overhead, but it is limited to tunnel up to 15 HDC-connections through an existing one.

Packets

Summary and glossary

Packetizing is the procedure of how a sender wraps a ***message*** as ***payload*** into one or more ***packets*** in a way that allows the receiver to decode ***chunks*** of received bytes back into the original message. When sending many messages or very large messages, they usually are received as a ***burst*** of multiple chunks of bytes.

Multi-packet messages

Most messages fit in a single packet.
Messages larger than 254 bytes must be sent in multiple, consecutive packets.
The first packet contains the first 255 bytes of the message, the second packet the next 255 bytes and so forth until the remainder of the message is sent in a packet containing less than 255 bytes. Should the message size be an exact multiple of 255 bytes, then an empty packet will be signaling that the message transfer is complete.

Multi-packet messages must be sent as strictly consecutive packets. No other packets should be sent in between. (Be especially aware of event-messages not interrupting the transmission of any ongoing multi-packet message!)

Building and decoding of Packets

Messages are encoded into and decoded from a stream of bytes as payload of packets that have the following structure:

Byte Index	Description
`0`	Payload size given as number of 8-bit bytes and subsequently referred to as `PS`. Thus a single packet can contain payloads of up to 255 bytes. Messages larger than 254 bytes are sent as multiple, consecutive packets, the last of which is characterized by containing less than 255 bytes. Messages containing an exact multiple of 255 bytes must be terminated with an additional empty packet (`PS`=0). Empty packets are also allowed on their own, but they are pointless and will be silently ignored.
`1..PS` (or none, whenever `PS`=0)	Bytes of the payload. Usually a single message. Can be empty (`PS=0`). May be only a fragment of the message when this packet or its immediately preceding one(s) have a payload size of `PS`=255.
`PS+1`	Checksum of Payload Two's complement of the sum of all payload bytes. If there's no payload (`PS`=0) then this byte is 0x00 .
`PS+2`	Record Separator (0x1E)

The receiver algorithm assumes that the byte at `buffer[0]` is the size of the payload (`PS`) and uses its value to check whether the byte at `buffer[PS+2]` contains the value `0x1E` (A homage to

ASCII, because that's the code for the `RecordSeparator`) and then it further checks if the checksum byte at `buffer[PS+1]` is valid by checking whether the sum of all payload bytes, plus the checksum byte, yield a value of 0x00. The checksum is computed as the byte-wise sum with numeric overflow at 0xFF.
If the RecordSeparator is not where expected or the checksum is invalid, it assumes a reading-frame-error and skips the first byte and tries again as often as necessary to restore the correct reading frame.
If the buffer does not yet contain any byte at the index `[PS+2]`, then the receiver allows for a certain timeout, based on the assumption that any pending bytes of that packet must arrive as a quick burst. But if that timeout elapses, it also must assume a reading-frame-error (i.e. the tentative `PS` value actually isn't) and therefore skips the first byte and tries again as a way to restore the correct reading frame.
And finally, the payload is then passed to the message parser, which will additionally check whether the given payload is *well-formed*, i.e. whether the first byte of the message is one of the known `MessageTypeID` values and the second byte of the message is a valid `FeatureID` value, and so on.

Beware of the following:

- The byte value 0x1E can also occur in the payload.
- The receiver buffer might still be missing some pending bytes of upcoming chunks.

Serial connections

A point-to-point connection between one device and one host, that allows bi-directional transmission of a stream of bytes.
Typically this can be:

- a UART module on a microcontroller bridged into USB-CDC and exposed as a Virtual-COM-Port on a PC
- a USB-CDC module on a microcontroller, exposed as a Virtual-COM-Port on a PC
- A TCP/IP socket

Implementation details

Mandatory stuff looks like boilerplate, but it isn't!

Developers usually don’t need to bother about the mandatory stuff required by the HDC specification, because it’s taken care of in the `hdc.c` module of the firmware and the proxy base-classes on the host.

Hence, mandatory and custom implementations are kept separate in the source-code, thus improving the readability of custom implementations, because those won’t become polluted with any mandatory boilerplate.