Apogee Bluetooth API

2021-05-10

Revision 1.0

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Revision History

Table 1: Revision History

Revision	Date	Description
1.0	2021-05-10	Initial Release.

Apogee **Bluetooth®** Products

µCache

The µCache AT-100 makes precision environmental measurements using Apogee's analog sensors. The measurements are sent wirelessly to a central device via Bluetooth. The Apogee Connect mobile app interfaces with the µCache to collect, display, and export logged data.

The µCache has an M8 connector which is used to connect to an analog sensor.

The µCache can make live data measurements when connected to a central device. The mobile app displays the data and allows the user to record samples in the app and export them.

The µCache is also capable of internal data logging. Data logging is set up in sampling and averaging intervals. A Bluetooth connection with the mobile app is required to configure and collect data, but the µCache makes and stores measurements with no Bluetooth connection required. It has a large memory capacity of over 400,000 entries or over 9 months of one-minute data.

The µCache is powered by a 2/3 AA battery. Battery life is highly dependent on average daily time connected over Bluetooth and the sampling interval.

The µCache housing has a button and LED to manage Bluetooth connectivity and provide visual status feedback.

Button and LED Interface

The µCache has one button and one RGB LED. The button reads short, long, and extra-long presses, and the LED provides visual feedback.

A short button press (< 1 second) will be followed by one or more LED blinks indicating the current status.

- White indicates that it is not connected over Bluetooth, data logging is disabled, and the battery is in good condition.
- Blue indicates that it is connected over Bluetooth.
- Green indicates that data logging is enabled.
- One red blink indicates that the battery is "low."
- Three red blinks indicate that the battery is "critically low," too low to make measurements.
- If there is a solid red indication (without blinking) for 30 seconds, the µCache is in Bootloader Mode.

A long button press (> 1 second) will toggle Bluetooth connectivity of the µCache.

- If it is not connected, a long button press will start Bluetooth advertising.
- If it is advertising, a long button press will stop Bluetooth advertising.
- If it is connected, a long button press will cause the µCache to disconnect from the central device.

An extra-long button press (10 seconds) will toggle the data logging status of the µCache. Once data logging has been toggled it will give the same LED indication as a short button press.

- If it is not data logging, data logging will start. LED indication will include a green LED blink.
- If it is data logging, data logging will stop. LED indication will not include a green LED blink.

When the µCache is advertising, the LED blinks blue every two seconds. Advertising will time out after 30 seconds if no connection is made.

Generic Access Profile (GAP)

Company Identifier

The Company Identifier for Apogee Instruments assigned by the Bluetooth SIG is 0x0644.

https://www.bluetooth.com/specifications/assigned-numbers/company-identifiers

Advertising

Advertising is started 1) when the Bluetooth device is first powered up, and 2) with a long button press. Advertising takes place until connected to a central device or until it times out after 30 seconds.

Advertising can also be set up to take place periodically, synchronized with data logging using the Data Log Collection Rate characteristic in the Apogee Service. See Data Log Collection Rate Characteristic section for more information.

Advertising Data

Advertising Data only contains the Company Identifier in Manufacturer Specific Data to minimize packet size.

Scan Response Data

Scan Response Data contains the Company Identifier and the Alias in Manufacturer Specific Data. Alias is one of the characteristics of the Apogee Service. See Alias Characteristic. This allows the central device to read and display the Alias of the peripheral device when searching for sensors.

Table 2: Example Manufacturer Specific Data in Scan Response Packet

44 06 47 72 65 65 6E 68 6F 75 73 65	
Field	**Description**
44-06	Company Identifier: 0x0644
47-72-65-65-6E-68-6F-75-73-65	Alias: “Greenhouse”

Generic Attribute Profile (GATT)

The Apogee Profile consists of the Device Information Service (DIS), the Battery Service (BAS), the Secure DFU service, and the custom Apogee Service. **Table 3**, **Table 4**, and **Table 5** summarize important information about some of these services.

Device Information Service (DIS)

Table 3: Device Information Service

Service/Characteristic	UUID	Properties	Value Contents
Device Information Service	0x180A		
Manufacturer Name	0x2A29	Read	UTF8S
Model Number	0x2A24	Read	UTF8S
Serial Number	0x2A25	Read	UTF8S
Firmware Revision	0x2A26	Read	UTF8S
Hardware Revision	0x2A27	Read	UTF8S

The Device Information Service contains basic information about the Apogee Bluetooth device in several characteristics. These characteristics include the Manufacturer Name, Model Number, Serial Number, Firmware Revision, and Hardware Revision. Firmware Revision and Hardware Revision are significant to the Bootloader.

Battery Service

Table 4: Battery Service

Service/Characteristic	UUID	Properties	Value Contents
Battery Service	0x180F		
Battery Level	0x2A19	Read/Notify	UINT8

The Battery Level characteristic in the Battery Service contains the battery level as a percentage. A battery level between 1 and 100% indicates the approximate battery level. A battery level of 0% indicates that the battery level is too low to make a measurement.

The battery in the µCache is a primary lithium-thionyl chloride (Li-SOCl2), which is difficult chemistry to monitor. The discharge curve is fairly flat through most of the battery life with a fast drop-off at the end. An algorithm has been optimized to determine the remaining battery life, but the accuracy may vary according to temperature and other conditions.

Secure DFU Service

The Secure DFU service provides a way to enter a bootloader mode to update firmware. See the Bootloader section for more information.

Apogee Service

Table 5: Apogee Service

Service/Characteristic	UUID	Properties	Value Contents
Apogee Service	0x0001[1]		
Live Data	0x0002[1]	Notify	(1-4) INT32s
Sensor ID	0x0003[1]	Read/Write	UINT8
Alias	0x0004[1]	Read/Write	UTF8S up to 20 bytes
Live Data Control	0x0005[1]	Read/Write	UINT8
Current Time	0x000A[1]	Read/Write	UINT32
Data Log Full Time	0x000C[1]	Read	UINT32
Data Log Entries Available	0x000D[1]	Read	3 UINT32s
Data Log Latest Timestamp Transferred	0x000E[1]	Read/Write	UINT32
Data Log Control	0x0010[1]	Read/Write	UINT8
Data Log Timing	0x0012[1]	Read/Write	2 or 3 UINT32s
Data Log Transfer	0x0013[1]	Notify or Indicate	UINT32 + (0-4) INT32s
Data Log Collection Rate	0x0014[1]	Read/Write/Notify	UINT8
Calibration	0x00FF[1]	Read/Write	UINT8
Coefficients1	0x0100[1]	Read/Write	3 FLOAT32s
Coefficients2	0x0101[1]	Read/Write	3 FLOAT32s
Base UUID for Apogee Service	0xB3E0_ _ _ _259442A1A5FE4E660FF2868F		
[1] This UUID must be inserted into the base UUID for the Apogee Service to make a 128-bit UUID.			

The Apogee Service is a custom service that serves two primary purposes: transmit real-time sensor measurements (live data) and data logging sensor measurements. Data logging will take place continually even when the Apogee Bluetooth device is not connected to a central device. The data log can then be transferred over Bluetooth when it is connected.

Following is a detailed description of each characteristic in the Apogee service.

Chronological Overview

The typical use of the Apogee Service proceeds as follows:

1. Bluetooth advertising is started via button press or other means.
2. A central device scans for Apogee Bluetooth devices by searching for the Apogee Company Identifier 0x0644 in the Manufacturer Specific Data portion of the Advertising packet.
3. The Alias of the Apogee Bluetooth device can be read in the Scan Response Data. The central device could display the Alias in a list of available Apogee Bluetooth devices.
4. The central device connects to an Apogee Bluetooth device.
5. Once connected, the Current Time Characteristic should be checked (read) and updated (written) if not accurate.
6. The Alias Characteristic can be used to give the device a name for reference. This name will show up in advertising packets when the central device is scanning for Apogee Bluetooth devices.
7. The Sensor ID Characteristic can be read to find out which sensor to expect data from. It can also be changed to another sensor as needed.
8. Coefficients need to be programmed for some sensors using Coefficients1 and Coefficients2 Characteristics.
9. Calibration can be done for some sensors using the Calibration Characteristic.
10. The Live Data Control Characteristic can be used to set averaging time for live data.
11. Live data can be received by enabling notifications of the Live Data Control Characteristic.
12. Data Logging can be set up at desired intervals using the Data Log Timing Characteristic. It includes sampling interval, averaging interval, and an optional start time.
13. Data logging can be enabled or disabled using the Data Log Control Characteristic.
14. When data logging is enabled, the Data Log Full Time Characteristic can be read to know when the data log will be full and start overwriting entries that have not been transferred.
15. The Data Log Latest Timestamp Transferred Characteristic can be read to find out the latest timestamp that has been transferred. This characteristic can also be written to move the starting point of the transfer forward, skipping a portion of the data log, or back to transfer data that has already been transferred before. It can also be used to ensure the data log transfer picks up where it left off from the previous transfer. Following is an example:
    a. A central device has the following data log stored from previous connections shown in **Table 6**.

Table 6: Example Data Log

Timestamp	Timestamp Converted to Date and Time	Measurement
1562884620	2019-07-11 22:37:00	888.5174
1562884680	2019-07-11 22:38:00	890.2397
1562884740	2019-07-11 22:39:00	891.3032
1562884800	2019-07-11 22:40:00	891.2341

    b. The central device reads the Data Log Latest Timestamp Transferred Characteristic.

    c. The central device compares the characteristic value to the most recent timestamp from the collected data log. In this example, it is 1562884800.
    d. If these values do not match, 1562884800 is written to Data Log Latest Timestamp Transferred characteristic.
    e. The central device proceeds with the data log transfer.
16. The Data Log Entries Available Characteristic can be read to find out how many data log entries are available to be transferred, the timestamp of the oldest entry in the data log, and the total number of entries in the data log.
17. A data log transfer is done using notifications or indications of the Data Log Transfer Characteristic.
18. The Data Log Collection Rate Characteristic can be written to advertise only with a button press or to advertise synchronized with data logging to collect data as it becomes available.
19. The central device disconnects from the Apogee Bluetooth device.

Live Data Characteristic

Table 7: Live Data Characteristic

UUID (within base)	Properties	Value Contents
0x0002	Notify	(1-4) INT32s

The Live Data characteristic sends notifications of the sensor output. It is an array of 1 to 4 32-bit signed fixed-point values with a decimal exponent of -4.

The number of outputs for each sensor is listed in **Table 10** in the Sensor ID Characteristic section.

Each value in the array is a unique simultaneous value from the sensor. For example, the IR sensor will have a packet with two values. The first is the target temperature and the second is the sensor temperature.

Live data is unconditionally sent every 0.5 seconds when notifications are enabled. The entire array of values is sent each time.

Characteristic data length is always a multiple of 4 bytes, up to 16 bytes.

Table 8: Live Data Characteristic Examples

Live Data Characteristic	Value(s)	Description
25-E7-83-00	864.4389	Live data is one value of 864.4389
89-EF-FF-FF-CD-26-02-00	-0.4215, 14.1005	Live data is two values of -0.4215 and 14.1005

Sensor ID Characteristic

Table 9: Sensor ID Characteristic

UUID (within base)	Properties	Value Contents
0x0003	Read/Write	UINT8

The Sensor ID characteristic is an enumeration of the sensor connected to the Apogee Bluetooth Device. This must be chosen by the user and set by the central device. **Table 10** lists each enumeration, sensor name, description, number of outputs, and units.

When the sensor ID is changed, the Calibration, Coefficients1, and Coefficients2 characteristics must be carefully managed. See the Calibration Characteristic section and the Coefficients1 and Coefficients2 Characteristics section for more information.

Data length is one byte.

Table 10: Sensor ID Enumeration

Key	Sensor Name	Sensor Description	Number of Outputs	Units
0	No sensor chosen			
1	SP-110	Pyranometer	1	W m^{-2}
2	SP-510	Thermopile Pyranometer	1	W m^{-2}
3	SP-610	Thermopile Pyranometer (Downward)	1	W m^{-2}
4	SQ-110	Quantum (Electric)	1	µmol m^{-2} s^{-1}
5	SQ-120	Quantum (Solar)	1	µmol m^{-2} s^{-1}
6	SQ-500	Quantum (Full Spectrum)	1	µmol m^{-2} s^{-1}
7	SL-510	Pyrgeometer	1	W m^{-2}, °C
8	SL-610	Pyrgeometer (Downward)	1	W m^{-2}, °C
9	SI-100	IR Sensor	2	°C, °C
10	SU-200	UV Sensor	1	W m^{-2}
11	SE-100	Photometric	1	lm m^{-2}
12	S2-111	NDVI	2	W m^{-2}, W m^{-2}
13	S2-112	NDVI (Downward)	2	W m^{-2}, W m^{-2}
14	S2-121	PRI	2	W m^{-2}, W m^{-2}
15	S2-122	PRI (Downward)	2	W m^{-2}, W m^{-2}
16	S2-131	Red/FarRed	2	µmol m^{-2} s^{-1}, µmol m^{-2} s^{-1}
17	S2-141	PAR/FAR	2	µmol m^{-2} s^{-1}, µmol m^{-2} s^{-1}
18	SQ-610	ePAR	1	µmol m^{-2} s^{-1}

Table 10 Continued: Sensor ID Enumeration

Key	Sensor Name	Sensor Description	Number of Outputs	Units
19	ST-1X0	Thermistor	1	°C
20	SP-700	Albedometer	2	W m^{-2}, W m^{-2}
21	SQ-620	Extended Range LED Quantum	1	µmol m^{-2} s^{-1}
22	SQ-640	Low Light Extended Range LED Quantum	1	µmol m^{-2} s^{-1}
23	NDVI Pair	NDVI and NDVI (Downward)	4	W m^{-2}, W m^{-2}, W m^{-2}, W m^{-2}
24	PRI Pair	PRI and NDVI (Downward)	4	W m^{-2}, W m^{-2}, W m^{-2}, W m^{-2}
25	4 Single Ended	4 Single-Ended Measurements	4	mV, mV, mV, mV
26	2 Differential	2 Differential Measurements	2	mV, mV
27	SQ-100X	Quantum	1	µmol m^{-2} s^{-1}
28	SQ-31X	Line Quantum	1	µmol m^{-2} s^{-1}
35	SO-100	Oxygen Sensor Soil Response	3	% O_2, °C, mV
36	SO-200	Oxygen Sensor Fast Response	3	% O_2, °C, mV

Alias Characteristic

Table 11: Alias Characteristic

UUID (within base)	Properties	Value Contents
0x0004	Read/Write	UTF8S up to 16 bytes

The Alias characteristic is used to give a name to an Apogee Bluetooth device unit for reference. It is displayed in advertising data in the Scan Response packet.

Data length is up to 16 bytes.

Table 12: Alias Characteristic Example

Characteristic Packet	Description
41-71-75-61-72-69-75-6D-20-32	The Alias of this Apogee Bluetooth device is "Aquarium 2"

Live Data Control Characteristic

Table 13: Live Data Control Characteristic

UUID (within base)	Properties	Value Contents
0x0005	Read/Write	UINT8

The Live Data Control Characteristic controls averaging time of the Live Data Characteristic. Valid values are 0-127 in units of 0.25 seconds. A value of 0 is interpreted as no averaging with data calculated from a single ADC sample. It is okay to write this value while live data is running. More averaging buffers the data more, although it is less responsive.

When live data is first turned on and the averaging buffer is not yet full, live data is calculated only from measured values.

Data length is one byte.

Table 14: Data Log Control Characteristic Bitfield

Bit	Name	Description
7	RESERVED	Reserved for future use.
6:0	AVERAGING_TIME	0: Live data is calculated from one sample. 1-127: Time in units of 0.25 seconds. Live data is calculated from an averaging buffer of .25 to 31.75 seconds.

Table 15: Live Data Control Characteristic Examples

Characteristic Packet	Value	Description
00	0	Live Data is calculated from 1 measurement sample.
01	1	The averaging time for Live Data is 0.25 seconds.
28	40	The averaging time for Live Data is 10 seconds.
7F	127	The averaging time for Live Data is 31.75 seconds.

Current Time Characteristic

Table 16: Current Time Characteristic

UUID (within base)	Properties	Value Contents
0x000A	Read/Write	UINT32

The Current Time characteristic is formatted in Epoch/Unix Time. It is a 32-bit unsigned integer. It is used to track time for data logging.

The Current Time is recommended to be in Greenwich Mean Time (GMT). The central device would then convert GMT and display local time. This simplifies Daylight Savings Time changes.

The Real-Time Clock (RTC) on the Apogee Bluetooth device is temperature corrected, although it will get ahead and behind a little throughout the temperature swings of the day.

The Current Time characteristic should only be written responsively. A few seconds of tolerance should be allowed before writing the characteristic to correct it. Each time the characteristic is written, sample data is reset and a data log entry may be skipped. Therefore, the characteristic should not be written arbitrarily. Instead, the Current Time characteristic should be read, checked whether it is out of tolerance, and written only if it is out of tolerance.

The Apogee Bluetooth device uses an internal RTC. It has a supercapacitor as a backup power source that will last for a limited amount of time when the battery is not installed. When the RTC is first powered on and hasn't been running on backup power, the default time is January 1, 2000, 12:00 AM. When a battery is changed or power temporarily lost, a central device should connect to the Apogee Bluetooth device to verify that the time is correct and the logging status is as desired.

Data length is 4 bytes.

Table 17: Current Time Characteristic Example

Characteristic Packet	Value	Description
20-60-AB-5B	1537957920	Current time is 2018-09-26 10:32:00 GMT.

Data Log Full Time Characteristic

Table 18: Data Log Full Time Characteristic

UUID (within base)	Properties	Value Contents
0x000C	Read	UINT32

The Data Log Full Time characteristic is the time that the last data log entry will be recorded before the data log entries that have not been transferred will be overwritten. The Data Log Latest Timestamp Transferred characteristic is the reference from which this time is calculated.

It is formatted in Epoch/Unix Time. It is relative to Current Time Characteristic which should be in GMT.

If data logging is disabled, Data Log Full Time will be 0. Note that this should not be interpreted as 1970-01-01 00:00:00.

Data length is 4 bytes.

Table 19: Data Log Full Time Example

Characteristic Packet	Value	Description
B0-39-23-5C	1545812400	The data log memory will be full 2018-12-26 08:20:00 and the next entry will overwrite data that has not been transferred.

Data Log Entries Available Characteristic

Table 20: Data Log Entries Available Characteristic

UUID (within base)	Properties	Value Contents
0x000D	Read	3 UINT32s

Data Log Entries Available gives information about the data log. It contains three fields: Number of Data Logs Available, Oldest Timestamp in Data Log, and Total Entries Available.

Table 21: Data Log Entries Available Characteristic Fields

Number of Entries Available	Oldest Timestamp in Data Log	Total Entries Available in Data Log
4 Bytes	4 Bytes	4 Bytes

Number of Data Logs Available indicates how many data logs are available for transfer continuing from where the previous transfer left off.

Oldest Timestamp in Data Log is the timestamp of the oldest entry in the data log. It is formatted in Epoch/Unix Time.

Total Entries Available is the total number of entries in data log memory.

If the data log is empty, the Oldest Timestamp in the Data Log field will be 0. Note that this should not be interpreted as 1970-01-01 00:00:00.

Data length is 12 bytes.

Table 22: Data Log Full Time Characteristic Example Packet

7D-00-00-00-7E-29-A2-5B-FE-22-00-00		
Field	**Value**	**Description**
7D-00-00-00	125	125 data log entries have not been transferred.
7E-29-A2-5B	1537354110	The oldest timestamp in the data log is 2018-09-19 10:48:30
FE-22-00-00	8958	There is a total of 8958 data log entries in the data log.

Data Log Latest Timestamp Transferred Characteristic

Table 23: Data Log Latest Timestamp Transferred Characteristic

UUID (within base)	Properties	Value Contents
0x000E	Read/Write	UINT32

The Data Log Latest Timestamp Transferred characteristic is the last timestamp that was transferred during the previous data log transfer. It is formatted in Epoch/Unix Time.

The most common use of the Data Log Latest Timestamp Transferred characteristic is to ensure the data log transfer picks up where it left off from the previous transfer. Ideally, the characteristic and the last timestamp in the collected log will always match.

This characteristic can also be used to change the starting point of the next data log transfer. A later time can be written to set the next transfer forward in time to skip a portion of the data log. An earlier time can be written to transfer data that may have already been transferred before.

If 0 is written to this characteristic, the oldest timestamp will be found. The next data log transfer will begin at the earliest entry.

If the current time or a time in the future is written, the next transfer

The Data Log Latest Timestamp Transferred Characteristic should not be written during a data log transfer.

If the data log is empty, this characteristic will be 0. Note that this should not be interpreted as 1970-01-01 00:00:00. If the first transfer has never taken place the characteristic value will be one averaging interval before the first entry.

Data length is 4 bytes.

Table 24: Data Log Latest Timestamp Transferred Characteristic Examples

Field	Value	Description
6A-BB-1A-5B	1528478570	The latest timestamp transferred is 2018-06-08 17:22:50. The next transfer will start at the next entry.
00-00-00-00	0	Data log is empty

Data Log Control Characteristic

Table 25: Data Log Control Characteristic

UUID (within base)	Properties	Value Contents
0x0010	Read/Write	UINT8

The Data Log Control characteristic uses one flag to enable and disable data logging.

Table 26: Data Log Control Characteristic Bitfield

Bit	Name	Description
7:1	RESERVED	Reserved for future use.
0	DATA_LOGGING_ACTIVE	Flag to indicate that data logging is active (on, enabled).

Before data logging is turned on, the Current Time characteristic should be checked for accuracy and updated if not accurate.

When the battery is too low to make accurate measurements, data logging will be turned off internally. This will happen when the battery is determined “critically low”.

Data length is 1 byte.

Table 27: Data Log Control Characteristic Examples

Characteristic Packet	Value	Description
00	0	Data logging is disabled.
01	1	Data logging is enabled.

Data Log Timing Characteristic

Table 28: Data Log Timing Characteristic

UUID (within base)	Properties	Value Contents
0x0012	Read/Write	2 or 3 UINT32s

Data Log Timing sets up intervals for data logging. It contains three fields: Sampling Interval, Averaging Interval, and Start Time. Start time is optional when writing to the characteristic.

Table 29: Data Log Timing Characteristic Fields

Sampling Interval	Averaging Interval	Start Time
4 Bytes	4 Bytes	4 Bytes

Sampling Interval is the time between sensor measurement samples in seconds. When the sampling interval is reached, a sensor measurement will be made.

Averaging Interval is the time between averages in seconds. When the averaging interval is reached, the samples will be averaged and placed in the data log for transfer later.

Note that “Logging Interval” and “Averaging Interval” terms are used interchangeably. It was originally named “Averaging Interval” in the documentation. The mobile app used the term “Logging Interval.” They are synonymous because every time an “averaging” interval occurs, a new data “log” is made.

Table 30 gives an example of timing for a 10-Second Sampling Interval and 60-Second Averaging Interval. The Apogee Bluetooth device measures or “samples” the sensor every 10 seconds and “averages” or “logs” the values every 60 seconds. The last row of the table is the data log entry that will be saved in memory and transferred by the Data Log Transfer characteristic.

Table 30: Example Measurement Times for 10-Second Sampling Interval and 60-Second Averaging Interval

	Timestamp	Measurement
Sampling Events	2019-07-11 08:05:10	1152.24
	2019-07-11 08:05:20	1160.45
	2019-07-11 08:05:30	1155.32
	2019-07-11 08:05:40	1150.15
	2019-07-11 08:05:50	1149.80
	2019-07-11 08:06:00	1152.47
Averaging Event (Data Log Entry)	2019-07-11 08:06:00	1153.41

Start Time is the time that data logging started. It is formatted in Epoch/Unix Time. It is optional on a write operation and always present on a read operation. When written it can be used to start data logging in the future at a given time.

If Start Time is not included when the characteristic is written, then data logging will be started automatically. The sampling and averaging times will be calculated to a time that aligns with minutes. For example, a ten-second sampling interval will take place at 0, 10, 20, 30 40, and 60 seconds of the minute and a one-minute averaging interval will start at the next minute.

If data logging is disabled, Start Time will be 0. Note that this should not be interpreted as 1970-01-01 00:00:00.

When a new Data Log Timing value is written it is validated as follows:

- Averaging Interval ≠ 0
- Sampling Interval ≠ 0
- Averaging Interval ≥ Sampling Interval
- Averaging Interval % Sampling Interval = 0

If these conditions are met, then the write will be successful. Otherwise, it will not be successful and the previous value will persist.

Data length is 8 or 12 bytes when written and 12 bytes when read.

Table 31: Data Log Timing Characteristic Examples

Characteristic Packet	Values	Description
0A-00-00-00-3C-00-00-00 (write)	10, 60	Averaging Interval of 10 seconds, Sampling Interval of 60 Seconds, Start Time will be calculated and started to align with the nearest minute.
10-00-00-00-3C-00-00-00 (write)	16, 60	Averaging Interval of 16 seconds, Sampling Interval of 60 Seconds. This write will fail because Averaging Interval % Sampling Interval ≠ 0.
3C-00-00-00-2C-01-00-00-00-47-8A-5B	60, 300, 1535788800	Averaging Interval of 60 seconds, Sampling Interval of 300 Seconds, Start Time 2018-09-01 08:00:00

Data Log Transfer Characteristic

Table 32: Data Log Transfer Characteristic

UUID (within base)	Properties	Value Contents
0x0013	Notify or Indicate	UINT32 + (0-4) INT32s

The Data Log Transfer characteristic transfers the data log from memory on the Apogee Bluetooth device to the central device via notification or indication. Notifications are much faster. Indications have a smaller chance of packet loss.

Each data log entry is transferred individually in one notification or indication. It contains one timestamp formatted in Epoch/Unix Time followed by an array of 1 to 4 32-bit signed fixed-point values with a decimal exponent of -4. This is similar to the Live Data Characteristic with the addition of a timestamp.

The number of outputs for each sensor is listed in a chart in the Sensor ID Characteristic section.

The timestamp is relative to Current Time Characteristic which should be in GMT. The central device should convert this to local time.

The end of the data log transfer is indicated with a packet of value FF-FF-FF-FF. When the end of the data log transfer is reached, notifications or indications must be turned off and on again to receive more entries when they are available.

Data length is always a multiple of 4 bytes between 8 and 20 bytes.

Table 33: Data Log Transfer Characteristic Examples

Characteristic Packet	Value(s)	Description
A0-6F-A3-5B-3E-2C-19-01	1537437600, 1842.6942	Data log entry with timestamp of 2018-09-20 10:00:00 and sensor value of 1842.6942
22-FA-A5-5B-57-75-04-00-9A-CF-FF-FF	1537604130, 29.2183, -1.2390	Data log entry with timestamp of 2018-09-22 08:15:30 and sensor values of 29.2183 and -1.2390
B2-50-A6-5B-FA-81-03-00-2B-AB-08-00 -BB-74-C4-00-86-19-03-00	1537626290, 22.9882, 56.8107, 1287.4939, 20.3142	Data log entry with timestamp of 2018-09-22 14:24:50 and sensor values of 22.9882, 56.8107, 1287.4939 and 20.3142
FF-FF-FF-FF	EoT	End of Transfer. (Do not place this value in the data log.)

Data Log Collection Rate Characteristic

Table 34: Data Log Collection Rate Characteristic

UUID (within base)	Properties	Value Contents
0x0014	Read/Write	UINT8

The Data Log Collection Rate characteristic provides the functionality for the Apogee Bluetooth device to advertise periodically, synchronized with data logging. This allows a central device to collect data log entries as they become available.

The value in the Data Log Collection Rate characteristic determines how often the Apogee Bluetooth device will advertise as new entries are added to the data log. It advertises once every n data log entries. For example, if the value is 0, the Apogee Bluetooth device will only advertise with a button press. If the value is 1, the Apogee Bluetooth device will advertise every time a new entry is added to the data log. If the value is 5, it will advertise every 5 entries that are added to the data log. However, if there is not a successful connection, the Apogee Bluetooth device will advertise for 10 seconds each time a new entry is added to the data log (as if the Data Log Collection Rate characteristic is 1). After a successful connection, the Apogee Bluetooth device reverts to the Data Log Collection Rate characteristic value; the Apogee Bluetooth device will accumulate the number of data logs in the Data Log Collection Rate characteristic and then advertise for 10 seconds again.

When advertising is initiated by the Data Log Collection Rate characteristic, the Apogee Bluetooth device will advertise for up to 10 seconds or until connected. Upon disconnection, the Apogee Bluetooth device does not advertise.

The Data Log Collection Rate characteristic value will have a major impact on battery life because advertising is far more power-intensive than sleeping. This characteristic is intended for use in a gateway or IoT environment, in which the central device is always in range of the Apogee Bluetooth device. To minimize the impact on battery life, the central device should connect, collect data, read and/or write any other characteristics necessary, and then disconnect as quickly as possible.

Data length is 1 byte.

Table 35: Data Log Collection Rate Characteristic Examples

Characteristic Packet	Value	Description
00	0	The Apogee Bluetooth device will not advertise periodically. It will only advertise with a button press.
01	1	The Apogee Bluetooth device will advertise every time a new entry is added to the data log.
03	3	The Apogee Bluetooth device will advertise every three entries that are added to the data log.

Calibration Characteristic

Table 36: Calibration Characteristic

UUID (within base)	Properties	Value Contents
0x00FF	Read/Write/Notify	UINT8

The Calibration characteristic is used for a dark offset calibration and oxygen sensor calibration. The dark offset is used to increase the accuracy of low light measurements. This characteristic can initiate a dark offset calibration routine, initiate an oxygen calibration routine, and control the use of the results.

The Calibration characteristic uses two flags and an enumeration as described in **Table 37**.

Table 37: Calibration Characteristic Bitfield

Bit	Name	Description
7:5	RESERVED	Reserved for future use.
4:2	0XYGEN_CALIBRATION	000 No Ongoing Oxygen Calibration 001 Oxygen Calibration for Zero Offset 010 *Oxygen Calibration for Relative Oxygen for Multiplier at Ambient Oxygen 011 *Oxygen Calibration for Relative Oxygen for Multiplier at 100% Oxygen 100 Oxygen Calibration for Absolute Oxygen at Ambient Oxygen Coefficient4 will be used for the pressure in the calculation, so it should be written before this command is called. Sensors other than oxygen ignore these bits.
1	CALIBRATION_BEGIN	Flag to indicate that calibration is in progress. Writing 1 to this bit will initiate the calibration routine. Writing 0 does not stop the routine. When the calibration is finished, the Apogee Bluetooth device will internally change this bit to 0 and send a notification if notifications are enabled.
0	OFFSETS_ACTIVE	Flag to indicate that the offset calibration is used in the sensor output calculation. For the oxygen sensor, this bit is ignored.
*After Calibration for Relative Oxygen for Multiplier, Pressure coefficient at Coefficient4 is set to 0.0.		

If notifications are enabled for this characteristic, a notification will be sent with CALIBRATION_BEGIN = 0 and OFFSETS_ACTIVE = 1 when the calibration process is complete.

When a new Sensor ID characteristic is written, the Calibration characteristic will automatically be reset to 0 internally, and a new dark offset calibration will need to be completed if desired. A new dark offset calibration should also be completed or turned off if a new sensor of the same type is plugged into the Apogee Bluetooth device.

This characteristic only is only applicable to some sensors. See **Table 38** for a list of supported sensors.

Data length is 1 byte.

Table 38: Dark Offset Calibration Sensor Support

Key	Sensor Name	Support Dark Offset Calibration?
0	No sensor chosen	No
1	SP-110	Yes
2	SP-510	Yes
3	SP-610	Yes
4	SQ-110	Yes
5	SQ-120	Yes
6	SQ-500	Yes
7	SL-510	No
8	SL-610	No
9	SI-100	No
10	SU-200	Yes
11	SE-100	Yes
12	S2-111	Yes
13	S2-112	Yes
14	S2-121	Yes
15	S2-122	Yes
16	S2-131	Yes
17	S2-141	Yes
18	SQ-610	Yes
19	ST-1X0	Yes
20	SP-700	Yes
21	SQ-620	Yes
22	SQ-640	Yes
23	NDVI Pair	Yes
24	PRI Pair	Yes

Table 38 Continued: Dark Offset Calibration Sensor Support

Key	Sensor Name	Support Dark Offset Calibration?
25	4 Single Ended	Yes
26	2 Differential	Yes
27	SQ-100X	Yes
28	SQ-31X	No
35	SO-100	No
36	SO-200	No

Table 39: Calibration Characteristic Examples

Characteristic Packet	Value	Description
00	OFFSET_CALIBRATION_BEGIN = 0 OFFSETS_ACTIVE = 0	Offset calibration is not in progress and it is not used in the sensor output calculation.
01	OFFSET_CALIBRATION_BEGIN = 0 OFFSETS_ACTIVE = 1	The offset calibration result is used in the sensor output calculation. If notifications are enabled, this will be the notification when calibration is complete.
03	OFFSET_CALIBRATION_BEGIN = 1 OFFSETS_ACTIVE = 1	Offset calibration is in progress and will be used in the sensor output calculation.
0A	0XYGEN_CALIBRATION = 0b010 OFFSET_CALIBRATION_BEGIN = 1	Oxygen Calibration is in progress for Relative Oxygen for Multiplier at Ambient Oxygen

Coefficients1 and Coefficients2 Characteristics

Table 40: Coefficients1 Characteristic

UUID (within base)	Properties	Value Contents
0x0100	Read/Write	3 FLOAT32s

Table 41: Coefficients2 Characteristic

UUID (within base)	Properties	Value Contents
0x0101	Read/Write	3 FLOAT32s

Coefficients1 and Coefficients2 characteristics are used to write custom coefficients for the calculation of sensor output. Each of these characteristics contains three 32-bit floating-point numbers.

Table 42: Coefficients1 Characteristic Fields

Coefficient 1	Coefficient 2	Coefficient 3
4 Bytes	4 Bytes	4 Bytes

Table 43: Coefficients2 Characteristic Fields

Coefficient 4	Coefficient 5	Coefficient 6
4 Bytes	4 Bytes	4 Bytes

Not all sensors use coefficients, and the sensors that use coefficients may use any number of them between one and six.

Some sensors have default coefficients that are recommended and are stored internally. To signal the Apogee Bluetooth device to use a default coefficient, a value of 0.0 needs to be written to a field in the Coefficients1 or Coefficients2 characteristic. A custom coefficient may be used for any sensor with a default coefficient. See **Table 46** for a complete list of coefficient usage for each sensor.

Coefficients1 and Coefficients2 characteristics are not reset or changed when the Sensor ID characteristic is changed. Therefore, when a different sensor is connected to an Apogee Bluetooth device, the Coefficients1 and Coefficients2 characteristics will need to be changed accordingly by the central device. If they are not changed, an unintended coefficient may be applied to the calculation of the output of the new sensor.

Data length is 12 bytes.

Table 44: Coefficients1 Characteristic Example

Characteristic Packet	Value(s)	Description
BD-C9-B4-4E-9A-BD-09-4B-9A-82-9E-47	1516560000.00, 9026970.00, 81157.20	Coefficient 1: 1516560000.00 Coefficient 2: 9026970.00 Coefficient 3: 81157.20
00-00-00-00-00-00-00-00-00-00-00-00	0, 0, 0	Use default coefficients in calculations.
9A-99-CC-42-00-00-00-00-00-00-00-00	102.3, 0, 0	Coefficient 1: 102.3

Table 45: Coefficients2 Characteristic Example

Characteristic Packet	Value(s)	Description
34-E5-51-CB-9A-90-9D-47-48-15-5F-45	-13755700.00, 80673.20, 3569.33	Coefficient 4: -13755700.00 Coefficient 5: 80673.20 Coefficient 6: 3569.33

Table 46: Coefficient Usage for Each Sensor

Key	Sensor Name	Default Coefficients	Custom Coefficients	Default Recommended?
0	No sensor chosen	Not Applicable	Not Applicable	Not Applicable
1	SP-110	Multiplier of 5 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
2	SP-510	Multiplier of 17.5 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	No
3	SP-610	Multiplier of 6.7 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	No
4	SQ-110	Multiplier of 5 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
5	SQ-120			
6	SQ-500	Multiplier of 100 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
7	SL-510	Multiplier of 8.5 if **C1** = 0 (C2 is required)	Multiplier of **C1** if **C1** ≠ 0 **C2** is required	No
8	SL-610			
9	SI-100	Default Not Available	**C1**, **C2**, **C3**, **C4**, **C5**, and **C6** are all required	Default Not Available
10	SU-200	Multiplier of 10 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
11	SE-100	Multiplier of 1000 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes

C1: Coefficient 1 **C2**: Coefficient 2 **C3**: Coefficient 3
C4: Coefficient 4 **C5**: Coefficient 5 **C2**: Coefficient 6

Table 46 Continued: Coefficient Usage for Each Sensor

Key	Sensor Name	Default Coefficients	Custom Coefficients	Default Recommended?
12	S2-111	Shorter Wavelength: Millivolt signal if **C1** = 0 Longer Wavelength: Millivolt signal if **C2** = 0	Shorter Wavelength: Multiplier of **C1** if **C1** ≠ 0 Longer Wavelength: Multiplier of **C2** if **C2** ≠ 0	No
13	S2-112			
14	S2-121			
15	S2-122			
16	S2-131			
17	S2-141			
18	SQ-610	Multiplier of 100.0 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
19	ST_1X0	No coefficients used	No coefficients used	Not Applicable
20	SP-700	Upward Facing Sensor: Multiplier of 17.5 if **C1** = 0 Downward Facing Sensor: Multiplier of 6.7 if **C2** = 0	Upward Facing Sensor: Multiplier of **C1** if **C1** ≠ 0 Downward Facing Sensor: Multiplier of **C2** if **C2** ≠ 0	No
21	SQ-620	Multiplier of 20.0 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
22	SQ-640	Multiplier of 1.0 if **C1** = 0	Multiplier of **C1** if **C1** ≠ 0	Yes
23	NDVI Pair	Upward Shorter Wavelength: Millivolt signal if **C1** = 0 Upward Longer Wavelength: Millivolt signal if **C2** = 0	Upward Shorter Wavelength: Multiplier of **C1** if **C1** ≠ 0 Upward Longer Wavelength: Multiplier of **C2** if **C2** ≠ 0	No
24	PRI Pair	Downward Shorter Wavelength: Millivolt signal if **C3** = 0 Downward Longer Wavelength: Millivolt signal if **C4** = 0	Downward Shorter Wavelength: Multiplier of **C3** if **C3** ≠ 0 Downward Longer Wavelength: Multiplier of **C4** if **C4** ≠ 0	
25	4 Single Ended	Millivolt signal if **C1** = 0 Millivolt signal if **C2** = 0 Millivolt signal if **C3** = 0 Millivolt signal if **C4** = 0	Multiplier of **C1** if **C1** ≠ 0 Multiplier of **C2** if **C2** ≠ 0 Multiplier of **C3** if **C3** ≠ 0 Multiplier of **C4** if **C4** ≠ 0	Not Applicable
26	2 Differential	Output1 = ((Yellow-Blue in mV) - **C2**) * **C1** Output2 = ((White-Black in mV) - **C4**) * **C3** If a multiplier coefficient (**C1** or **C3**) is 0, then 1.0 is used as default.		Not Applicable
27	SQ-100X	10 if **C1** = 0	**C1** if **C1** ≠ 0	Yes
28	SQ-31X	5 if **C1** = 0	**C1** if **C1** ≠ 0	Yes

C1: Coefficient 1 **C2**: Coefficient 2 **C3**: Coefficient 3
C4: Coefficient 4 **C5**: Coefficient 5 **C2**: Coefficient 6

Table 46 Continued: Coefficient Usage for Each Sensor

<table>
<tr><th>Key</th><th>Sensor Name</th><th>Default Coefficients</th><th>Custom Coefficients</th><th>Default Recommended?</th></tr>
<tr><td>35</td><td>SO-100</td><td colspan="2" rowspan="2">When the Sensor ID Characteristic is written to an Oxygen Sensor (35 or 36), the following default coefficients are written to the Coefficient Characteristics.
Multiplier C1: 0.4
Offset C2: 3.0
Temperature at Calibration C3: 20.0
Pressure at Absolute Calibration C4: 0.0
These may then be over-written manually using the Coefficients1 and Coefficients2 Characteristics or by running internal calibration routines using the Calibration Characteristic.</td><td rowspan="2">Use default as a starting point, then calibrate using the Calibration Characteristic.</td></tr>
<tr><td>36</td><td>SO-200</td></tr>
<tr><td colspan="5">C1: Coefficient 1 C2: Coefficient 2 C3: Coefficient 3
C4: Coefficient 4 C5: Coefficient 5 C2: Coefficient 6</td></tr>
</table>

Application Recommendations

Mobile App Interfacing

Mobile app interfacing with the Apogee Bluetooth device should proceed as described in the Chronological Overview section with additional consideration for the Data Log Collection Rate characteristic.

Mobile app users who have easy access to the button on the Apogee Bluetooth device will optimize battery life by setting the Data Log Collection Rate characteristic to 0 and only using a button press to initiate advertising.

Mobile app users can optionally set the Data Log Collection Rate Characteristic to a value greater than 0 to create the opportunity to automatically connect when the central device is in range, but it will decrease battery life.

Network Interfacing

The Apogee Bluetooth device may be used in a network environment where the central device is always in range such as a gateway. The benefit of such an environment is that data could be collected as it becomes available. Interfacing with the Apogee Bluetooth device should proceed as described in the Chronological Overview section, except some characteristics are not intended to be used in a network environment.

The characteristics that are not intended (although not restricted) to be used by the gateway are Live Data, Live Data Control, Data Log Full Time, and Calibration characteristics.

The Data Log Collection Rate Characteristic should be set to a number greater than 0 so that the Apogee Bluetooth device advertises periodically. When the Apogee Bluetooth device advertises, the central device should connect, collect data and carry out any other Bluetooth interfacing, then disconnect as quickly as possible to maximize battery life. The Apogee Bluetooth device will advertise again when there is more data to collect. The central device should not stay connected to the Apogee Bluetooth device.

Figure 1 shows a routine network connection to collect data from an Apogee Bluetooth device.

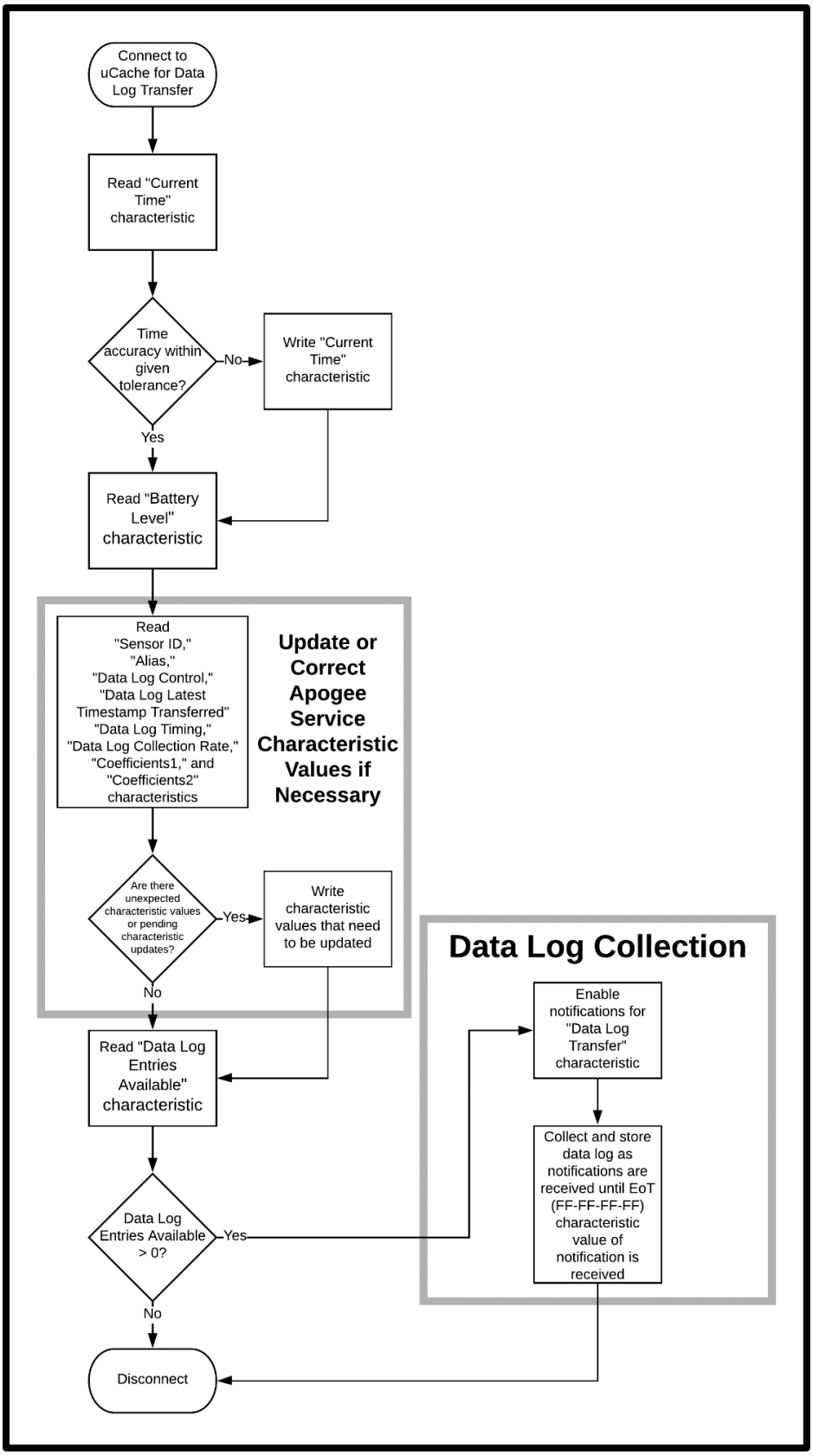

Figure 1 Routine Network Connection

Bootloader

Apogee Bluetooth devices have a bootloader to support Over-The-Air Device Firmware Updates (OTA-DFU). This allows a central device to update the firmware via Bluetooth.

Note that “revision” and “version” are used interchangeably when discussing the bootloader.

Button and LED Interface in Bootloader Mode

The button and LED are generally not needed during the OTA-DFU process; however, they do have functionality.

The LED will be solid red (not blinking) when the Apogee Bluetooth device is advertising in bootloader mode. Advertising times out after 30 seconds, and then the Apogee Bluetooth device goes to sleep. When the OTA-DFU goes correctly, the LED will be red for a few seconds and the central device will connect to the Apogee Bluetooth device and proceed with the update.

The button will wake up the Apogee Bluetooth device from sleeping and it will start advertising. When the OTA-DFU goes correctly, the Apogee Bluetooth device will not go to sleep or require a button press.

If an Apogee Bluetooth device is ever found to have a solid red LED for 30 seconds after a short button press, this indicates that there is not a valid application. Something may have gone wrong in a previous OTA-DFU attempt. A central device needs to connect and update the Apogee Bluetooth device with valid firmware.

Secure DFU Service

To get to bootloader mode, use the Secure DFU Service. The OTA-DFU bootloader is based on a bootloader written by Nordic Semiconductor. Resources can be found on their website to help implement it on a central device to update the firmware on Apogee Bluetooth devices.

Advertising

When the Apogee Bluetooth device advertises in bootloader mode, the following are in the advertising data:

- Apogee Company Identifier 0x0644, and
- Device name ApogeeDFU.

OTA-DFU Firmware Package

The OTA-DFU firmware image and resources are provided in a zip file. Following is an example file name:

ucache_app_update_hw6_fw7_s140_nrf52_7.0.1.zip

The package used to update the Apogee Bluetooth device needs to have the correct hardware version, firmware revision, and Nordic SoftDevice version. These three version numbers can be found in the file name.

The Hardware Version and Firmware Version can be read in the Device Information Service (DIS) of the Apogee Bluetooth device to help choose the correct OTA DFU package.

The hardware version of the OTA-DFU package must match the hardware version of the target Apogee Bluetooth device.

The firmware version of the OTA-DFU package must be equal to or greater than the current firmware version on the target Apogee Bluetooth device. The Bootloader allows the same version number to be loaded but blocks lower versions. For example, if the current firmware version is 2, it will allow an OTA-DFU of firmware version of 2, 3, 4... to be loaded, but not firmware version 1.

The Nordic SoftDevice version of the OTA-DFU package must match the Nordic SoftDevice version of the target Apogee Bluetooth device. It can be updated, but will likely remain the same. If firmware version 8 had a Nordic SoftDevice update, then upgrading from firmware version 7 to 9 will require a special package that includes the new SoftDevice or require updating from 7 to 8, and then 8 to 9.