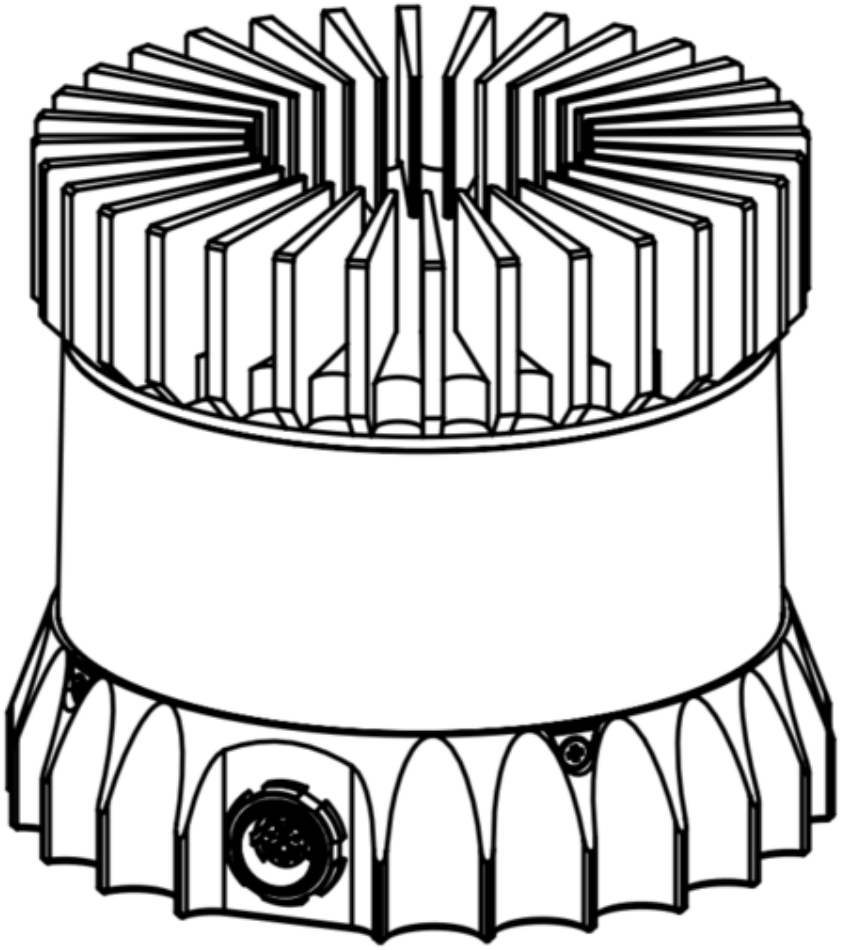
OUSTER



Software User Guide

Release v1.12.0

OS-1-64/16 High Resolution Imaging Lidar

May 02, 2019

Software User Guide

Version v1.6.0

Date 2018-08-16

Desciption Add: `get_sensor_info` command gives `prod_line` info.

Version v1.7.0

Date 2018-09-05

Desciption No TCP command change.

Version v1.8.0

Date 2018-10-11

Desciption Add: `get_sensor_info` command gives `INITIALIZING`, `UPDATING`, `RUNNING`, `ERROR` and `UNCONFIGURED` status.

Version v1.9.0

Date 2018-10-24

Desciption No TCP command change.

Version v1.10.0

Date 2018-12-11

Desciption Remove all references of "pulse_mode".

Add "get_alerts", "pps_rate" and "pps_angle" usage commands and expected output.

Remove TCP commands prior to v1.5.1.

Version v1.11.0

Date 2019-03-25

Desciption Add section on HTTP API commands.

TCP Port now hardcoded to 7501; port is no longer configurable.

Update to SYNC_PULSE_IN AND MULTIPURPOSE_IO interface and configuration parameters (see details below).

Details on interface changes:

Configuration parameters name changes:

- "pps_in_polarity" changed to "sync_pulse_in_polarity"
- "pps_out_mode" changed to "multipurpose_io_mode"
- "pps_out_polarity" changed to "sync_pulse_out_polarity"
- "pps_rate" changed to "sync_pulse_out_frequency"
- "pps_angle" changed to "sync_pulse_out_angle"
- "pps_pulse_width" changed to "sync_pulse_out_pulse_width"

New configuration parameters:

- "nmea_in_polarity"
- "nmea_ignore_valid_char"
- "nmea_baud_rate"
- "nmea_leap_seconds"

Configuration parameters option changes:

- **timestamp_mode**
  - "TIME_FROM_PPS" changed to "TIME_FROM_SYNC_PULSE_IN"
- **multipurpose_io_mode (formerly pps_out_mode)**
  - "OUTPUT_PPS_OFF" changed to "OFF"
  - "OUTPUT_FROM_PPS_IN_SYNCED" changed to "OUTPUT_FROM_SYNC_PULSE_IN"
  - Removed "OUTPUT_FROM_PPS_DEFINED_RATE"
  - Added "INPUT_NMEA_UART"

TCP command changes:

- **Added commands:**
  - "get_time_info"
- **Changed commands:**
  - "get_config_txt" (returned dictionary keys match parameter changes)
- **Removed commands:**
  - "set_pps_in_polarity"
  - "get_pps_out_mode"
  - "set_pps_out_mode"
  - "get_timestamp_mode"
  - "set_timestamp_mode"

Polarity changes:

- "sync_pulse_in_polarity" was corrected to match parameter naming.
- "sync_pulse_out_polarity" was corrected to match parameter naming.

Version v1.12.0

Date

Desciption Corrected IMU axis directions to match sensor coordinate frame. See section Section 4.1 for details on sensor coordinate frame. This change inverts IMU X, Y, and Z axis relative to v1.11.0.

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1 Introduction

The OS-1 family of sensors offer a market leading combination of price, performance, reliability and SWaP (Size, Weight, and Power). They are designed for indoor/outdoor all-weather environments and long lifetime. As the smallest high performance lidar on the market, the OS-1 can be directly integrated into vehicle fascias, windshields, side mirrors, and headlight clusters. The OS-1 family of sensors consist of two models, the OS-1-16 and OS-1-64, with differing resolution, but of identical mechanical dimensions.

HIGHLIGHTS

- Fixed resolution per frame operating mode
- Camera-grade intensity, ambient, and range data
- Multi-sensor crosstalk immunity
- Simultaneous and co-calibrated 2D and 3D output
- Industry leading intrinsic calibration
- Example client code available

For the purposes of this document, the term "OS-1" refers to the family of sensors, and only where there is a difference in performance will each model be referred to by its specific model designation.

2 Safety & Legal Notices

The OS-1-16 and OS-1-64 are Class 1 laser products per IEC 60825-1:2014 and operate in the 850nm band.

FDA 21CFR1040 Notice: OS-1-16 and OS-1-64 comply with FDA performance standards for laser products except for deviations pursuant to Laser Notice No. 50, dated July 26th, 2001.

WARNING: The OS-1 is a sealed unit, and is not user-serviceable.

Your use of the OS-1 is subject to the Terms of Sale that you signed with Ouster or your distributor/integrator. Included in these terms is the prohibition on removing or otherwise opening the sensor housing, inspecting the internals of the sensor, reverse-engineering any part of the sensor, or permitting any third party to do any of the foregoing.

"Ouster" and "OS-1" are both registered trademarks of Ouster, Inc. They may not be used without express permission from Ouster, Inc.

If you have any questions about the above points, contact us at legal@ouster.io

3 Drivers & Interface

By default, when newly provided power by the Interface Box, the sensor will start-up and then automatically start taking measurements, request an IP address, and stream UDP data packets to the configured destination address. Settings can be modified using a simple plaintext protocol over TCP.

Ouster provides sample code for connecting to the sensor, visualizing the output data, and interfacing with the popular ROS robotics suite. The source code repository can be found at: www.github.com/orgs/ouster-lidar/ouster_example

3.1 Network Configuration

Before attempting to configure and stream data from the sensor, please ensure that it is reachable over the network from the client PC. The OS-1 requires a network that can provide data throughput of approximately 129 Mbps between client and the sensor, and a DHCP server to reliably connect and stream data. Gigabit Ethernet hardware is recommended.

In a typical network environment, the OS-1 should obtain a DHCP lease and be reachable over the network a few moments after being plugged in. If your network is set up to provide DNS for DHCP clients, you should be able to check for connectivity using e.g.:

```
$ ping -c1 os1-991900123456
PING os1-991900123456 (10.5.5.94) 56(84) bytes of data.
64 bytes from os1-991900123456 (10.5.5.94): icmp_seq=1 ttl=64 time=0.163 ms

--- os1-991900123456 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.163/0.163/0.163/0.000 ms
```

where "991900123456" is the serial number printed on the top of the sensor.

Running A Local DHCP Server

If the sensor is plugged directly into the client machine, you will have to install and run a local DHCP server or use the IPV4 override mechanism described below. A common choice is *dnsmasq*, which is available for a variety of platforms. To connect to the sensor using a local dnsmasq instance on Linux:

1. Identify the ethernet interface to be used on the client (Linux) machine, e.g. enp6s0f1
2. Check that the sensor is **not** plugged in to the ethernet interface on the client machine
3. Make sure that the ethernet interface is "down" and not yet configured:

   ```
   $ ip addr flush dev enp6s0f1
   $ ip addr show dev enp6s0f1
   2: enp6s0f1: <BROADCAST,MULTICAST> ... state DOWN group default qlen 1000
   ```

4. Assign a static IP to the chosen interface:

   ```
   $ sudo ip addr add 10.5.5.1/24 dev enp6s0f1
   ```

5. Connect an ethernet cable between the sensor and the designated ethernet interface on the client machine. Power-on the sensor. Ensure that the link is now "up":

   ```
   $ sudo ip link set enp6s0f1 up
   $ ip addr show dev enp6s0f1
   2: enp6s0f1: <BROADCAST,MULTICAST,UP> ... state UP group default qlen 1000
   ```

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```
link/ether xx:xx:xx:xx:xx:xx brd ff:ff:ff:ff:ff:ff
inet 10.5.5.1/24 scope global enp6s0f1
   valid_lft forever preferred_lft forever
```

6. Run dnsmasq to listen for DHCP requests on the chosen interface:

```
$ sudo dnsmasq -C /dev/null -kd -F 10.5.5.50,10.5.5.100 -i enp6s0f1 --bind-dynamic
```

7. Within 10-15 seconds, you should see the DHCP negotiation take place:

```
dnsmasq-dhcp: DHCP, IP range 10.5.5.50 -- 10.5.5.100, lease time 1h
dnsmasq-dhcp: DHCP, sockets bound exclusively to interface enp6s0f1
dnsmasq: reading /etc/resolv.conf
dnsmasq: using nameserver 127.0.1.1#53
dnsmasq: read /etc/hosts - 7 addresses
dnsmasq-dhcp: DHCPDISCOVER(enp6s0f1) xx:xx:xx:xx:xx:xx
dnsmasq-dhcp: DHCPOFFER(enp6s0f1) 10.5.5.94 xx:xx:xx:xx:xx:xx
dnsmasq-dhcp: DHCPREQUEST(enp6s0f1) 10.5.5.94 xx:xx:xx:xx:xx:xx
dnsmasq-dhcp: DHCPACK(enp6s0f1) 10.5.5.94 xx:xx:xx:xx:xx:xx os1-991900123456
```

8. Check connectivity via the assigned IP address:

```
$ ping -c1 10.5.5.94
PING 10.5.5.94 (10.5.5.94) 56(84) bytes of data.
64 bytes from 10.5.5.94: icmp_seq=1 ttl=64 time=0.404 ms

--- 10.5.5.94 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.404/0.404/0.404/0.000 ms
```

9. See the documentation for your operating system on how to make these changes persistent, e.g., by using a network configuration daemon like NetworkManager.

3.2 HTTP Interface

The lidar sensor hosts a HTTP server that implements a versioned RESTful API to enable programmatic command and control of the sensor.

This HTTP interface is a convenient way to query the sensor for various information. The query can be done from the command line, programmatically or from within a web browser.

All of the responses are JSON objects and best handled with an HTTP client that can interpret and present JSON objects.

Note: See the *HTTP API Reference* for more information on usage of individual resources.

Clients and Tools

Many readily available tools exist to facilitate communication with the HTTP API.

Web browser

The simplest way to access the API is to issue a `GET` request using the web browser.

For example, to view the network configuration of a sensor load the following URL in a web browser:

http://192.0.2.123/api/v1/system/network

Extensions aid in viewing the JSON objects. Firefox includes a JSON formatter by default and the Chrome web store offers the JSON Formatter.

To send HTTP requests using things other then `GET` method REST clients are available as well. The Chrome web store offers the Advanced REST client.

Command line

For automated access from the command line a number exists for HTTP client as well as JSON formatters.

The httpie tool serves as a HTTP client as well as JSON formatter. Example usage:

```
$ http http://192.0.2.123/api/v1/system/network
HTTP/1.1 200 OK
content-length: 260
content-type: application/json; charset=UTF-8

{
    "carrier": true,
    "duplex": "full",
    "ethaddr": "bc:0f:a7:00:01:2c",
    "hostname": "os1-991900123456",
    "ipv4": {
        "addr": "192.0.2.123/24",
        "link_local": "169.254.245.183/16",
        "override": null
    },
    "ipv6": {
        "link_local": "fe80::be0f:a7ff:fe00:12c/64"
    },
    "speed": 1000
}
```

Curl is a popular and high performance command line tool (backed by `libcurl`), example usage is as follows:

```
$ curl -s http://192.0.2.123/api/v1/system/network
{"ipv6": {"link_local": "fe80::be0f:a7ff:fe00:12c/64"}, "ethaddr": "bc:0f:a7:00:01:2c
↪", "ipv4": {"override": null, "link_local": "169.254.245.183/16", "addr": "192.0.2.
↪123/24"}, "speed": 1000, "duplex": "full", "carrier": true, "hostname": "os1-
↪991900123456"}
```

The unformatted JSON output is hard to read, but this can be improved with the command line jq formatter:

```
$ curl -s http://192.0.2.123/api/v1/system/network | jq -S
{
  "carrier": true,
  "duplex": "full",
  "ethaddr": "bc:0f:a7:00:01:2c",
  "hostname": "os1-991900123456",
  "ipv4": {
    "addr": "192.0.2.123/24",
    "link_local": "169.254.245.183/16",
    "override": null
  },
  "ipv6": {
    "link_local": "fe80::be0f:a7ff:fe00:12c/64"
  },
  "speed": 1000
}
```

Programmatic access

Several popular libraries are available for interfacing with the sensor interface via common programming languages:

- C - libcurl
- Python - requests

Response Codes

The HTTP API uses HTTP response codes to provide result status information. The sensor will return HTTP response codes that comply with the HTTP standards.

The `http` command shows the response code as part of the returned response in the console.

Common response code classes:

2XX Request was success (e.g., when a `GET` command succeeded)

4XX Client request error not allowed (e.g., when a `POST` on `system/time` is attempted)

5XX Server errors

3.3 TCP API Command Set

Querying Sensor Info and Intrinsic Calibration

The sensor can be queried and configured using a simple plaintext protocol over TCP on port 7501. The following commands will return sensor configuration and calibration information:

Command	Description	Response Example

`get_config_txt`	Return JSON-formatted sensor	{
		"auto_start_flag": 1,
		"lidar_mode": "1024x10",
		"multipurpose_io_mode": "OUTPUT_OFF",
		"sync_pulse_in_polarity": "ACTIVE_HIGH"
		"sync_pulse_out_angle": 360,
		"sync_pulse_out_frequency": 1,
		"sync_pulse_out_polarity": "ACTIVE_HIGH"
		"sync_pulse_out_pulse_width": 10,
		"tcp_port": 7501,
		"timestamp_mode": "TIME_FROM_INTERNAL_OSC",
		"udp_ip": "",
		"udp_port_imu": 7503,
		"udp_port_lidar": 7502,
		"window_rejection_enable": 1
		}

`get_sensor_info`	Return JSON-formatted sensor metadata: serial number, hardware and software revision, and sensor status.	{
		"base_pn": "000-101323-01",
		"base_sn": "11E0211",
		"build_date": "2018-05-02T18:37:13Z",
		"build_rev": "v1.2.0",
		"image_rev": "ousteros-image-prod-aries-v1.2.0-201804232039",
		"prod_line": "OS-1-64",
		"prod_pn": "840-101396-02",
		"prod_sn": "991900123456",
		"proto_rev": "v1.1.0",
		"status": "RUNNING"
		}

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Table 1 – continued from previous page

Command	Description	Response Example

`get_time_info`	Return JSON-formatted sensor timing configuration and status of udp timestamp, synce_pulse_in, and synce_pulse_out.	{
		"sync_pulse_in": {
		"diagnostics": {
		"count_unfiltered": 0,
		"last_period_nsec": 0,
		"count": 1
		},
		"polarity": "ACTIVE_HIGH",
		"locked": 0
		},
		"nmea": {
		"polarity": "ACTIVE_HIGH",
		"baud_rate": "BAUD_9600",
		"diagnostics": {
		"io_checks": {
		"bit_count": 1,
		"start_char_count": 0,
		"bit_count_unfilterd": 0,
		"char_count": 0
		},
		"decoding": {
		"not_valid_count": 0,
		"last_read_message": "",
		"utc_decoded_count": 0,
		"date_decoded_count": 0
		}
		},
		"leap_seconds": 0,
		"ignore_valid_char": 0,
		"locked": 0
		},
		"sync_pulse_out": {
		"frequency_hz": 1,
		"angle_deg": 360,
		"pulse_width_ms": 10,
		"polarity": "ACTIVE_HIGH",
		"mode": "OFF"
		},
		"timestamp": {
		"time_options": {
		"ptp_1588": 1552926167,
		"sync_pulse_in": 1,
		"internal_osc": 53
		},
		"mode": "TIME_FROM_INTERNAL_OSC",
		"time": 53.71712347
		}
		}

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Table 1 – continued from previous page

Command	Description	Response Example
`get_beam_intrinsics`	Returns JSON-formatted beam altitude and azimuth offsets, in degrees.	`{ "beam_altitude_angles": [ 16.926, 16.313, "...", -16.078, -16.689 ], "beam_azimuth_angles": [ 3.052, 0.857, "...", -0.868, -3.051 ] }`
`get_imu_intrinsics`	Returns JSON-formatted imu transformation matrix needed to adjust to the Sensor Coordinate Frame.	`{ "imu_to_sensor_transform": [ 1, 0, 0, 6.253, 0, 1, 0, -11.775, 0, 0, 1, 7.645, 0, 0, 0, 1 ] }`

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Table 1 – continued from previous page

Command	Description	Response Example

`get_lidar_intrinsics`	Returns JSON-formatted lidar transformation matrix needed to adjust to the Sensor Coordinate Frame.	{
		"lidar_to_sensor_transform": [
		-1,
		0,
		0,
		0,
		0,
		-1,
		0,
		0,
		0,
		0,
		1,
		36.18,
		0,
		0,
		0,
		1
		]
		}

`get_alerts`	Returns JSON-formatted alerts of the sensor if `get_sensor_info` is `ERROR`. It has a buffer to hold up to 8 errors sequentially.	{
		"alerts": [
		{"cursor": 0,
		"code": "ETHERNET_LINK_BAD",
		"level": "Warning",
		"realtime": "1552568810910286848",
		"brief": "Ethernet Link Bad",
		"description": "Link transitioned to 0/Unknown which != 1000/Full"
		}
		],
		"next_cursor": 1
		}

An example session using the unix netcat utility is shown below:

```
$ nc os1-991900123456 7501
get_sensor_info
{``prod_line``: ``OS-1-64``, "prod_pn": "840-101396-02", "prod_sn": "991900123456",
 "base_pn": "000-101323-01", "base_sn": "11E0211",
 "image_rev": "ousteros-image-prod-aries-v1.2.0-201804232039", "build_rev": "v1.2.0",
 "proto_rev": "v1.1.0", "build_date": "2018-05-02T18:37:13Z", "status": "RUNNING"}
```

Potentially, sensor may have the following status:

Status	Occurs . . .
INITIALIZING	When the sensor is booting and not yet outputting data.
UPDATING	When the sensor is updating the FPGA firmware on the first reboot after a firmware upgrade.
RUNNING	When the sensor has reached the final running state where it can output data.
ERROR	Check error codes in the `errors` field for more information.
UNCONFIG-URED	An error with factory calibration that requires a return.

If sensor is in an `ERROR` or `UNCONFIGURED` state, please contact Ouster with the output of `get_sensor_info` and `get_alerts` for support.

Querying Active or Staged Parameters

Sensor configurations / operating modes can also be queried over TCP. Below is the latest command format:

`get_config_param active <parameter>` will return the current active configuration parameter values.

`get_config_param staged <parameter>` will return the parameter values that will take place after issuing `reinitialize` command or after sensor reset.

get_config_param	Command Description	Response
udp_ip	Returns the ip to which the sensor sends UDP traffic..	"" (default)
udp_port_lidar	Returns the port number of Lidar UDP data packets	7502 (default)
udp_port_imu	Returns the port number of IMU UDP data packets	7503 (default)
lidar_mode	Returns a string indicating the horizontal resolution	One of `512x10`, `1024x10`, `2048x10`, `512x20`, `1024x20`
timestamp_mode	Get the method used to timestamp measurements. See Section 5.2 for a detailed description of each option.	One of `TIME_FROM_INTERNAL_OSC`, `TIME_FROM_PTP_1588`, `TIME_FROM_SYNC_PULSE_IN`
sync_pulse_in_polarity	Returns the polarity of SYNC_PULSE_IN input, which controls polarity of SYNC_PULSE_IN pin when timestamp_mode is set in `TIME_FROM_SYNC_PULSE_IN`.	One of `ACTIVE_HIGH` or `ACTIVE_LOW`. Default `ACTIVE_LOW`.
nmea_in_polarity	Returns the polarity of NMEA UART input $GPRMC messages. See Section 5.2 NMEA use case. Use `ACTIVE_HIGH` if UART is active high, idle low, and start bit is after a falling edge.	One of `ACTIVE_HIGH` or `ACTIVE_LOW`. Default `ACTIVE_HIGH`.
nmea_ignore_valid_char	Returns `0` if NMEA UART input $GPRMC messages should be ignored if valid character is not set, and "1" if messages should be used for time syncing regardless of the valid character.	0 (default)
nmea_baud_rate	Returns "BAUD_9600" (default) or "BAUD_115200" for the expected baud rate the sensor is attempting to decode for NMEA UART input $GPRMC messages.	One of "BAUD_9600", "BAUD_115200"

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Table 2 – continued from previous page

get_config_param	Command Description	Response
nmea_leap_seconds	Returns the number of leap seconds that will be added to the UDP timestamp when calculating seconds since 00:00:00 Thursday, 1 January 1970. For Unix Epoch time, this should be set to 0.	0 (default)
multipurpose_io_mode	Returns the source of the the SYNC_PULSE_OUT signal output by the sensor. See Section 5.3 for a detailed description of each option.	One of `OUTPUT_FROM_INTERNAL_OSC`, `OUTPUT_FROM_SYNC_PULSE_IN`, `OFF`, `OUTPUT_FROM_PTP_1588`
sync_pulse_out_polarity	Returns the polarity of SYNC_PULSE_OUT output, if sensor is using this for time synchronization	One of `ACTIVE_HIGH` or `ACTIVE_LOW`. Default `ACTIVE_LOW`.
sync_pulse_out_frequency	Returns the output SYNC_PULSE_OUT pulse rate in Hz	1 (default)
sync_pulse_out_angle	Returns the output SYNC_PULSE_OUT pulse rate defined in rotation angles.	360 (default)
sync_pulse_out_pulse_width	Returns the output SYNC_PULSE_OUT pulse width in ms.	10 (ms, default)
auto_start_flag	Returns `1` if sensor is on auto start, and `0` if not. Normal operation is to use auto start. If not in auto start, the sensor must be manually commanded in order to operate.	1 (default)
window_rejection_enable	1: The default. Enabled. Allows the sensor to achieve full spec. 0: Disabled. Reduces the sensor range to zero meters but also causes the sensor to select the window return echo instead of a target return echo if the window echo is stronger. Depending on window cleanliness this can significantly reduce sensor range. No sensor specs are guaranteed in this mode.	1 (default)

An example session using the unix netcat utility is shown below:

```
$ nc os1-991900123456 7501
get_config_param active lidar_mode
1024x10
```

Setting Configuration Parameters

`set_config_param <parameter> <value>` will set new values for configuration parameters, which will take effect after issuing `reinitialize` command, or after sensor reset.

set_config_param	Command Description	Response
udp_ip <ip address>	Specifies the ip to which the sensor sends UDP traffic. On boot, the sensor will not output data until this is set.	`set_config_param` on success, `error:` otherwise
udp_port_lidar <port>	Lidar data will be sent to <udp_ip>:	`set_config_param` on success, `error:` otherwise
udp_port_imu <port>	Imu data will be sent to <udp_ip>:	`set_config_param` on success, `error:` otherwise
lidar_mode <mode>	Set the horizontal resolution and rotation rate of the sensor. Valid modes are `512x10`, `1024x10`, `2048x10 512x20`, `1024x20`. Each 50% the total number of points gathered is reduced - e.g., from 2048x10 to 1024x10 - extends range by 15-20%.	`set_config_param` on success, `error:` otherwise
timestamp_mode <mode>	Set the method used to timestamp measurements. Valid modes are `TIME_FROM_INTERNAL_OSC`, `TIME_FROM_SYNC_PULSE_IN`, or `TIME_FROM_PTP_1588`	`set_config_param` on success, `error:` otherwise
sync_pulse_in_polarity <1/0>	Set the polarity of SYNC_PULSE_IN input, which controls polarity of SYNC_PULSE_IN pin when timestamp_mode is set in `TIME_FROM_SYNC_PULSE_IN`.	`set_config_param` on success, `error:` otherwise
nmea_in_polarity <1/0>	Set the polarity of NMEA UART input $GPRMC messages. See Section 5.2 NMEA use case. Use `ACTIVE_HIGH` if UART is active high, idle low, and start bit is after a falling edge.	`set_config_param` on success, `error:` otherwise
nmea_ignore_valid_char <1/0>	Set `0` if NMEA UART input $GPRMC messages should be ignored if valid character is not set, and "1" if messages should be used for time syncing regardless of the valid character.	`set_config_param` on success, `error:` otherwise
nmea_baud_rate <rate in baud/s>	Set "BAUD_9600" (default) or "BAUD_115200" for the expected baud rate the sensor is attempting to decode for NMEA UART input $GPRMC messages.	`set_config_param` on success, `error:` otherwise
nmea_leap_seconds <s>	Set an integer number of leap seconds that will be added to the UDP timestamp when calculating seconds since 00:00:00 Thursday, 1 January 1970. For Unix Epoch time, this should be set to 0.	`set_config_param` on success, `error:` otherwise
multipurpose_io_mode <mode>	Set the source of the SYNC_PULSE_OUT signal. Valid modes are `OUTPUT_OFF`, "INPUT_NMEA_UART", `OUTPUT_FROM_INTERNAL_OSC`, `OUTPUT_FROM_SYNC_PULSE_IN`, `OUTPUT_FROM_PTP_1588`, or `OUTPUT_FROM_ENCODER_ANGLE`	`set_config_param` on success, `error:` otherwise

sync_pulse_out_polarity <1/0>	Set the polarity of SYNC_PULSE_OUT output, if sensor is set as the master sensor used for time synchronization	`set_config_param` on success, `error:` otherwise
sync_pulse_out_frequency <rate in Hz>	Set output SYNC_PULSE_OUT rate. Valid inputs are integers > 0 Hz, but also limited by the criteria described in Section 5.3 of this user manual.	`set_config_param` on success, `error:` otherwise
sync_pulse_out_angle <angle in deg>	Set output SYNC_PULSE_OUT rate defined by rotation angle. Valid inputs are integers < 360 degrees, but also limited by the criteria described in Section 5.3 of this user manual.	`set_config_param` on success, `error:` otherwise
sync_pulse_out_pulse_width <width in ms>	Set output SYNC_PULSE_OUT pulse width in ms, in 1ms increments. Valid inputs are integers > 0 ms, but also limited by the criteria described in Section 5.3 of this user manual.	`set_config_param` on success, `error:` otherwise
window_rejection_enable <1/0>	1: The default. Enabled. Allows the sensor to achieve full spec. 0: Disabled. Reduces the sensor range to zero meters but also causes the sensor to select the window return echo instead of a target return echo if the window echo is stronger. Depending on window cleanliness this can significantly reduce sensor range. No sensor specs are guaranteed in this mode.	`set_config_param` on success, `error:` otherwise

`reinitialize` will reinitialize the sensor so the staged values of the parameters will take effect immediately.

`write_config_txt` will write new values of active parameters into a configuration file, so they will persist after sensor reset. In order to permanently change a parameter in the configuration file, first use `set_config_param` to update the parameter in a staging area, then use `reinitialize` to make that parameter active. Only after the parameter is made active will `write_config_txt` capture it to take effect on reset.

set_config_param Command	Description	Response
reinitialize	Restarts the sensor. Changes to lidar, sync_pulse_out, and timestamp modes will only take effect after reinitialization.	`reinitialize` on success
write_config_txt	Make the current settings persist until the next reboot.	`write_config_txt` on success

```
$ nc os1-991900123456 7501
set_config_param lidar_mode 512x20
set_config_param
set_config_param udp_ip 10.5.5.1
set_config_param
reinitialize
reinitialize
write_config_txt
write_config_txt
```

3.4 Lidar Data Format

By default UDP data is forwarded to Port 7502. Lidar data packets consist of 16 azimuth blocks and are always 12608 Bytes in length. The packet rate is dependent on the output mode. Words are 32 bits in length.

Word	Azimuth Block 0	Azimuth Block 1	. . .	Azimuth Block 15
(Word 0,1)	Timestamp	Timestamp	. . .	Timestamp
(Word 2[0:15])	Measurement ID	Measurement ID	. . .	Measurement ID
(Word 2[16:31])	Frame ID	Frame ID	. . .	Frame ID
(Word 3)	Encoder Count	Encoder Count	. . .	Encoder Count
(Word 4,5,6)	Channel 0 Data Block	Channel 0 Data Block	. . .	Channel 0 Data Block
(Word 7,8,9)	Channel 1 Data Block	Channel 1 Data Block	. . .	Channel 1 Data Block
	.	.		.
(Word 193, 194, 195)	Channel 63 Data Block	Channel 63 Data Block	. . .	Channel 63 Data Block
(Word 196)	Packet Status	Packet Status	. . .	Packet Status

Each azimuth block contains:

- Timestamp [64 bit unsigned int] - Timestamp of the measurement in nanoseconds
- Measurement ID[16 bit unsigned int] - a sequentially incrementing azimuth measurement counting up from 0 to 511, or 0 to 1023, or 0 to 2047 depending on lidar_mode.
- Frame ID[16 bit unsigned int] - index of the lidar scan. Increments every time the sensor completes a rotation, crossing the zero point of the encoder.
- Encoder Count[32 bit unsigned int] - an azimuth angle as a raw encoder count, starting from 0 with a max value of 90111 - incrementing 44 ticks every azimuth angle in 2048 mode, 88 ticks in 1024 mode, and 176 ticks in 512 mode.
- Data Block[96 bits] - 3 data words for each of the 16 or 64 pixels. See Table below for full definition.
  - Range [20 bits] - Range in millimeters, discretized to the nearest 12 millimeters.
  - Reflectivity [16 bits] - Sensor signal_photon measurements are scaled based on measured range and sensor sensitivity at that range, providing an indication of target reflectivity. Calibration of this measurement has not currently been rigorously implemented, but this will be updated in a future firmware release.
  - Signal Photons [16 bits] - Signal photons in the signal return measurement are reported
  - Ambient Noise Photons [16 bits] - Ambient noise photons in the ambient noise return measurement are reported.
- Packet Status- indicates whether the azimuth block is good or bad. Good = 0xFFFFFFFF, Bad = 0x0. If a packet is bad Measurement ID, Encoder Count, and Data Bock:Range and Data Block:Reflectivity will also be set to 0x0.

Full Description of Data Block:

Word	Byte 3	Byte 2	Byte 1	Byte 0
(Word 0)	unused[31:24]	unused[23:20] range_mm[19:16]	range_mm[15:8]	range_mm[7:0]
(Word 1)	signal_photons[31:24]	signal_photons[23:16]	reflectivity[15:8]	reflectivity[7:0]
(Word 2)	unused[31:24]	unused[23:16]	noise_photons[15:8]	noise_photons[7:0]

3.5 IMU Data Format

UDP Packets - 48 Bytes - Port 7503 - at 100 Hz

Word	IMU and Gyro Data Block
(Word 0,1)	64-bit unsigned integer for IMU read time (ns, monotonic system time since boot)
(Word 2,3)	64-bit unsigned integer for accelerometer read time (ns, relative to *timestamp_mode*)
(Word 4,5)	64-bit unsigned integer for gyroscope read time (ns, relative to *timestamp_mode*)
(Word 6)	32-bit float for acceleration in x-axis (g)
(Word 7)	32-bit float for acceleration in y-axis (g)
(Word 8)	32-bit float for acceleration in z-axis (g)
(Word 9)	32-bit float for angular velocity about in x-axis (deg per sec)
(Word 10)	32-bit float for angular velocity about in y-axis (deg per sec)
(Word 11)	32-bit float for angular velocity about in z-axis (deg per sec)

3.6 Data Rates

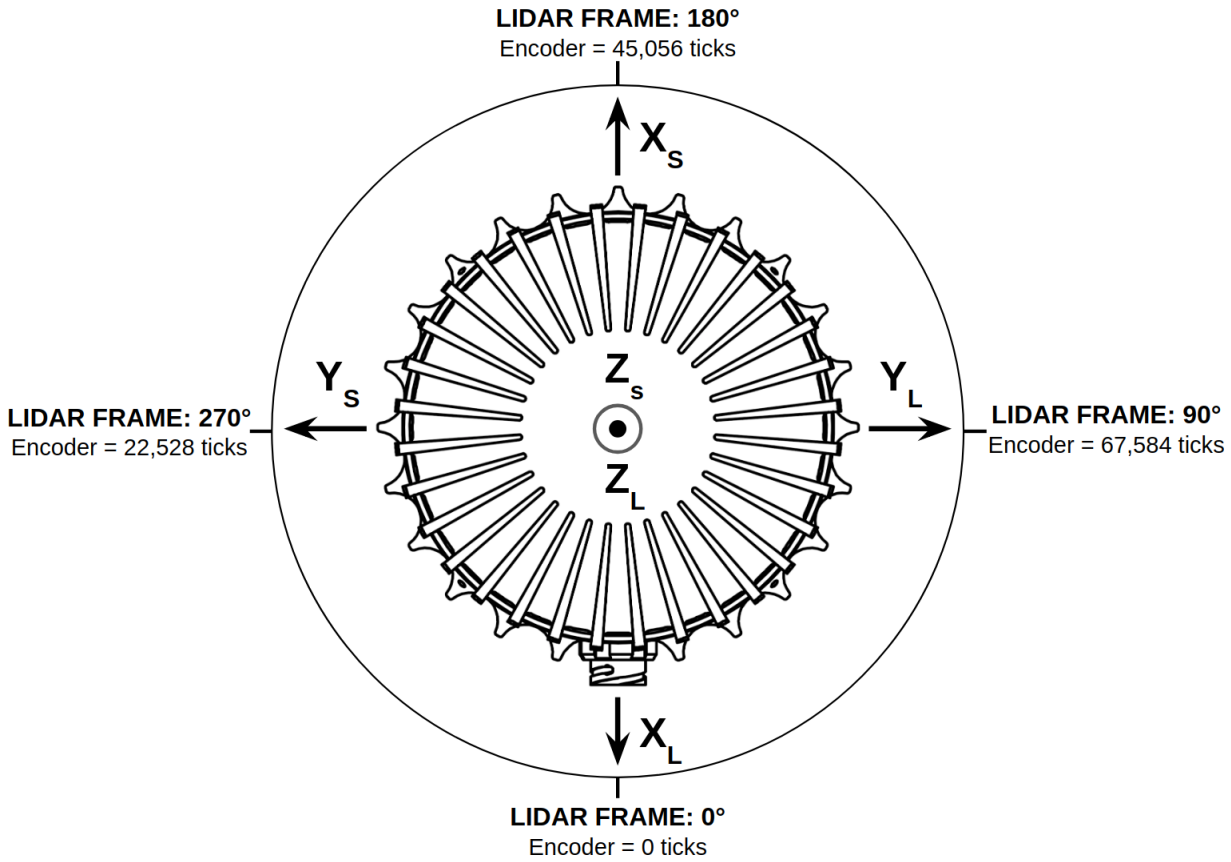
Based on 12,608 Bytes/packet and 1280 packets/sec, in 2048x10 or 1048x20 mode the OS-1 outputs 16.138 MB/s (129 Mbps). For this reason a gigabit ethernet network is required for reliable performance.

4 Coordinate Frames

4.1 Sensor Coordinate Frame

The Sensor Coordinate Frame follows the right-hand rule convention and is defined at the center of the sensor housing on the bottom, with the x-axis pointed forward, y-axis pointed to the left and z-axis pointed towards the top of the sensor. The external connector is located in the negative x direction. The Sensor Coordinate Frame is marked in the diagram below with X_S, Y_S, Z_S.

The Lidar Coordinate Frame follows the right-hand rule convention and is defined at the intersection of the lidar axis of rotation and the lidar optical midplane (a plane parallel to Sensor Coordinate Frame XY plane and coincident with the 0 deg elevation beam angle of the lidar). The Lidar Coordinate Frame axes are arranged with the x-axis pointed at encoder angle 0, the y-axis pointed to the right and the z-axis pointed towards the top of the sensor. The external connector is located in the positive x direction. The Lidar Coordinate Frame is marked in the diagram below with X_L, Y_L, Z_L.



NOTE: The Lidar Coordinate Frame's positive x-axis (0 encoder value) is opposite the Sensor Coordinate Frame's positive x-axis to center lidar data about the Sensor Coordinate Frame's positive x-axis. A single measurement frame starts at the Lidar Coordinate Frame's 0 degree position and ends at the 360 degree position. This is convenient when viewing a "range image" of the Ouster Sensor measurements, allowing the "range image" to be centered in the Sensor Coordinate Frame's positive x-axis, which is generally forward facing in most robotic systems.

NOTE: The Ouster Sensor scans in the clockwise direction when viewed from the top, which is a negative rotational velocity about the z-axis. Thus, as encoder ticks increases from 0 to 90111, the actual angle about the z-axis in the Lidar Coordinate Frame will decrease.

4.2 Lidar Intrinsic Beam Angles

The intrinsic beam angles for each beam may be queried with a TCP command (see OS-1 Software User Guide) and provide an azimuth and elevation adjustment to the each beam. The azimuth adjustment is referenced off of the current encoder angle and the elevation adjustment is referenced from the XY plane in the Sensor and lidar Coordinate Frames.

4.3 Lidar Range Data To XYZ Lidar Coordinate Frame

The origin and axes of the lidar Coordinate Frame are defined by the position of the lidar lens aperture stop in the sensor and the 0º position of the rotary encoder, which is aligned with the sensor connector and the negative X axis of the Sensor Coordinate Frame.

For many applications, it is sufficient to calculate the XYZ point cloud in the lidar Coordinate Frame using a combination of the intrinsic beam angles and the encoder reading. The intrinsic azimuth and elevation beam angles may be queried over TCP as two vectors each 64 elements long.

Lidar data may be transformed into 3D cartesian x, y, z coordinates in the lidar coordinate frame. Given:

- **encoder_count** of the azimuth block
- **range** from the data block of the *i*-th channel
- **beam_altitude_angles** and
- **beam_azimuth_angles** from **get_beam_intrinsics** in the TCP interface described in Section 3.3

the corresponding 3D point can be computed using:

$$
\begin{aligned}
r &= \texttt{range}\ \text{mm} \\
\theta &= 2\pi \left(\frac{\texttt{encoder\_count}}{90112} + \frac{\texttt{beam\_azimuth\_angles[i]}}{360} \right) \\
\phi &= 2\pi \frac{\texttt{beam\_altitude\_angles[i]}}{360} \\
x &= r \cos(\theta) \cos(\phi) \\
y &= -r \sin(\theta) \cos(\phi) \\
z &= r \sin(\phi)
\end{aligned}
$$

4.4 Lidar Range Data To Sensor XYZ Coordinate Frame

For applications that require calibration against a precision mount or use the IMU data in combination with the lidar data, the xyz points should be adjusted to the Sensor Coordinate Frame. This requires a z translation and a rotation of the x,y,z points about the z axis. The z translation is the height of the lidar aperture stop above the sensor origin, which is 36.180 mm, and the data must be rotated 180° around the z axis. This information can be queried over TCP in the form of an intrinsic transformation matrix:

M_lidar_to_sensor = [[X, X, X, X], [X, X, X, X], [X, X, X, X], [0, 0, 0, 1]

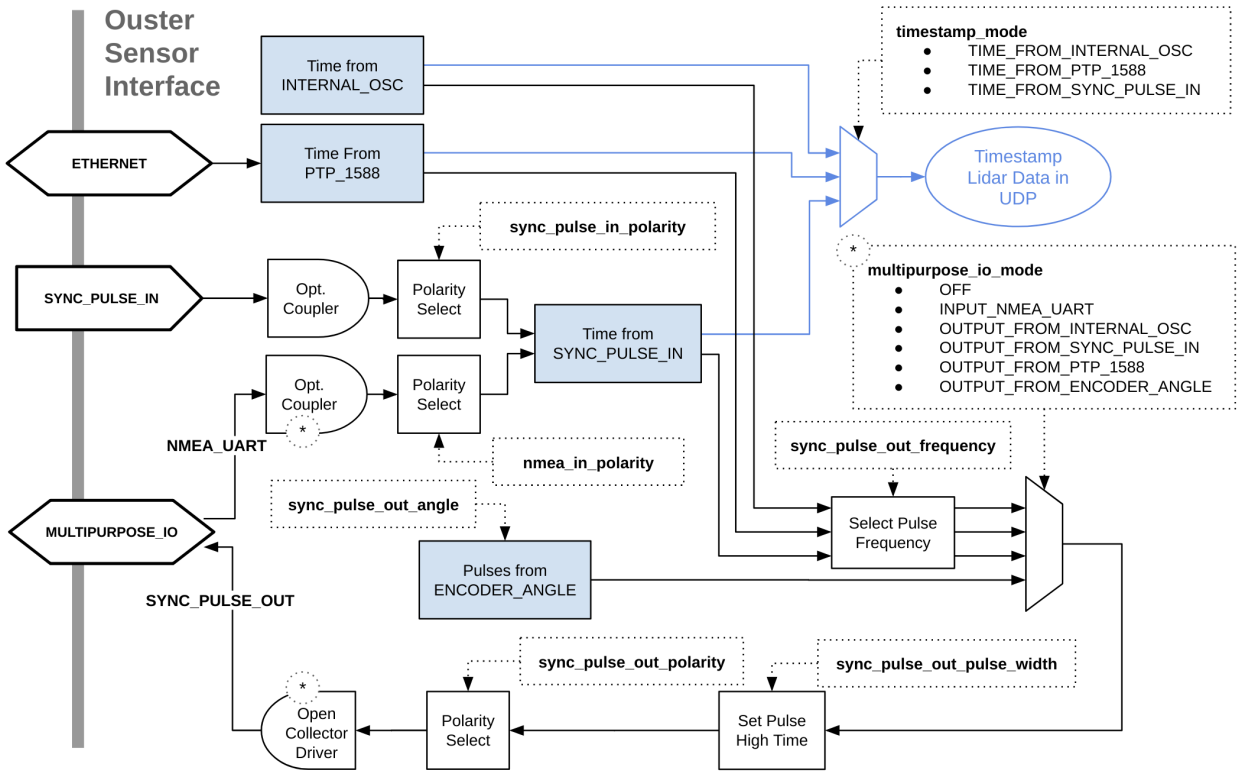
4.5 IMU Data To Sensor XYZ Coordinate Frame

The IMU is slightly offset in the Sensor Coordinate Frame for practical reasons. The IMU origin in the Sensor Coordinate Frame can be queried over TCP in the form of an intrinsic transformation matrix:

M_imu_to_sensor = [[X, X, X, X], [X, X, X, X], [X, X, X, X], [0, 0, 0, 1]

5 Time Synchronization

5.1 Timing Overview Diagram



5.2 Sensor Time Source

- All LIDAR and IMU data are timestamped to a common timer with 10 nanosecond precision.
- The common timer can be programmed to run off one of three clock sources:
  - An internal clock derived from a high accuracy, low drift oscillator
  - An opto-isolated digital input from the external connector for timing off an external hardware trigger such as a GPS. The polarity of this input signal is programmable. For instance, both a GPS PPS pulse and a 30 Hz frame sync from an industrial camera can supply a timing signal to the OS-1.
  - Using the IEEE 1588 Precision Time Protocol. PTP provides the convenience of configuring timing over a network that supports IEEE 1588 with no additional hardware signals.

Setting Ouster Sensor Time Source

The source for measurement timestamps can be configured using the `set_timestamp_mode` TCP command (see Section 3.3). The available modes are described below:

Command	Response
TIME_FROM_INTERNAL_OSC	Use the internal clock. Measurements are time stamped with ns since power-on. Free running counter based on the OS-1's internal oscillator. Counts seconds and nanoseconds since OS-1 turn on, reported at ns resolution (both a second and nanosecond register in every UDP packet), but min increment is on the order of 10 ns. Accuracy is +/- 90ppm.
TIME_FROM_SYNC_PULSE_IN	A free running counter synced to the SYNC_PULSE_IN input counts seconds (# of pulses) and nanoseconds since OS-1 turn on. If `multipurpose_io_mode` is set to `INPUT_NMEA_UART` then the seconds register jumps to time extracted from a NMEA $GPRMC message read on the `multipurpose_io` port. Reported at ns resolution (both a second and nanosecond register in every UDP packet), but min increment is on the order of 10 ns. Accuracy is +/- 1 µs from a perfect SYNC_PULSE_IN source.
TIME_FROM_PTP_1588	Synchronize with an external PTP master. A monotonically increasing counter that will begin counting seconds and nanoseconds since startup. As soon as a 1588 sync event happens, the time will be updated to seconds and nanoseconds since 1970. The counter must always count forward in time. If another 1588 sync event happens the counter will either jump forward to match the new time, or slow itself down. It is reported at ns resolution (there is both a second and nanosecond register in every UDP packet), but the minimum increment varies. Accuracy is +/- <50 us from the 1588 master.

Configuring the sensor to time off of an external hardware trigger requires sending a series of TCP commands. To set the sensor into external hardware clock source the user must send the following TCP commands:

- set_timestamp_mode `TIME_FROM_SYNC_PULSE_IN`
- reinitialize
- [set the polarity of the external trigger] - not yet implemented, to be added in firmware update
- [set the frequency of the external trigger] - not yet implemented, to be added in firmware update
- [set timebase source to either an external SPI NEMA GPS message or to the seconds since the first hardware trigger] - Available on sensors shipping September 2018

If configured to an external UART NEMA message, the following additional commands must be sent:

- [set the polarity of the UART data] - Available on sensors shipping September 2018
- [set the frequency of the UART data] - Available on sensors shipping September 2018

If configured to count seconds from the first hardware trigger, this counter may be reset to any arbitrary integer value of seconds with the following commands

- [command] [seconds value] - not yet implemented, to be added in firmware update

5.3 External Trigger Clock Source

Additionally, the OS-1 can be configured to output a SYNC_PULSE_OUT signal from a variety of sources. See example commands in Section 3.3. Pulses will always be evenly spaced.

This can be enabled through the `multipurpose_io_mode` configuration parameter.

Command	Response
OFF	Do not output a SYNC_PULSE_OUT signal.
INPUT_FROM_NMEA_UART	Reconifures the MULTIPURPOSE_IO port as an input. See Section 5.2 for more information.
OUTPUT_FROM_INTERNAL_OSC	Output a SYNC_PULSE_OUT signal synchronized with the internal clock.
OUTPUT_FROM_SYNC_PULSE_IN	Output a SYNC_PULSE_OUT signal synchronized with a SYNC_PULSE_IN provided to the unit.
OUTPUT_FROM_PTP_1588	Output a SYNC_PULSE_OUT signal synchronized with an external PTP IEEE 1588 master.
OUTPUT_FROM_ENCODER_ANGLE	Output a SYNC_PULSE_OUT signal with a user defined rate in an integer number of degrees.

When the sensor's `multipurpose_io_mode` is set to `OUTPUT_FROM_INTERNAL_OSC`, then `OUTPUT_FROM_SYNC_PULSE_IN` or `OUTPUT_FROM_PTP_1588`, then `sync_pulse_out_frequency` (Hz) parameter can be used to define the output rate. It defaults to 1 Hz. It should be greater than 0 Hz and maximum sync_pulse_out_frequency is limited by the criterion below.

When the sensor is set to `OUTPUT_FROM_ENCODER_ANGLE`, then the `sync_pulse_out_angle` (deg) parameter can be used to define the output pulse rate. This allows the user to output a SYNC_PULSE_OUT signal when the encoder passes a specified angle, or multiple of the angle, indexed from 0 crossing, in degrees. It should be an integer between 0 and 360 degrees, inclusive. However, the minimum `sync_pulse_out_angle` is also limited by the criterion below.

In all modes, the output pulse width is defined by `sync_pulse_out_pulse_width` (ms).

NOTE: If `sync_pulse_out_pulse_width` x `sync_pulse_out_frequency` is close to 1 second, the output pulses will not function (will not return to 0). For example, at 10 Hz rotation and a 10ms pulse width, the limitation on the number of pulses per rotation is 9.

EXAMPLE COMMANDS: Here are example commands and their effect on output pulse when LIDAR_MODE is 1024x10, and assuming sync_pulse_out_pulse_width is 10ms.

Command	Response
set_config_param multipurpose_io_mode OUTPUT_FROM_SYNC_PULSE_IN set_config_param sync_pulse_out_pulse_width 10 set_config_param sync_pulse_out_frequency 1 reinitialize	The output pulse frequency is 1Hz. Each pulse is 10ms wide. sync_pulse_out_pulse_width and sync_pulse_out_frequency commands are optional because they just re-command the default values
set_config_param multipurpose_io_mode OUTPUT_FROM_SYNC_PULSE_IN set_config_param sync_pulse_out_frequency 50 reinitialize	The output pulse frequency is 50 Hz. Each pulse is 10ms wide.
set_config_param multipurpose_io_mode OUTPUT_FROM_ENCODER_ANGLE set_config_param sync_pulse_out_angle 360 reinitialize	The output pulse frequency is 10Hz, since the sensor is in 10 Hz mode (10 rotations per second) and the angle is set to 360 degrees, a full rotation. Each pulse is 10ms wide.
set_config_param multipurpose_io_mode OUTPUT_FROM_ENCODER_ANGLE set_config_param sync_pulse_out_angle 45 reinitialize	The output pulse frequency is 80Hz, since the sensor is in 10 Hz mode (10 rotations per second) and the angle is set to 45 degrees. Each full rotation will have 8 pulses. Each pulse is 10ms wide.

5.4 NMEA Message Format

The Ouster Sensor expects a standard NMEA $GPRMC UART message. Data (called a sentence) is a simple ASCII string starting with a '$' character and ending with a return character. Fields of the sentence are separated with a ',' character, and the last field (a checksum) is separated by a '*' character.

The max character length of a standard message is 80 characters; however, the Ouster sensor can support non-standard messages up to 85 characters (see Example 2 below).

The Ouster Sensor will deliver time in the UDP packet by calculating seconds since 00:00:00 Thursday, 1 January 1970. `nmea_leap_seconds` by default is 0, meaning this calculation will not take into account any leap seconds. If `nmea_leap_seconds` is 0 then the reported time is Unix Epoch time. As of February, 2019 Coordinated Universal Time (UTC) lags behind International Atomic Time (TAI) by an offset of 37 seconds (10 seconds from the initial UTC offset when UTC was introduced in 1972 + 27 leap seconds announced in the intervening years). Therefore, setting `nmea_leap_seconds` to 37 in February of 2019 would make the timestamps match the TAI standard.

`nmea_in_polarity` by default is ACTIVE_HIGH. This means that a UART start bit would occur directly after a falling edge. If using RS-232, the UART signal may be inverted (where a start bit occurs directly after a rising edge). In this case, `nmea_in_polarity` should be set to ACTIVE_LOW.

Example 1 Message:

```
$GPRMC,123519,A,4807.038,N,01131.000,E,022.4,084.4,230394,003.1,W*6A
```

Field	Description
$GPRMC	Recommended Minimum sentence C
123519	Fix taken at 12:35:19 UTC
A	Status A=active or V=Void
4807.038	Latitude 48 deg 07.038’
N	Latitude cardinal reference
01131.000	Longitude 11 deg 31.000’
E	Longitude cardinal reference
022.4	Speed over the ground in knots
084.4	Track angle in degrees True
230394	Date - 23rd of March 1994
003.1	Magnetic Variation
W	Magnetic cardinal reference
A	[Optional] A=autonomous, D=differential, E=Estimated, N=not valid, S=Simulator
*6A	The checksum data, always begins with *

Example 2 Message:

```
$GPRMC,042901.00,A,3745.871698,N,12224.825960,W,0.874,327.72,130219,13.39,E,A,
V*60
```

Field	Description
$GPRMC	Recommended Minimum sentence C
042901.00	Fix taken at 4:29:01 UTC
A	Status A=active or V=Void
3745.871698	Latitude 37 deg 45.871698’
N	Latitude cardinal reference
12224.825960	Longitude 12 deg 24.825960’
W	Longitude cardinal reference
0.874	Speed over the ground in knots
327.72	Track angle in degrees True
130219	Date - 13th of February 2019
13.39	Magnetic Variation
E	Magnetic cardinal reference
A	[Optional] A=autonomous, D=differential, E=Estimated, N=not valid, S=Simulator
*60	The checksum data, always begins with *

6 Updating Firmware

Sensor firmware can be updated with an Ouster-provided firmware file from www.ouster.io/downloads (or directly from the deployment engineering team) by accessing the sensor over http - e.g. http://os1-991900123456.local/ and uploading the file as prompted.

Always check your firmware version before attempting an update. Only update to a equal or higher version number. Do not `roll back` firmware to lower numbered versions without having been instructed to do so by Ouster deployment engineering.

7 Troubleshooting

Starting from FW v1.11, the sensor HTTP server page http://os1-991900123456.local/ has `Home`, `Diagnostics`, `Documentation` and `Reset Configuration` buttons:

- `Home`: Current page that lists some basic sensor information, and allows sensor firmware upgrade.
- `Diagnostics`: Diagnostic information and system journal that can be downloaded and included when contacting Ouster for service.
- `Documentation`: Sensor User Guide
- `Reset Configuration`: Sensor factory configuration that can be reset to if desired. This will erase any custom configuration that you set on the sensor previously.

Most problems we get contacted about are associated with the sensor not properly being assigned an IP address by a network switch or DHCP server on a client computer. Check your networking settings, the steps in Section 3, and that all wires are firmly connected if you suspect this problem.

NOTE: If the sensor is not connected to Gigabit ethernet, it will stop sending data and will output an error code if the cabling is wired incorrectly and fails to achieve a 1000Mb/s + full duplex link.

To check for hardware errors, use the `get_sensor_info` command as described above.

If the watchdog is triggered (various temperatures limits exceeded, uplink/downlink status), an error code (up to 8) will be appended to the end of TCP command get_sensor_info. The sensor has an 8 deep buffer that will record the first 8 errors detected by the sensor with the code itself, timestamp, and an info field (temperature that caused it to trip for temp failures, true/false for uplink/downlink).

Example showing forced temp sensor failures being sampled at 1 Hz (Three fails at 1533579080, Three at 1533579801, and the last two at 153379082 time):

- {“prod_pn”: “840-101396-03”, “prod_sn”: “991900123456”, “base_pn”: “000-101323-02”, “base_sn”: “101823000127”, “image_rev”: “ousteros-image-prod-aries-v1.5.2-20180720031809”, “build_rev”: “v1.5.2-71-g43c87c6”, “proto_rev”: “v1.1.1”, “build_date”: “2018-08-04T23:43:55Z”, “status”:
- “ERROR”, “errors”: [{“error_code”: “BASE_A_OVERTEMP”, “error_timestamp”: “1533579080”, “error_info”: “30.000000”}, {“error_code”: “BASE_B_OVERTEMP”, “error_timestamp”: “1533579080”, “error_info”: “29.801411”}, {“error_code”: “STATOR_OVERTEMP”, “error_timestamp”: “1533579080”, “error_info”: “30.000000”}, {“error_code”: “BASE_A_OVERTEMP”, “error_timestamp”: “1533579081”, “error_info”: “30.000000”}, {“error_code”: “BASE_B_OVERTEMP”, “error_timestamp”: “1533579081”, “error_info”: “29.975849”}, {“error_code”: “STATOR_OVERTEMP”, “error_timestamp”: “1533579081”, “error_info”: “30.000000”}, {“error_code”: “BASE_A_OVERTEMP”, “error_timestamp”: “1533579082”, “error_info”: “30.000000”}, {“error_code”: “BASE_B_OVERTEMP”, “error_timestamp”: “1533579082”, “error_info”: “29.997059”}]}

8 HTTP API Reference

HTTP API developer reference guide. This documents the interface for HTTP API and is accessible via `/api/v1` on the sensor hosted HTTP server.

API Resources

- *system/firmware*
- *system/network*
- *system/time*

8.1 system/firmware

GET system/firmware

```
GET /api/v1/system/network HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
Host: 192.0.2.123
content-type: application/json; charset=UTF-8

{
  "fw": "ousteros-image-prod-aries-v1.11.0"
}
```

Response JSON Object

- **fw** (*string*) – Running firmware image name and version.

Status Codes

- 200 OK – No error

8.2 system/network

GET system/network

Get the system network configuration.

```
GET /api/v1/system/network HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
content-type: application/json; charset=UTF-8

{
   "carrier": true,
   "duplex": "full",
   "ethaddr": "bc:0f:a7:00:01:2c",
   "hostname": "os1-991900123456",
```

(continues on next page)

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```
    "ipv4": {
        "addr": "192.0.2.123/24",
        "link_local": "169.254.245.183/16",
        "override": null
    },
    "ipv6": {
        "link_local": "fe80::be0f:a7ff:fe00:12c/64"
    },
    "speed": 1000
}
```

Response JSON Object

- **carrier** (*boolean*) – State of Ethernet link, `true` when physical layer is connected.
- **duplex** (*string*) – Duplex mode of Ethernet link, `half` or `full`.
- **ethaddr** (*string*) – Ethernet hardware (MAC) address.
- **hostname** (*string*) – Hostname of the sensor, also used when requesting *DHCP* lease.
- **ipv4** (*object*) – See *ipv4 object*
- **ipv6.link_local** (*string*) – Link-local IPv6 address.
- **speed** (*integer*) – Ethernet physical layer speed in Mbps, should be 1000 Mbps.

Status Codes

- 200 OK – No error

GET system/network/ipv4

Get the IPv4 network configuration.

```
GET /api/v1/system/network/ipv4 HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
content-type: application/json; charset=UTF-8

{
  "addr": "192.0.2.123/23",
  "link_local": "169.254.245.183/16",
  "override": null
}
```

Response JSON Object

- **addr** (*string*) – Current global or private IPv4 address.
- **link_local** (*string*) – Link-local IPv4 address.
- **override** (*string*) – Static IP override value, this should match `addr`. This value will be `null` when unset and operating in *DHCP* mode.

Status Codes

- 200 OK – No error

GET system/network/ipv4/override
Get the current IPv4 static IP address override.

```
GET /api/v1/system/network/ipv4/override HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
content-type: application/json; charset=UTF-8

null
```

Response JSON Object

- **string** – Static IP override value, this should match `addr`. This value will be `null` when unset and operating in *DHCP* mode.

Status Codes

- 200 OK – No error

PUT system/network/ipv4/override
Override the default dynamic behavior and set a static IP address.

Note: The sensor will reset the network configuration after a short sub second delay (to allow for the HTTP response to be sent). After this delay the sensor will only be reachable on the newly set IPv4 address.

The sensor needs to be reachable either by dynamic *DHCP* configuration or by an existing static IP override from the host reconfiguring the sensor.

Warning: If an unreachable network address is set, the sensor will become unreachable.

Static IP override should only be used in special use cases. The dynamic *DHCP* configuration is recommended where possible.

```
PUT /api/v1/system/network/ipv4/override HTTP/1.1
Content-Type: application/json
Host: 192.0.2.123

"192.0.2.100/24"
```

Request JSON Object

- **string** – Static IP override value with subnet mask

Response JSON Object

- **string** – Static IP override value that system will set after a short delay.

Status Codes

- 200 OK – No error

DELETE system/network/ipv4/override
Delete the static IP override value and return to dynamic configuration.

Note: The sensor will reset the network configuration after a short sub second delay (to allow for the HTTP response to be sent). After this delay the sensor will only be reachable on the newly set IPv4 address.

The sensor may be unreachable for several seconds while a *DHCP* lease is obtained from a network *DHCP* server.

```
DELETE /api/v1/system/network/ipv4/override HTTP/1.1
Host: 192.0.2.123
```

Status Codes

- 204 No Content – No error, no content

8.3 system/time

GET system/time

Get the system time configuration for all timing components of the sensor.

```
GET /api/v1/system/time HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
content-type: application/json; charset=UTF-8

{
  "ptp": {
    "current_data_set": {
      "mean_path_delay": 37950,
      "offset_from_master": -211488,
      "steps_removed": 1
    },
    "parent_data_set": {
      "gm_clock_accuracy": 33,
      "gm_clock_class": 6,
      "gm_offset_scaled_log_variance": 20061,
      "grandmaster_identity": "001747.fffe.700038",
      "grandmaster_priority1": 128,
      "grandmaster_priority2": 128,
      "observed_parent_clock_phase_change_rate": 2147483647,
      "observed_parent_offset_scaled_log_variance": 65535,
      "parent_port_identity": "001747.fffe.700038-1",
      "parent_stats": 0
    },
    "port_data_set": {
      "announce_receipt_timeout": 3,
      "delay_mechanism": 1,
      "log_announce_interval": 1,
      "log_min_delay_req_interval": 0,
      "log_min_pdelay_req_interval": 0,
      "log_sync_interval": 0,
      "peer_mean_path_delay": 0,
      "port_identity": "bc0fa7.fffe.00012c-1",
      "port_state": "SLAVE",
      "version_number": 2
```

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```
    },
    "time_properties_data_set": {
      "current_utc_offset": 37,
      "current_utc_offset_valid": 1,
      "frequency_traceable": 1,
      "leap59": 0,
      "leap61": 0,
      "ptp_timescale": 1,
      "time_source": 32,
      "time_traceable": 1
    },
    "time_status_np": {
      "cumulative_scaled_rate_offset": 0,
      "gm_identity": "001747.fffe.700038",
      "gm_present": true,
      "gm_time_base_indicator": 0,
      "ingress_time": 1552413985821448000,
      "last_gm_phase_change": "0x0000'0000000000000000.0000",
      "master_offset": -211488,
      "scaled_last_gm_phase_change": 0
    }
  },
  "sensor": {
    "nmea": {
      "baud_rate": "BAUD_9600",
      "diagnostics": {
        "decoding": {
          "date_decoded_count": 0,
          "last_read_message": "",
          "not_valid_count": 0,
          "utc_decoded_count": 0
        },
        "io_checks": {
          "bit_count": 1,
          "bit_count_unfilterd": 0,
          "char_count": 0,
          "start_char_count": 0
        }
      },
      "ignore_valid_char": 0,
      "leap_seconds": 0,
      "locked": 0,
      "polarity": "ACTIVE_HIGH"
    },
    "sync_pulse_in": {
      "diagnostics": {
        "count": 1,
        "count_unfiltered": 0,
        "last_period_nsec": 0
      },
      "locked": 0,
      "polarity": "ACTIVE_HIGH"
    },
    "sync_pulse_out": {
      "angle_deg": 360,
      "frequency_hz": 1,
      "mode": "OFF",
```


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```
      "polarity": "ACTIVE_HIGH",
      "pulse_width_ms": 10
    },
    "timestamp": {
      "mode": "TIME_FROM_INTERNAL_OSC",
      "time": 57178.44114677,
      "time_options": {
        "internal_osc": 57178,
        "ptp_1588": 1552413986,
        "sync_pulse_in": 1
      }
    }
  },
  "system": {
    "monotonic": 57191.819600378,
    "realtime": 1552413949.3948405,
    "tracking": {
      "frequency": -7.036,
      "last_offset": 5.942e-06,
      "leap_status": "normal",
      "ref_time_utc": 1552413947.8259742,
      "reference_id": 70747000,
      "remote_host": "ptp",
      "residual_frequency": 0.006,
      "rms_offset": 5.358e-06,
      "root_delay": 1e-09,
      "root_dispersion": 0.000129677,
      "skew": 1.144,
      "stratum": 1,
      "system_time_offset": -2.291e-06,
      "update_interval": 2
    }
  }
}
```


Response JSON Object

- **string** – See sub objects for details.

Status Codes

- 200 OK – No error

GET system/time/system

Get the operating system time status. These values relate to the operating system clocks, and not clocks related to hardware timestamp data from the lidar sensor.

```
GET /api/v1/system/time/system HTTP/1.1
Host: 192.0.2.123
```


```
HTTP/1.1 200 OK
content-type: application/json; charset=UTF-8

{
  "monotonic": 345083.599570944,
  "realtime": 1551814510.730453,
```


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```
  "tracking": {
    "frequency": -6.185,
    "last_offset": -3.315e-06,
    "leap_status": "normal",
    "ref_time_utc": 1551814508.1982567,
    "reference_id": 70747000,
    "remote_host": "ptp",
    "residual_frequency": -0.019,
    "rms_offset": 4.133e-06,
    "root_delay": 1e-09,
    "root_dispersion": 0.000128737,
    "skew": 1.14,
    "stratum": 1,
    "system_time_offset": 4.976e-06,
    "update_interval": 2
  }
}
```


Response JSON Object

- **monotonic** (*float*) – Monotonic time of operating system. This timestamp never counts backwards and is the time since boot in seconds.
- **realtime** (*float*) – Time in seconds since the Unix epoch, should match wall time if synchronized with external time source.
- **tracking** (*object*) – Operating system time synchronization tracking status. See chronyc tracking documentation for more information.

Status Codes

- 200 OK – No error

System `tracking` fields of interest:

rms_offset Long-term average of the offset value.

system_time_offset Time delta (in seconds) between estimate of the operating system time and the current true time.

last_offset Estimated local offset on the last clock update.

ref_time_utc UTC Time at which the last measurement from the reference source was processed.

remote_host This is either `ptp` if the system is synchronizing to a *PTP* time source or the address of a remote NTP server the system has selected if the sensor is connected to the Internet.

GET system/time/ptp

Get the status of the *PTP* time synchronization daemon.

Note: See the IEEE 1588-2008 standard for more details on the standard management messages.

```
GET /api/v1/system/time/ptp HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
content-type: application/json; charset=UTF-8

{
  "current_data_set": {
    "mean_path_delay": 30110,
    "offset_from_master": 224159,
    "steps_removed": 1
  },
  "parent_data_set": {
    "gm_clock_accuracy": 33,
    "gm_clock_class": 6,
    "gm_offset_scaled_log_variance": 20061,
    "grandmaster_identity": "001747.fffe.700038",
    "grandmaster_priority1": 128,
    "grandmaster_priority2": 128,
    "observed_parent_clock_phase_change_rate": 2147483647,
    "observed_parent_offset_scaled_log_variance": 65535,
    "parent_port_identity": "001747.fffe.700038-1",
    "parent_stats": 0
  },
  "port_data_set": {
    "announce_receipt_timeout": 3,
    "delay_mechanism": 1,
    "log_announce_interval": 1,
    "log_min_delay_req_interval": 0,
    "log_min_pdelay_req_interval": 0,
    "log_sync_interval": 0,
    "peer_mean_path_delay": 0,
    "port_identity": "bc0fa7.fffe.00012c-1",
    "port_state": "SLAVE",
    "version_number": 2
  },
  "time_properties_data_set": {
    "current_utc_offset": 37,
    "current_utc_offset_valid": 1,
    "frequency_traceable": 1,
    "leap59": 0,
    "leap61": 0,
    "ptp_timescale": 1,
    "time_source": 32,
    "time_traceable": 1
  },
  "time_status_np": {
    "cumulative_scaled_rate_offset": 0,
    "gm_identity": "001747.fffe.700038",
    "gm_present": true,
    "gm_time_base_indicator": 0,
    "ingress_time": 1551814546772493800,
    "last_gm_phase_change": "0x0000'0000000000000000.0000",
    "master_offset": 224159,
    "scaled_last_gm_phase_change": 0
  }
}
```

Response JSON Object

- **current_data_set** (*object*) – Result of the PMC `GET CURRENT_DATA_SET`

command.

- **parent_data_set** (*object*) – Result of the PMC `GET PARENT_DATA_SET` command.
- **port_data_set** (*object*) – Result of the PMC `GET PORT_DATA_SET` command.
- **time_properties_data_set** (*object*) – Result of the PMC `GET TIME_PROPERTIES_DATA_SET` command.
- **time_status_np** (*object*) – Result of the PMC `GET TIME_STATUS_NP` command. This is a linuxptp non-portable command.

Status Codes

- 200 OK – No error

Fields of interest:

current_data_set.offset_from_master Offset from master time source in nanoseconds as calculated during the last update from master.

parent_data_set.grandmaster_identity This should match the local grandmaster clock. If this displays the sensor's clock identity (derived from Ethernet hardware address) then this indicates the sensor is not properly synchronized to a grandmaster.

parent_data_set Various information about the selected master clock.

port_data_set.port_state This value will be `SLAVE` when a remote master clock is selected. See `parent_data_set` for selected master clock.

port_data_set Local sensor *PTP* configuration values. Grandmaster clock needs to match these for proper time synchronization.

time_properties_data_set *PTP* properties as given by master clock.

time_status_np.gm_identity Selected grandmaster clock identity.

time_status_np.gm_present True when grandmaster has been detected. This may stay true even if grandmaster goes off-line. Use `port_data_set.port_state` to determine up-to-date synchronization status. When this is false then the local clock is selected.

time_status_np.ingress_time Indicates when last *PTP* message was received. Units are in nanoseconds.

time_status_np Linux *PTP* specific diagnostic values. The Red Hat manual provides some more information on these fields

GET system/time/sensor

Get the lidar sensor time status. These values relate to the hardware timestamping mechanism of the sensor.

```
GET /api/v1/system/time/sensor HTTP/1.1
Host: 192.0.2.123
```

```
HTTP/1.1 200 OK
content-type: application/json; charset=UTF-8

{
  "nmea": {
    "baud_rate": "BAUD_9600",
    "diagnostics": {
```

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```
      "decoding": {
        "date_decoded_count": 0,
        "last_read_message": "",
        "not_valid_count": 0,
        "utc_decoded_count": 0
      },
      "io_checks": {
        "bit_count": 1,
        "bit_count_unfilterd": 0,
        "char_count": 0,
        "start_char_count": 0
      }
    },
    "ignore_valid_char": 0,
    "leap_seconds": 0,
    "locked": 0,
    "polarity": "ACTIVE_HIGH"
  },
  "sync_pulse_in": {
    "diagnostics": {
      "count": 1,
      "count_unfiltered": 0,
      "last_period_nsec": 0
    },
    "locked": 0,
    "polarity": "ACTIVE_HIGH"
  },
  "sync_pulse_out": {
    "angle_deg": 360,
    "frequency_hz": 1,
    "mode": "OFF",
    "polarity": "ACTIVE_HIGH",
    "pulse_width_ms": 10
  },
  "timestamp": {
    "mode": "TIME_FROM_INTERNAL_OSC",
    "time": 57178.44114677,
    "time_options": {
      "internal_osc": 57178,
      "ptp_1588": 1552413986,
      "sync_pulse_in": 1
    }
  }
}
```


For more information on these parameters refer to Section 3.3 for the `get_time_info` TCP command.

9 PTP Quickstart Guide

There are many configurations for a PTP network, this quick start guide aims to cover the basics by using Ubuntu 18.04 as an example. It provides configuration settings for a commercial PTP grandmaster clock and also provides directions on setting up a Linux computer (Ubuntu 18.04) to function as a PTP grandmaster.

The linuxptp project provides a suite of PTP tools that can be used to serve as a PTP master clock for a local network of sensors.

Table of Contents

9.1 Assumptions

- Command line Linux knowledge (e.g. package management, command line familiarity, etc.).
- Ethernet interfaces that support hardware timestamping.
- Ubuntu 18.04 is assumed for this tutorial, but any modern distribution should suffice.
- Knowledge of systemd service configuration and management.
- Familiarity with Linux permissions.

9.2 Physical Network Setup

Ensure the Ouster sensor is connected to the PTP master clock with at most one network switch. Ideally the sensor should be connected directly to the PTP grandmaster. Alternatively, a simple layer-2 gigabit Ethernet switch will suffice. Multiple switches are not recommended and will add unnecessary jitter.

9.3 Third Party Grandmaster Clock

A dedicated grandmaster clock should be used for the highest absolute accuracy often with a GPS receiver.

It must be configured with the following parameters which match the *linuxptp* client defaults:

- Transport: `UDP IPv4`
- Delay Mechanism: `E2E`
- Sync Mode: `Two-Step`
- Announce Interval: `1` - sent every 2 seconds
- Sync Interval: `0` - sent every 1 second
- Delay Request Interval: `0` - sent every 1 second

For more settings, review the `port_data_set` field returned from the sensor's *HTTP system/time/ptp* interface.

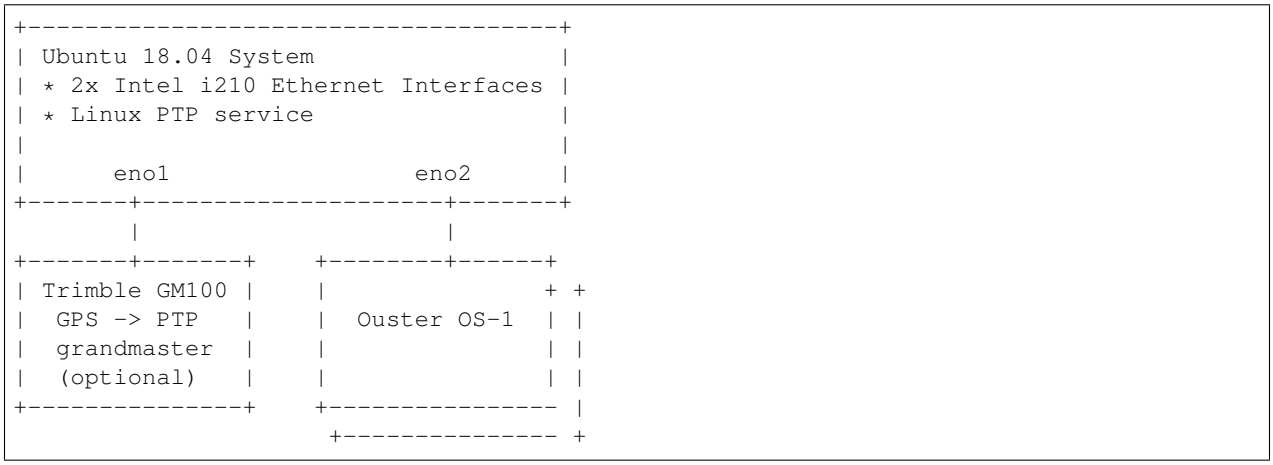
9.4 Linux PTP Grandmaster Clock

An alternative to an external grandmaster PTP clock is to run a local Linux PTP master clock if accuracy allows. This is often implemented on a vehicle computer that interfaces directly with the lidar sensors.

This section outlines how to configure a master clock.

Example Network Setup

This section assumes the following network setup as it has elements of a local master clock and the option for an upstream PTP time source.



The focus is on configuring the Linux PTP service to serve a common clock to all the downstream Ouster OS-1 sensors using the Linux system time from the Ubuntu host machine.

Optionally, a grandmaster clock can be added to discipline the system time of the Linux host.

Installing Necessary Packages

Several packages are needed for PTP functionality and verification:

- `linuxptp` - Linux PTP package with the following components:
  - `ptp4l` daemon to manage hardware and participate as a PTP node
  - `phc2sys` to synchronize the Ethernet controller's hardware clock to the Linux system clock or shared memory region
  - `pmc` to query the PTP nodes on the network.
- `chrony` - A NTP and PTP time synchronization daemon. It can be configured to listen to both NTP time sources via the Internet and a PTP master clock such as one provided a GPS with PTP support. This will validate the time configuration makes sense given multiple time sources.
- `ethtool` - A tool to query the hardware and driver capabilities of a given Ethernet interface.

```
$ sudo apt update
...
Reading package lists... Done
Building dependency tree
Reading state information... Done

$ sudo apt install linuxptp chrony ethtool
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following NEW packages will be installed:
  chrony ethtool linuxptp
0 upgraded, 3 newly installed, 0 to remove and 29 not upgraded.
Need to get 430 kB of archives.
```

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```
After this operation, 1,319 kB of additional disk space will be used.
Get:1 http://us.archive.ubuntu.com/ubuntu bionic/main amd64 ethtool amd64 1:4.15-
↪0ubuntu1 [114 kB]
Get:2 http://us.archive.ubuntu.com/ubuntu bionic/universe amd64 linuxptp amd64 1.8-1␣
↪[112 kB]
Get:3 http://us.archive.ubuntu.com/ubuntu bionic-updates/main amd64 chrony amd64 3.2-
↪4ubuntu4.2 [203 kB]
Fetched 430 kB in 1s (495 kB/s)
Selecting previously unselected package ethtool.
(Reading database ... 117835 files and directories currently installed.)
Preparing to unpack .../ethtool_1%3a4.15-0ubuntu1_amd64.deb ...
Unpacking ethtool (1:4.15-0ubuntu1) ...
Selecting previously unselected package linuxptp.
Preparing to unpack .../linuxptp_1.8-1_amd64.deb ...
Unpacking linuxptp (1.8-1) ...
Selecting previously unselected package chrony.
Preparing to unpack .../chrony_3.2-4ubuntu4.2_amd64.deb ...
Unpacking chrony (3.2-4ubuntu4.2) ...
Setting up linuxptp (1.8-1) ...
Processing triggers for ureadahead (0.100.0-20) ...
ureadahead will be reprofiled on next reboot
Setting up chrony (3.2-4ubuntu4.2) ...
Processing triggers for systemd (237-3ubuntu10.13) ...
Processing triggers for man-db (2.8.3-2ubuntu0.1) ...
Setting up ethtool (1:4.15-0ubuntu1) ...
```

Ethernet Hardware Timestamp Verification

Identify the ethernet interface to be used on the client (Linux) machine, e.g. eno1. Run the ethtool utility and query this network interface for supported capabilities.

Output of `ethtool -T` for a functioning Intel i210 Ethernet interface:

```
$ sudo ethtool -T eno1
Time stamping parameters for eno1:
Capabilities:
        hardware-transmit     (SOF_TIMESTAMPING_TX_HARDWARE)
        software-transmit     (SOF_TIMESTAMPING_TX_SOFTWARE)
        hardware-receive      (SOF_TIMESTAMPING_RX_HARDWARE)
        software-receive      (SOF_TIMESTAMPING_RX_SOFTWARE)
        software-system-clock (SOF_TIMESTAMPING_SOFTWARE)
        hardware-raw-clock    (SOF_TIMESTAMPING_RAW_HARDWARE)
PTP Hardware Clock: 0
Hardware Transmit Timestamp Modes:
        off                   (HWTSTAMP_TX_OFF)
        on                    (HWTSTAMP_TX_ON)
Hardware Receive Filter Modes:
        none                  (HWTSTAMP_FILTER_NONE)
        all                   (HWTSTAMP_FILTER_ALL)
```

Configuring `ptp4l` for Multiple Ports

On a Linux system with multiple Ethernet ports (i.e. Intel i210) `ptp4l` needs to be configured to support all of them.

Modify `/etc/linuxptp/ptp4l.conf` and append the following, replacing `eno1` and `eno2` with the appropriate interface names:

```
boundary_clock_jbod 1
[eno1]
[eno2]
```

The default systemd service file for Ubuntu 18.04 attempts to use the eth0 address on the command line. Override systemd service file so that the configuration file is used instead of hard coded in the service file.

Create a systemd drop-in directory to override the system service file:

```
$ sudo mkdir -p /etc/systemd/system/ptp4l.service.d
```

Create a file at `/etc/systemd/system/ptp4l.service.d/override.conf` with the following contents:

```
[Service]
ExecStart=
ExecStart=/usr/sbin/ptp4l -f /etc/linuxptp/ptp4l.conf
```

Restart the `ptp4l` service so the change takes effect:

```
$ sudo systemctl daemon-reload
$ sudo systemctl restart ptp4l
$ sudo systemctl status ptp4l
* ptp4l.service - Precision Time Protocol (PTP) service
   Loaded: loaded (/lib/systemd/system/ptp4l.service; enabled; vendor preset: enabled)
  Drop-In: /etc/systemd/system/ptp4l.service.d
           └─override.conf
   Active: active (running) since Wed 2019-03-13 14:38:57 PDT; 3s ago
     Docs: man:ptp4l
 Main PID: 25783 (ptp4l)
    Tasks: 1 (limit: 4915)
   CGroup: /system.slice/ptp4l.service
           └─25783 /usr/sbin/ptp4l -f /etc/linuxptp/ptp4l.conf

Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.756] port 1: INITIALIZING to␣
↪LISTENING on INITIALIZE
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.756] driver changed our HWTSTAMP␣
↪options
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.756] tx_type   1 not 1
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.756] rx_filter 1 not 12
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.756] port 2: INITIALIZING to␣
↪LISTENING on INITIALIZE
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.757] port 0: INITIALIZING to␣
↪LISTENING on INITIALIZE
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.757] port 1: link up
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.757] port 2: link down
Mar 13 14:38:57 leadlizard ptp4l[25783]: [590188.757] port 2: LISTENING to FAULTY on␣
↪FAULT_DETECTED (FT_UNSPECIFIED)
Mar 13 14:38:58 leadlizard ptp4l[25783]: [590189.360] port 1: new foreign master␣
↪001747.fffe.700038-1
```

The above `systemctl status ptp4l` console output shows systemd correctly read the override file created earlier before starting several seconds after the restart command.

The log output shows that a grandmaster clock has been discovered on port 1 (`eno1`) and port 2 (`eno2`) is currently disconnected and in the faulty state as expected. In the test network a Trimble Thunderbolt PTP GM100 Grandmaster Clock is attached on `eno1`.

Logs can be monitored (i.e. followed) like so:

```
$ journalctl -f -u ptp4l
-- Logs begin at Fri 2018-11-30 06:40:50 PST. --
Mar 13 14:51:37 leadlizard ptp4l[25783]: [590948.224] master offset        -17 s2␣
↪freq  -25963 path delay     14183
Mar 13 14:51:38 leadlizard ptp4l[25783]: [590949.224] master offset        -13 s2␣
↪freq  -25964 path delay     14183
Mar 13 14:51:39 leadlizard ptp4l[25783]: [590950.225] master offset         35 s2␣
↪freq  -25920 path delay     14192
Mar 13 14:51:40 leadlizard ptp4l[25783]: [590951.225] master offset        -59 s2␣
↪freq  -26003 path delay     14201
Mar 13 14:51:41 leadlizard ptp4l[25783]: [590952.225] master offset        -24 s2␣
↪freq  -25986 path delay     14201
Mar 13 14:51:42 leadlizard ptp4l[25783]: [590953.225] master offset        -39 s2␣
↪freq  -26008 path delay     14201
Mar 13 14:51:43 leadlizard ptp4l[25783]: [590954.225] master offset         53 s2␣
↪freq  -25928 path delay     14201
Mar 13 14:51:44 leadlizard ptp4l[25783]: [590955.226] master offset        -85 s2␣
↪freq  -26050 path delay     14207
Mar 13 14:51:45 leadlizard ptp4l[25783]: [590956.226] master offset        127 s2␣
↪freq  -25863 path delay     14207
Mar 13 14:51:46 leadlizard ptp4l[25783]: [590957.226] master offset          9 s2␣
↪freq  -25943 path delay     14208
Mar 13 14:51:47 leadlizard ptp4l[25783]: [590958.226] master offset        -23 s2␣
↪freq  -25973 path delay     14208
Mar 13 14:51:48 leadlizard ptp4l[25783]: [590959.226] master offset        -61 s2␣
↪freq  -26018 path delay     14190
Mar 13 14:51:49 leadlizard ptp4l[25783]: [590960.226] master offset         69 s2␣
↪freq  -25906 path delay     14190
Mar 13 14:51:50 leadlizard ptp4l[25783]: [590961.226] master offset        -73 s2␣
↪freq  -26027 path delay     14202
Mar 13 14:51:51 leadlizard ptp4l[25783]: [590962.226] master offset         19 s2␣
↪freq  -25957 path delay     14202
Mar 13 14:51:52 leadlizard ptp4l[25783]: [590963.226] master offset        147 s2␣
↪freq  -25823 path delay     14202
...
```

Configuring `ptp4l` as a Local Master Clock

The IEEE-1588 Best Master Clock Algorithm (*BMCA*) will select a grandmaster clock based on a number of masters. In most networks there should be only a single master. In the example network the Ubuntu machine will be configured with a non-default *clockClass* so its operation qualifies it to win the BMCA.

Replace the default value with a lower clock class (higher priority) and restart linuxptp. Edit `/etc/linuxptp/ptp4l.conf` and comment out the default `clockClass` value and insert a line setting it 128.

```
#clockClass      248
clockClass       128
```

Restart ptp4l so the configuration change takes effect.

```
$ sudo systemctl restart ptp4l
```

This will configure `ptp4l` to advertise a master clock on eno2 as a clock that will win the BMCA for an Ouster OS-1 sensor.

However, the ptp4l service is only advertising the Ethernet controller's PTP hardware clock, not the Linux system time as is often expected.

Configuring phc2sys to Synchronize the System Time to the PTP Clock

To synchronize the Linux system time to the the PTP hardware clock the phc2sys utility needs to be run. The following configuration will tell phc2sys to take the Linux CLOCK_REALTIME and write that time to the PTP hardware clock in the Ethernet controller for eno2. These interfaces are then connected to PTP slaves such as Ouster OS-1 sensors.

Create a systemd drop-in directory to override the system service file:

```
$ sudo mkdir -p /etc/systemd/system/phc2sys.service.d
```

Create a file at /etc/systemd/system/phc2sys.service.d/override.conf with the following contents:

```
[Service]
ExecStart=
ExecStart=/usr/sbin/phc2sys -w -s CLOCK_REALTIME -c eno2
```

Note: If multiple interfaces need to be synchronized from CLOCK_REALTIME then multipe instances of the phc2sys service need to be run as it only accepts a single slave (i.e. -c) argument.

Restart the phc2sys service so the change takes effect:

```
$ sudo systemctl daemon-reload
$ sudo systemctl restart phc2sys
$ sudo systemctl status phc2sys
```

Configuring Chrony to Set System Clock Using PTP

An upstream PTP grandmaster clock (e.g. a GPS disciplined PTP clock) can be used to set the system time if precise absolute time is needed for sensor data. Chrony is a Linux time service that can read from NTP and PTP and set the Linux system time using the most accurate source available. With a proper functioning PTP grandmaster the PTP time source will be selected and the error from the public time servers can be reviewed.

The following phc2shm service will synchronize the time from eno1 (where the external grandmaster is attached) to the system clock.

Create a file named /etc/systemd/system/phc2shm.service with the following contents:

```
# /etc/systemd/system/phc2shm.service
[Unit]
Description=Synchronize PTP hardware clock (PHC) to NTP SHM
Documentation=man:phc2sys
After=ntpdate.service
Requires=ptp4l.service
After=ptp4l.service

[Service]
Type=simple
ExecStart=/usr/sbin/phc2sys -s eno1 -E ntpshm -w
```

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```
[Install]
WantedBy=multi-user.target
```

Then start the newly created service and check that it started.

```
$ sudo systemctl start phc2shm
$ sudo systemctl status phc2shm
```

Add the PTP time source to the chrony configuration which will read the shared memory region managed by the `phc2shm` service created above.

Append the following to the `/etc/chrony/chrony.conf` file:

```
refclock SHM 0 poll 1 refid ptp
```

Restart chrony so the updated configuration file takes effect:

```
$ sudo systemctl restart chrony
```

After waiting a minute for the clock to synchronize, review the chrony client timing accuracy:

```
$ chronyc tracking
Reference ID    : 70747000 (ptp)
Stratum         : 1
Ref time (UTC)  : Thu Mar 14 02:22:58 2019
System time     : 0.000000298 seconds slow of NTP time
Last offset     : -0.000000579 seconds
RMS offset      : 0.001319735 seconds
Frequency       : 0.502 ppm slow
Residual freq   : -0.028 ppm
Skew            : 0.577 ppm
Root delay      : 0.000000001 seconds
Root dispersion : 0.000003448 seconds
Update interval : 2.0 seconds
Leap status     : Normal

$ chronyc sources -v
210 Number of sources = 9

  .-- Source mode  '^' = server, '=' = peer, '#' = local clock.
 / .- Source state '*' = current synced, '+' = combined , '-' = not combined,
| /   '?' = unreachable, 'x' = time may be in error, '~' = time too variable.
||                                                 .- xxxx [ yyyy ] +/- zzzz
||      Reachability register (octal) -.           |  xxxx = adjusted offset,
||      Log2(Polling interval) --.      |          |  yyyy = measured offset,
||                                \     |          |  zzzz = estimated error.
||                                 |    |           \
MS Name/IP address         Stratum Poll Reach LastRx Last sample
===============================================================================
#* ptp                           0   1   377     1    +27ns[  +34ns] +/-  932ns
^- chilipepper.canonical.com     2   6   377    61   -482us[ -482us] +/-   99ms
^- pugot.canonical.com           2   6   377    62   -498us[ -498us] +/-  112ms
^- golem.canonical.com           2   6   337    59   -467us[ -468us] +/-   95ms
^- alphyn.canonical.com          2   6   377    58   +957us[ +957us] +/-   95ms
^- legacy13.chi1.ntfo.org        3   6   377    62    -10ms[  -10ms] +/-  178ms
^- tesla.selinc.com              2   6   377   128   +429us[ +514us] +/-   42ms
```

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```
^- io.crash-override.org          2   6   377    59   +441us[ +441us] +/-   58ms
^- hadb2.smatwebdesign.com        3   6   377    58  +1364us[+1364us] +/-   99ms
```

Note that the `Reference ID` matches the `ptp` refid from the chrony.conf file and that the sources output shows the `ptp` reference id as selected (signified by the `*` state in the second column). Additionally, the NTP time sources show a small relative error to the high accuracy PTP time source.

In this case the PTP grandmaster is properly functioning.

If this error is large, chrony will select the NTP time sources and mark the PTP time source as invalid. This typically signifies that something is mis-configured with the PTP grandmaster upstream of this device or the linuxptp configuration.

9.5 Verifying Operation

If the PTP grandmaster was just setup and configured, it's recommended to power cycle the sensor. The sensor will then jump to the correct time instead of slowly easing in the time adjustment which will take time if the grandmaster initially set the sensor to the wrong time.

HTTP API

The sensor can be queried for the state of its local PTP service through the *HTTP system/time/ptp*.

JSON response fields to check:

- `parent_data_set.grandmaster_identity` should list the identity of the local grandmaster
- `port_data_set.port_state` should be `SLAVE`

LinuxPTP PMC Tool

The sensor will respond to PTP management messages. The linuxptp `pmc` (see `man pmc`) utility can be used to query all PTP devices on the local network.

On the Linux host for the `pmc` utility to communicate with then run the following command:

```
$ sudo pmc 'get PARENT_DATA_SET' 'get CURRENT_DATA_SET' 'get PORT_DATA_SET' 'get TIME_
↪STATUS_NP' -i eno2
sending: GET PARENT_DATA_SET
sending: GET CURRENT_DATA_SET
sending: GET PORT_DATA_SET
sending: GET TIME_STATUS_NP
        bc0fa7.fffe.c48254-1 seq 0 RESPONSE MANAGEMENT PARENT_DATA_SET
                parentPortIdentity                    ac1f6b.fffe.1db84e-2
                parentStats                           0
                observedParentOffsetScaledLogVariance 0xffff
                observedParentClockPhaseChangeRate    0x7fffffff
                grandmasterPriority1                  128
                gm.ClockClass                         6
                gm.ClockAccuracy                      0x21
                gm.OffsetScaledLogVariance            0x4e5d
                grandmasterPriority2                  128
                grandmasterIdentity                   001747.fffe.700038
        bc0fa7.fffe.c48254-1 seq 1 RESPONSE MANAGEMENT CURRENT_DATA_SET
                stepsRemoved     2
```

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```
        offsetFromMaster 613554162.0
        meanPathDelay    117977.0
bc0fa7.fffe.c48254-1 seq 2 RESPONSE MANAGEMENT PORT_DATA_SET
        portIdentity            bc0fa7.fffe.c48254-1
        portState               LISTENING
        logMinDelayReqInterval  0
        peerMeanPathDelay       0
        logAnnounceInterval     1
        announceReceiptTimeout  3
        logSyncInterval         0
        delayMechanism          1
        logMinPdelayReqInterval 0
        versionNumber           2
bc0fa7.fffe.c48254-1 seq 3 RESPONSE MANAGEMENT TIME_STATUS_NP
        master_offset              613554162
        ingress_time               0
        cumulativeScaledRateOffset +0.000000000
        scaledLastGmPhaseChange    0
        gmTimeBaseIndicator        0
        lastGmPhaseChange          0x0000'0000000000000000.0000
        gmPresent                  true
        gmIdentity                 001747.fffe.700038
```

9.6 Tested Grandmaster Clocks

- **Trimble Thunderbolt PTP GM100 Grandmaster Clock**
  - Firmware version: `20161111-0.1.4.0, November 11 2016 15:58:25`
  - PTP configuration:

```
> get ptp eth0
            Enabled : Yes
           Clock ID : 001747.fffe.700038-1
            Profile : 1588
      Domain number : 0
  Transport protocol : IPV4
            IP Mode : Multicast
    Delay Mechanism : E2E
          Sync Mode : Two-Step
        Clock Class : 6
         Priority 1 : 128
         Priority 2 : 128
      Multicast TTL : 0
      Sync interval : 0
   Del Req interval : 0
      Ann. interval : 1
Ann. receipt timeout : 3
```

- **Ubuntu 18.04 + Linux PTP as a master clock**
  - Intel i210 Ethernet interface
    - PCI hardware identifiers: `8086:1533 (rev 03)`
  - Ubuntu 18.04 kernel package: `linux-image-4.18.0-16-generic`
  - Ubuntu 18.04 linuxptp package: `linuxptp-1.8-1`

HTTP Routing Table

/system