1. Multi Destination Application Layer Protocol Client

Send data to a MDALP server.

Contacts an *orchestrator* server to receive a list of *receiving* servers. Distributes sending of data to receiving servers according to latency.

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1.1. Requirements

```
Python >= 3.6
```

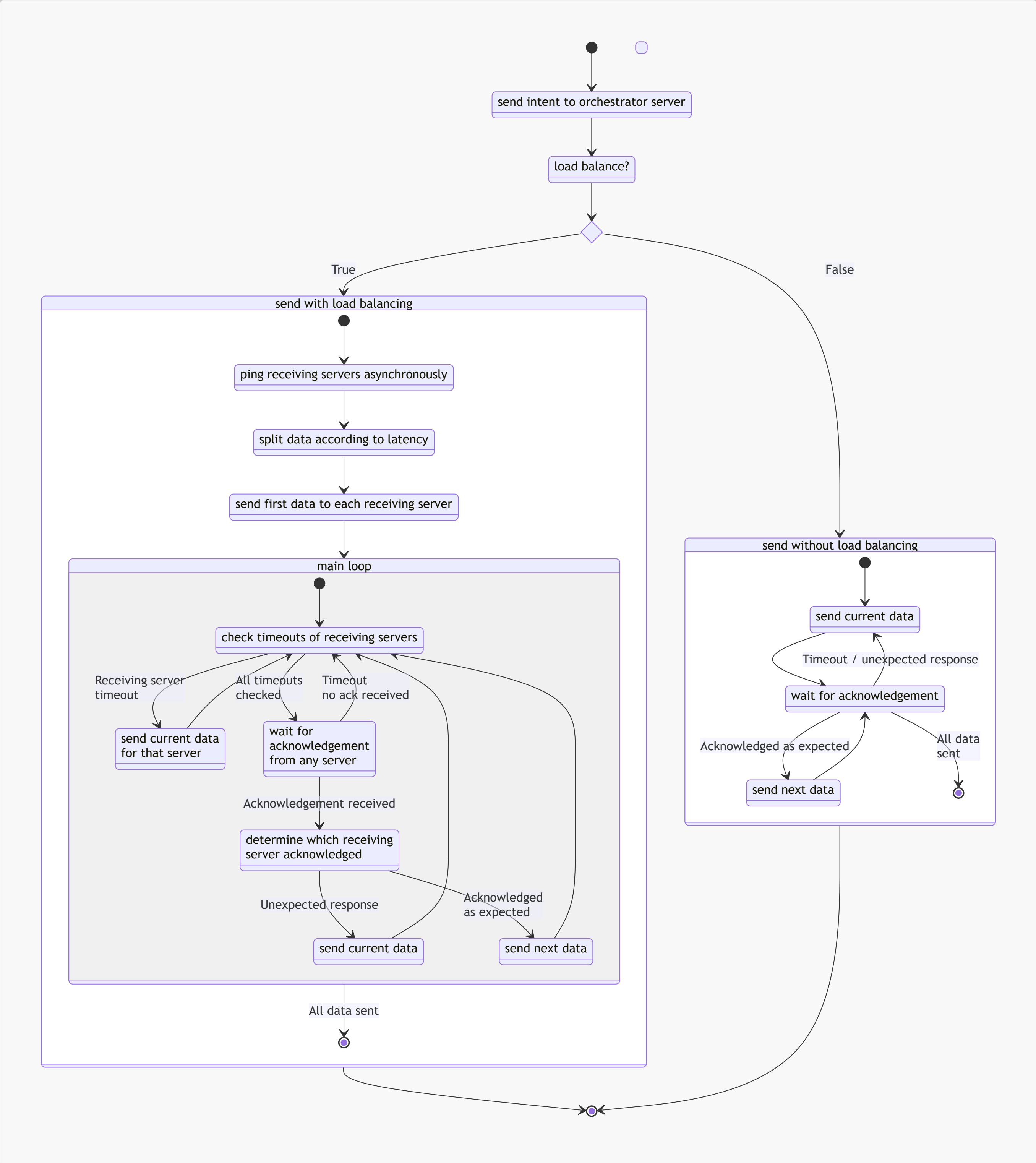
2. Implementation level

Level 4

- Able to send Type 0 messages, and solicit Type 1 message reply from the orchestrator server.
- Able to send payload to a single receiving server among those listed by the receiving server. Able to do retransmissions properly.
- Able to load-balance across several receiving servers specified by the the orchestrator server, in a way compliant with specifications given (ratio, sequence number, etc.).
- Submission has a performance comparison between load-balancing and non-load-balancing modes.

3. Overview

The following shows the overview of how the load balancing send and non load balancing send work. Observe that in both modes, it uses the **stop-and-wait** protocol to send packets to a receiving server as required in the specifications. But in load balancing mode, it is able to handle multiple receiving servers at once which effectively saves time by *asynchronously* sending data.



4. Documentation

Import required python modules.

```python
import argparse
import asyncio
import itertools
import logging
import socket
import selectors
import re
import math
import platform
from subprocess import SubprocessError
from time import perf_counter
from typing import Any, Dict, Iterable, Iterator, List, Sequence, Tuple, Union
```

Initialize logging for logging messages.

```python
logging.basicConfig()
logger = logging.getLogger(__name__)
```

4.1. Utility functions

4.1.1. argsort

```python
def argsort(seq: Sequence, *args, **kargs) -> List:
    '''Returns the indices that would sort an array.

    Args:
        seq (Sequence): Sequence to sort.

    Returns:
        List: List of indices that sort `seq`.
    '''
```

Sorts the indices using the `seq.__getitem__` key which effectively produces the indices that would sort an array.

```python
    return sorted(range(len(seq)), key=seq.__getitem__, *args, **kargs)
```

4.1.2. normalize to sum

```
def normalize_to_sum(iter: Iterable[Union[int, float]]) -> List[float]:
    '''Returns the scaled `iter` to have a sum of 1.

    Args:
        iter (Iterable[Union[int, float]]): The iterable to normalize.

    Returns:
        List[float]: Scaled `iter`
    '''
    it1, it2 = itertools.tee(iter)
```

Get the sum and divide each value by the sum.

```
    total = sum(it1)
    return [float(i) / total for i in it2]
```

4.1.3. split by ratio

```
def split_by_ratio(seq: Sequence,
                   weights: Iterable,
                   min_length: int = 0) -> Iterator[Sequence]:
    '''Split `seq` according to `weights`. Tries to satisfy the optional
    `min_length` argument.

    Args:
        seq (Sequence): Sequence to split
        weights (Iterable): Ratio
        min_length (int, optional): Minimum splice length. Defaults to 0.

    Yields:
        Iterator[Sequence]: a splice of `seq`
    '''
    ratio_norm = normalize_to_sum(weights)
    ratio_norm_argsort = argsort(ratio_norm)

    seq_len = len(seq)
    sub_seq_lens = [0] * len(ratio_norm)
```

Keep track of the remaining allocations left in `remaining`.

```
    remaining = seq_len
```

Iterate over the ratios in increasing order. Allocate with minimum length of `min_length` and maximum length of `remaining`. Subtract the allocated `sub_len` from `remaining`.

```
    for idx, ratio in zip(ratio_norm_argsort, sorted(ratio_norm)):
        sub_len = min(max(round(ratio * seq_len), min_length), remaining)
        remaining -= sub_len
        sub_seq_lens[idx] = sub_len
```

Calculate the resulting split indices and store it to `splits`.

```
    splits = [0]
    for sub_len in sub_seq_lens:
        splits.append(splits[-1] + sub_len)

    for start, end in zip(splits, splits[1:]):
        yield seq[start:end]
```

4.1.4. get average ping

```
async def get_average_ping(host: str, n: int = 3) -> float:
    '''Async function to get average ping of `n` echo requests to `host`

    Args:
        host (str): host
        n (int, optional): Number of echo requests. Defaults to 3.

    Raises:
        SubprocessError: OS ping command error
        RuntimeError: Cannot parse ping command

    Returns:
        float: Average ping
    '''
    number = r'\d+(?:\.\d+)?'
```

Initialize platform dependent flags and regex patterns.

```
    if platform.system().lower() == 'windows':
        count_flag = '-n'
        pattern = f'Average = ({number})ms'
    else:
        count_flag = '-c'
        pattern = f'min/avg/max/mdev = {number}/({number})'
```

Create the ping subprocess. Pipe the stdout.

```
    proc = await asyncio.create_subprocess_exec('ping',
                                                count_flag,
                                                str(n),
                                                host,
                                                stdout=asyncio.subprocess.PIPE)
```

Get the output and parse the average ping using regex.

```
    stdout, stderr = await proc.communicate()
    if proc.returncode < 0:
        raise SubprocessError('ping command error')
    match = re.search(pattern, stdout.decode())
    if match is None:
        raise RuntimeError(
            f'no match found for pattern {pattern} in output\n{stdout}')
    average = float(match.group(1))
    return average
```

4.1.5. get latencies

Pings the hosts *asynchronously*.

```
def get_latencies(hosts: Iterable[str]) -> List:
    '''Returns a list of the round trip times of `hosts`

    Args:
        hosts (Iterable[str]): Hosts

    Returns:
        List: List of round trip times
    '''
```

Create a list of Coroutine objects.

```
    async_pings = [get_average_ping(host) for host in hosts]
```

Gather the Coroutines into a Future object. Get an async event loop and run the Future and get the return values.

```
    pings_future = asyncio.gather(*async_pings)

    loop = asyncio.get_event_loop()
    returns = loop.run_until_complete(pings_future)
    if not loop.is_running(): loop.close()
```

```
    return returns
```

4.1.6. batch seq

```
def batch_seq(seq: Sequence, size: int) -> Iterator[Sequence]:
    '''Batch a sequence into `size` lenghts

    Args:
        seq (Sequence): The sequence
        size (int): Length size

    Returns:
        Iterator[Sequence]: Batched `seq`
    '''
    return (seq[i:i + size] for i in range(0, len(seq), size))
```

4.2. MDALP abstract class

```
class MDALP:
```

4.2.1. init

Create the socket if not provided. Create a selector and register the socket for read events.

```
def __init__(self, addr, sock: socket.socket = None):
    '''
    Args:
        addr: IP address of the server
        sock (socket.socket, optional): Socket to use, creates a new socket object
if None. Defaults to None.
    '''
    self._sock: socket.socket = sock if sock is not None else socket.socket(
        socket.AF_INET, socket.SOCK_DGRAM)
    self._sock.setblocking(False)
    self._sel = selectors.DefaultSelector()
    self._sel.register(self._sock, selectors.EVENT_READ)
    self._addr = addr
```

4.2.2. enter

Used by Python's context manager.

```
def __enter__(self):
    return self
```

4.2.3. close

Unregeisters the socket and closes the socket.

```
def close(self):
    '''Call when done'''
    self._sel.unregister(self._sock)
    self._sock.close()
    logger.info(f'MDALP: {self._addr} closed.')
```

4.2.4. exit

Used by Python's context manager. Call close on exit.

```
def __exit__(self, type, value, traceback):
    self.close()
```

4.2.5. parse message

Parses a message into a dictionary using regex pattern matching.

```
@staticmethod
def _parse_message(message: str) -> Dict[str, Any]:
    '''Parses a message into a dictionary

    Args:
        message (str): Message

    Returns:
        Dict[str, Any]: Parsed info, None if pattern matching failed.
    '''
```

Add a `;` at the end for consistency when needed.

```
    if len(message) > 0 and message[-1] != ';': message += ';'
```

Produce the regex pattern with the appropriate named capture groups.

```

```

```
    fields = [
        ('Type', r'\d+'),
        ('TID', r'\d+'),
        ('SEQ', r'\d+'),
        ('DATA', r'.*')  # greedy
    ]
    regex = ''.join('({0}:(?P<{0}>{1});)?'.format(*field)
                    for field in fields)
```

Match with the message and get the dictionary of named capture groups and its values.

```
    match = re.match(regex, message)
    if match is None: return None

    parsed = match.groupdict()
```

Convert to appropriate types then return the dictionary.

```
    for field in fields[0:3]:
        name = field[0]
        if parsed.get(name) is not None: parsed[name] = int(parsed[name])

    if parsed.get('Type') == 1 and parsed.get('DATA') is not None:
        parsed['DATA'] = eval(parsed['DATA'])

    logger.debug(f'Parsed data: {parsed}')
    return parsed
```

4.2.6. send packet

```
def send_packet(self,
                type: int,
                tid: int = None,
                seq: int = None,
                data: bytes = None) -> int:
    '''Send a packet

    Args:
        type (int): Packet type
        tid (int, optional): Transaction ID. Defaults to None.
        seq (int, optional): Sequence number. Defaults to None.
        data (bytes, optional): Payload. Defaults to None.

    Returns:
        int: Number of bytes of `data` sent not including header.
    '''
```

Create the packet header and append the payload (if needed) based on provided arguments.

```
    header = f'Type:{type};'
    if tid is not None: header += f'TID:{tid};'
    if seq is not None: header += f'SEQ:{seq};'
    header = header.encode()

    payload = b''
    if data is not None:
        header += b'DATA:'
        payload = data

    message = header + payload
```

Send the produced message.

```
    ret = max(0, self._sock.sendto(message, self._addr) - len(header))
    logger.debug(f'client -> {self._addr} (return {ret}): {message}')
    return ret
```

4.2.7. recv packet

```
def recv_packet(self,
                buf_size: int = 1024,
                timeout: float = None) -> Dict[str, Any]:
    '''Returns parsed message received

    Args:
        buf_size (int, optional): Buffer size. Defaults to 1024.
        timeout (float, optional): Timeout in seconds. Defaults to None.

    Returns:
        Dict[str, Any]: Parsed message.
    '''
```

Wait for a read event from the selector. Pass the timeout argument.

```
    events = self._sel.select(timeout)
    if len(events) == 0:
        logger.info(f'Receive timeout!')
        return None
```

A read is available. Read the data and get the address from where it came from.

```
    data, addr = self._sock.recvfrom(buf_size)
```

Check if the address and data are correct then parse and return it.

```
    if addr != self._addr:
        logger.info(
            f'Data received from {addr}, expected address is {self._addr}.')
        return None

    if not data:
        logger.info(f'Data received from {addr} is empty.')
        return None

    data = data.decode()
    parsed = self._parse_message(data)
    if parsed is None: logger.warn(f'Parsed failed with data {data}')
    return parsed
```

4.2.8. recv packet from

```
def recv_packet_from(self,
                        buf_size: int = 1024,
                        timeout: float = None) -> Tuple[Dict[str, Any], Any]:
    '''Returns tuple of parsed message and address of sender

    Args:
        buf_size (int, optional): Buffer size. Defaults to 1024.
        timeout (float, optional): Timeout in seconds. Defaults to None.

    Returns:
        Tuple[Dict[str, Any], Any]: Parsed message and address
    '''
```

Wait for a read event from the selector. Pass the timeout argument.

```
    events = self._sel.select(timeout)
    if len(events) == 0:
        logger.info(f'Receive timeout!')
        return None, None
```

A read is available. Read the data and get the address from where it came from.

```
    data, addr = self._sock.recvfrom(buf_size)
```

Check if the data is correct then parse and return it with the address.

```
    if not data:
        logger.info(f'Data received from {addr} is empty.')
        return None, None

    data = data.decode()
    parsed = self._parse_message(data)
    if parsed is None: logger.warn(f'Parsed failed with data {data}')
    return parsed, addr
```

4.3. MDALPRecvClient

Used to interface with the receiving servers.

```
class MDALPRecvClient(MDALP):
'''Client class for the MDALP receiving server.'''
```

4.3.1. init

Assign a data sequence to be sent to the receiving server and a base sequence number.

```
def __init__(self,
             addr,
             sock: socket.socket,
             tid: int,
             data_seq: Sequence[bytes],
             seq_start: int = 0):
    '''
    Args:
        addr ([type]): IP address of the server
        sock (socket.socket): Socket to use
                              Usually the socket of the   MDALP client
        tid (int): Transaction ID
        data_seq (Sequence[bytes]): Data to be sent to the receiving server
        seq_start (int, optional): Starting sequence number. Defaults to 0.
    '''
    super().__init__(addr, sock=sock)
    self._tid = tid
    self._last_send = None
    self._seq = tuple(data_seq)
    self._base = seq_start
    self._curr_idx = 0
```

4.3.2. properties

Length of the data assigned.

```
@property
def data_len(self) -> int:
    return len(self._seq)
```

The minimum sequence number. The base sequence number.

```
@property
def seq_min(self) -> int:
    return self._base
```

The maximum sequence number.

```
@property
def seq_max(self) -> int:
    return len(self._seq) + self._base - 1
```

The current sequence number in iteration.

```
@property
def seq_curr(self) -> int:
    return self._curr_idx + self._base
```

Set the current sequence number. Internally, modifies the current index.

```
@seq_curr.setter
def seq_curr(self, i: int):
    self._curr_idx = i - self._base
```

Returns a bool that indicates if iteration is finished.

```
@property
def data_exhausted(self) -> bool:
    return self._curr_idx >= len(self._seq)
```

Returns the time elapsed in seconds since the last send.

```
@property
def time_since_last_send(self) -> float:
```

```
    return perf_counter() - self._last_send
```

4.3.3. reset

Resets the iteration.

```
def reset(self):
    '''Reset data iteration'''
    self._curr_idx = 0
```

4.3.4. get curr data

Return the current data in iteration if there is any, else returns None.

```
def get_curr_data(self) -> bytes:
    '''Returns the current data in iteration

    Returns:
        bytes: Bytes of data, None if iteration is finished
    '''
    return self._seq[self._curr_idx] if not self.data_exhausted else None
```

4.3.5. get next data

Return the next data in iteration if there is any, else returns None. Increments the index / sequence number.

```
def get_next_data(self) -> bytes:
    '''Returns the next data in iteration.
    Current index/sequence is incremented

    Returns:
        bytes: Bytes of data, None if iteration is finished
    '''
    self._curr_idx = min(self._curr_idx + 1, len(self._seq))
    if self.data_exhausted: return None
    return self._seq[self._curr_idx]
```

4.3.6. send curr

Send the current data in iteration. If it exists, returns True, else nothing is done and returns False.

```
def send_curr(self) -> bool:
    '''Sends the current data in iteration
```

```
    Returns:
        bool: Returns True if there was data to send, else False
    '''
    data = self.get_curr_data()
    if data is None: return False
    self.send_packet(type=2, tid=self._tid, seq=self.seq_curr, data=data)
    self._last_send = perf_counter()
    return True
```

4.3.7. send next

Send the next data in iteration. If it exists, returns True, else nothing is done and returns False.

```
def send_next(self) -> bool:
    '''Sends the next data in iteration
    Current index/sequence is incremented

    Returns:
        bool: Returns True if there was data to send, else False
    '''
    data = self.get_next_data()
    if data is None: return False
    self.send_packet(type=2, tid=self._tid, seq=self.seq_curr, data=data)
    self._last_send = perf_counter()
    return True
```

4.4. MDALPClient

The class that is mainly used. Used to interface with the orchestrator server and instantiates the MDALPRecvClient class to interface with multiple receiving servers too.

```
class MDALPClient(MDALP):
    '''Client class for the MDALP orchestrator server.'''
    MAX_PAYLOAD = 100
    RECV_PORT = 4650
    TIMEOUT = 3
    TIMEOUT_INTENT = 120
    MIN_RATIO = 0.1
```

4.4.1. send intent

Sends a type 1 message to the orchestrator server and returns the parsed response.

```
def _send_intent(self) -> Dict[str, Any]:
    '''Returns the parsed type 1 message after sending the type 0.
```

```
        Returns:
            Dict[str, Any]: Parsed message
        '''
        self.send_packet(0)
        logger.info(f'Intent message sent to {self._addr}.')
        response = None
        while response is None:
            response = self.recv_packet(timeout=self.TIMEOUT_INTENT)

        if response.get('Type') != 1: return None
        logger.info(f'Response: {response}')
        return response
```

4.4.2. send single server

Used to send data to a single server without load balancing.

```
    def _send_single_server(self, host: str, tid: int, data: bytes) -> int:
        '''Send `data` to `host` with transactio ID `tid`.

        Args:
            host (str): Host
            tid (int): Transaction ID
            data (bytes): Data

        Returns:
            int: Number of data in bytes sent
        '''
```

Instantiate an MDALPRecvClient object. Assign all the data to it. Pass a duplicate of own socket.

```
        addr = (host, self.RECV_PORT)
        server = MDALPRecvClient(addr, self._sock.dup(), tid,
                                 batch_seq(data, self.MAX_PAYLOAD))
```

Send the first packet.

```
        ret = 0
        server.send_curr()
```

While not all data is sent, wait for a response with a timeout of `self.TIMEOUT`.

```
        while not server.data_exhausted:
            response = server.recv_packet(timeout=self.TIMEOUT)
```

On timeout, resend the current data.

```
        if response is None:
            server.send_curr()
            continue
```

If the response message is not as expected, resend the current data.

```
        if not all((response.get('Type') == 3, response.get('TID')
                    == tid, response.get('SEQ') == server.seq_curr)):
            server.send_curr()
            continue
```

The data sent is successfully acknowledged. Add the number of data bytes sent. Send the next data.

```
        ret += len(server.get_curr_data())
        server.send_next()
```

Return the number of data bytes sent.

```
    return ret
```

4.4.3. send load balance

Send data with load balancing.

```
def _send_load_balance(self, hosts: Iterable[str], tid: int,
                       data: bytes) -> int:
    '''Send `data` to `hosts` with transactio ID `tid`.
    Load balances using the inverse of round trip times

    Args:
        hosts (Iterable[str]): Hosts
        tid (int): Transaction ID
        data (bytes): Data

    Returns:
        int: Number of data in bytes sent
    '''
    hosts = list(hosts)
```

Get the latencies of the hosts. Split the data by the inverse of the latencies. This way, more data is allocated for receiving servers with lower latencies.

```
    # get round trip times
    latencies = get_latencies(hosts)
    # split by inverse of RTTs
    split_data = split_by_ratio(data, (1 / l for l in latencies),
                                math.ceil(self.MIN_RATIO * len(data)))
```

Instantiate the MDALPRecvClient objects with the correct data assignment and base sequence numbers.

```
    recv_servers: List[MDALPRecvClient] = []
    seq_base = 0
    for host, d in zip(hosts, split_data):
        addr = (host, self.RECV_PORT)
        recv_servers.append(
            MDALPRecvClient(addr, self._sock.dup(), tid,
                            batch_seq(d, self.MAX_PAYLOAD), seq_base))
        seq_base += recv_servers[-1].data_len
```

Output the summary.

```
    # summary
    for server, latency in zip(recv_servers, latencies):
        logger.info(
            f'addr: {server._addr}, latency: {latency}, data_len:
{server.data_len}'
        )
```

Send the first packet of each receiving server.

```
    ret = 0
    # initial send
    for server in recv_servers:
        server.send_curr()
```

Loop while not all of the data is sent.

```
    # send the rest
    while any(map(lambda s: not s.data_exhausted, recv_servers)):
```

Check for time elapsed since last send for each server, resend the current data for each server that reached timeout.

```
        # check server timeouts
        for server in recv_servers:
            if server.data_exhausted: continue
            if server.time_since_last_send >= self.TIMEOUT:
                logger.info(
                    f'Timeout! {server._addr} | seq: {server.seq_curr}')
                server.send_curr()
```

Wait for a maximum of `self.TIMEOUT` to receive a packet. If no packet is received, `continue`.

```
        response, addr_from = self.recv_packet_from(timeout=self.TIMEOUT)
        if response is None: continue
```

Check the received packet and identify the receiving server that acknowledged. If not found, `continue`.

```
        if not (response.get('Type') == 3 and response.get('TID') == tid):
            continue

        server = next((s for s in recv_servers if s._addr == addr_from),
                        None)
        if server is None: continue
```

Update the sequence number if needed.

```
        if response.get('SEQ') != server.seq_curr:
            # not expected acknowledgement sequence number
            new_seq = response.get('SEQ') + 1
            if server.seq_min <= new_seq <= server.seq_max:
                logger.info(
                    f'Server {server._addr}: Seq number mismatch. Updating
seq_curr to {new_seq} from {server.seq_curr}.'
                )
                server.seq_curr = new_seq
```

All checks to the received packet passed. The receiving server acknowledged as expected. Send the next data.

```
        # server acknowledged as expected
        ret += len(server.get_curr_data())
        server.send_next()
```

Close the socket used for each receiving server and return the number of data bytes sent.

```
    for s in recv_servers:
        s.close()

    return ret
```

4.4.4. send

```
def send(self,
            data: bytes,
            load_balance: bool = True,
            nth_server: int = 1) -> int:
    '''Send data.

    Args:
        data (bytes): Data to send
        load_balance (bool, optional): Flag if load balancing should be used.
Defaults to True.
        nth_server (int, optional): The 1-indexed server number to use. Defaults
to 1.

    Returns:
        int: Number of data in bytes sent
    '''
```

Send intent message to orchestrator server. Get the transaction ID and produce the list of receiving servers.

```
    response = self._send_intent()
    if response is None: return 0

    tid = response.get('TID')
    if tid is None: return 0

    hosts = [server.get('ip_address') for server in response.get('DATA')]
    if len(hosts) == 0: return 0
```

Send the data and return the number of bytes sent. Take the performance in terms of elapsed time and log it.

```
    start = perf_counter()
    ret = 0
    if load_balance:
        ret = self._send_load_balance(hosts, tid, data)
    else:
        ret = self._send_single_server(hosts[nth_server - 1], tid, data)
    end = perf_counter()
```

```
    logger.info(f'Send took {end - start}s.')
    return ret
```

4.5. main

```
def main(args):
```

Set logging level based on command-line argument.

```
    if args.verbose == 1:
        logger.setLevel(logging.INFO)
    elif args.verbose >= 2:
        logger.setLevel(logging.DEBUG)
    else:
        logger.setLevel(logging.WARNING)

    logger.info(f'Parsed args: {args}')
```

Send the data. Use a context manager using the `with` and `as` keywords.

```
    with MDALPClient((args.addr, args.port)) as client:
        data = args.file.read().encode()
        if args.mode == 1:
            ret = client.send(data)
        else:
            ret = client.send(data, load_balance=False, nth_server=args.server)
        logger.debug(f'return: {ret} | data length: {len(data)}')
```

4.5.1. command-line parsing

Create a parser based on the project specifications.

```
if __name__ == '__main__':
    parser = argparse.ArgumentParser(
        description=
        'Send text files using  multidestination application-layer protocol
(MDALP)',
        add_help=False)

    required = parser.add_argument_group(title='required arguments')
    optional = parser.add_argument_group(title='optional arguments')

    required.add_argument('-a',
                          '--addr',
```

```
                            required=True,
                            help='IPv4 address of the server')
        required.add_argument('-p',
                            '--port',
                            required=True,
                            type=int,
                            help='UDP port of the server')
        required.add_argument('-f',
                            '--file',
                            type=argparse.FileType(mode='r', encoding='UTF-8'),
                            required=True,
                            help='filename of the payload')

        optional.add_argument('-h',
                            '--help',
                            action='help',
                            default=argparse.SUPPRESS,
                            help='show this help message and exit')
        optional.add_argument('-v', '--verbose', action="count", default=0)
        optional.add_argument(
            '-m',
            '--mode',
            default=1,
            type=int,
            choices=[1, 2],
            help='mode of the load balancing {1=load balance, 2=no load balancing}'
        )
        optional.add_argument(
            '-s',
            '--server',
            default=1,
            type=int,
            help='index of the server to use when no load balancing mode is used')

        args = parser.parse_args()

        main(args)
```

5. Load balancing vs Non load balancing

Just from the concept and the code, we could infer that load balancing should be able to send a payload faster. Here, we look at a specific case, observing the logs and tracefiles.

5.1. Load balancing

We look at a specific transaction with load balancing with `TID=3740`. Observe that the transaction completed.

TID	IP Address	Status	Comments
3740	13.250.16.215	True	Transaction completed!

The following shows the `DEBUG` level logs from the MDALP client. The command used to send this is

```
python3 mdalp.py -a 18.139.29.142 -p 4650 -f large_payload -vv
```

The client parses the command-line arguments.

```
INFO:__main__:Parsed args: Namespace(addr='18.139.29.142', file=<_io.TextIOWrapper
name='large_payload' mode='r' encoding='UTF-8'>, mode=1, port=4650, server=1,
verbose=2)
```

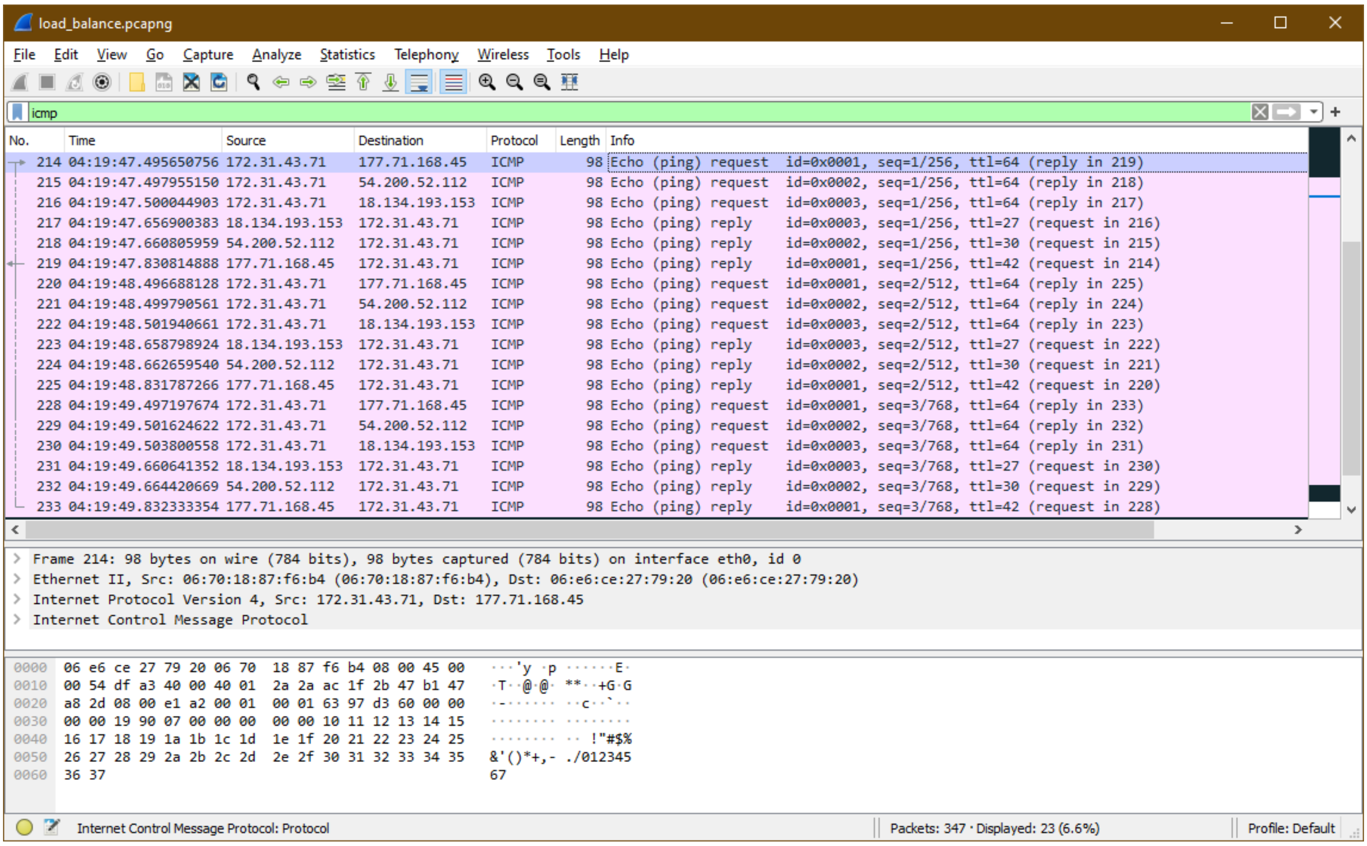
The intent message is sent to the orchestrator server (`18.139.29.142`) and its response is parsed.

```
DEBUG:__main__:client -> ('18.139.29.142', 4650) (return 0): b'Type:0;'
INFO:__main__:Intent message sent to ('18.139.29.142', 4650).
DEBUG:__main__:Parsed data: {'Type': 1, 'TID': 3740, 'SEQ': None, 'DATA':
[{'ip_address': '177.71.168.45', 'name': '5th Receiver'}, {'ip_address':
'54.200.52.112', 'name': '4th Receiver'}, {'ip_address': '18.134.193.153', 'name':
'2nd Receiver'}]}
INFO:__main__:Response: {'Type': 1, 'TID': 3740, 'SEQ': None, 'DATA':
[{'ip_address': '177.71.168.45', 'name': '5th Receiver'}, {'ip_address':
'54.200.52.112', 'name': '4th Receiver'}, {'ip_address': '18.134.193.153', 'name':
'2nd Receiver'}]}
```

From here, denote that `server A = 177.71.168.45`, `server B = 54.200.52.112`, and `server C = 18.134.193.153`.

Note that the start of the send is when the client receives the `Type 1` message. This is because there is a queue in the orchestrator server and this transaction is processed once a `Type 1` message is sent.

The receiving servers are pinged asynchronously. Looking at the packet capture, we see this as the client sending ICMP Echo requests to the receiving servers (`packets 214 - 216`) and the receiving servers replying ICMP Echo replies (`packets 217 - 219`). This is done three times and the average is taken as the latency.



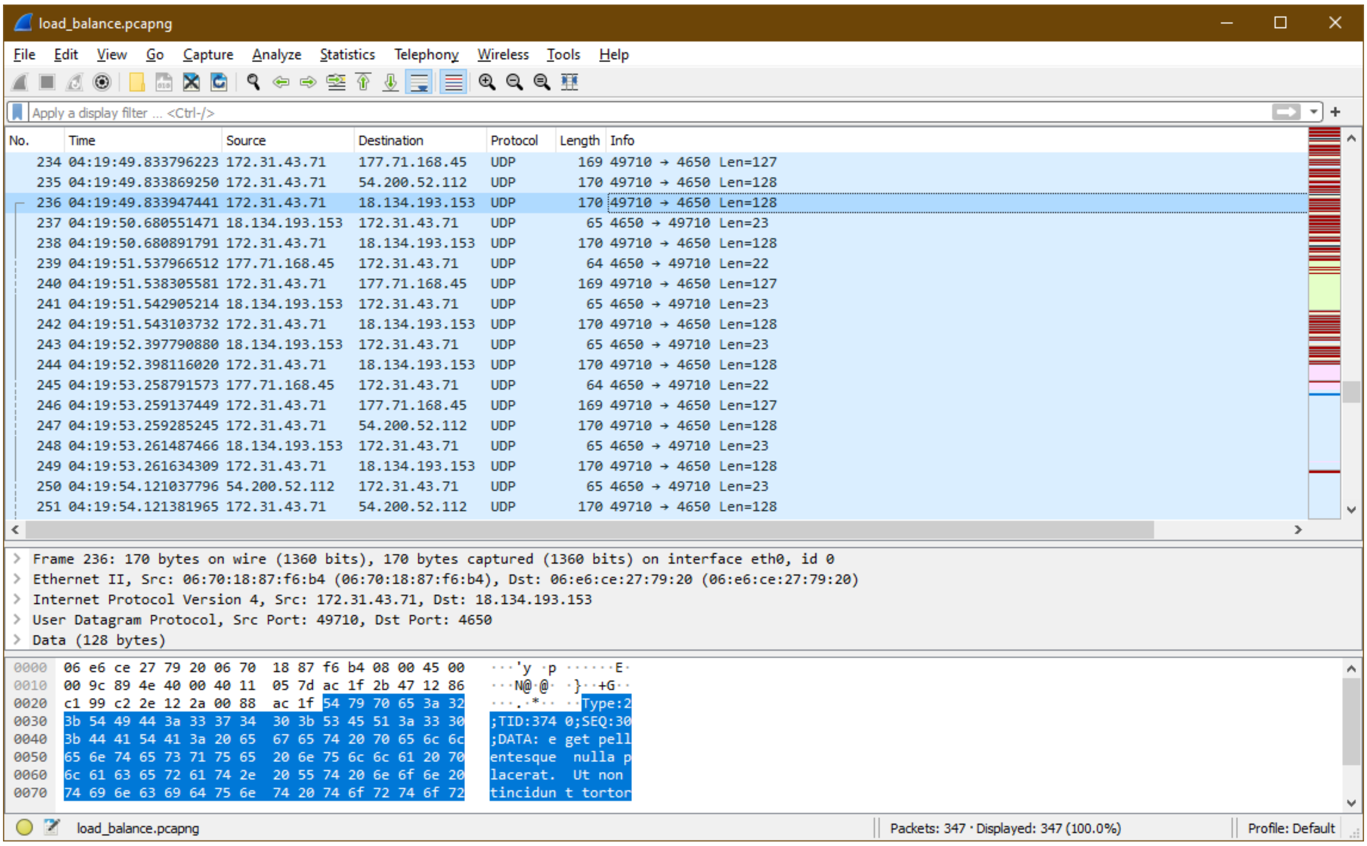
Observe that the length of data assigned to each server is based on the inverse of latency. `Server C`, the lowest latency server, got the most data assigned to it with a length of `21`.

```
INFO:__main__:addr: ('177.71.168.45', 4650), latency: 335.148, data_len: 10
INFO:__main__:addr: ('54.200.52.112', 4650), latency: 162.844, data_len: 20
INFO:__main__:addr: ('18.134.193.153', 4650), latency: 156.857, data_len: 21
```

The first packet for each server is sent. Observe the correct sequence numbers of `0`, `0 + 10 = 10`, and `10 + 20 = 30`.

```
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3740;SEQ:0;DATA:Lorem ipsum dolor sit amet, consectetur adipiscing
elit. Aliquam viverra quis risus sed luctus. Aliq'
DEBUG:__main__:client -> ('54.200.52.112', 4650) (return 100):
b'Type:2;TID:3740;SEQ:10;DATA:r turpis id imperdiet mattis. Nulla eu metus in
velit lobortis efficitur. Duis pulvinar risus eget d'
DEBUG:__main__:client -> ('18.134.193.153', 4650) (return 100):
b'Type:2;TID:3740;SEQ:30;DATA: eget pellentesque nulla placerat. Ut non tincidunt
tortor, a fringilla ligula. Ut eu purus eget tor'
```

In the packet capture, we can easily see the corresponding packets.Observe that `packet 236` corresponds to the packet sent to `Server C` with `SEQ = 30`.



Once the receiving server acknowledges a packet successfully, the next packet is sent. If a timeout occurs, the current packet is resent.

```
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 30, 'DATA': None}
DEBUG:__main__:client -> ('18.134.193.153', 4650) (return 100):
b'Type:2;TID:3740;SEQ:31;DATA:tor tempor volutpat. Sed sed urna non mauris tempor
tempor. Sed accumsan, mauris nec efficitur fauci'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 0, 'DATA': None}
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3740;SEQ:1;DATA:uam erat volutpat. Aliquam eget massa non dolor
finibus pulvinar id vitae metus. Praesent pellentesq'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 31, 'DATA': None}
DEBUG:__main__:client -> ('18.134.193.153', 4650) (return 100):
b'Type:2;TID:3740;SEQ:32;DATA:bus, orci massa dignissim nunc, eu suscipit lorem
libero eu turpis. Quisque non est vitae turpis eff'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 32, 'DATA': None}
DEBUG:__main__:client -> ('18.134.193.153', 4650) (return 100):
b'Type:2;TID:3740;SEQ:33;DATA:icitur placerat vel et augue. Sed vitae dolor leo.
Praesent vestibulum faucibus nisi, non finibus lo'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 1, 'DATA': None}
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3740;SEQ:2;DATA:ue nulla at elit consectetur sollicitudin. Fusce
velit enim, cursus fringilla ante id, sollicitudin '
```

`Server B` experienced a timeout with `SEQ = 10`. Thus, this packet is sent again. The rest of the logs are provided for completeness.

```
INFO:__main__:Timeout! ('54.200.52.112', 4650) | seq: 10
DEBUG:__main__:client -> ('54.200.52.112', 4650) (return 100):
b'Type:2;TID:3740;SEQ:10;DATA:r turpis id imperdiet mattis. Nulla eu metus in
velit lobortis efficitur. Duis pulvinar risus eget d'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 33, 'DATA': None}
DEBUG:__main__:client -> ('18.134.193.153', 4650) (return 100):
b'Type:2;TID:3740;SEQ:34;DATA:rem mattis in. Praesent pulvinar venenatis felis,
vitae tincidunt nunc posuere a. Vestibulum et enim'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 10, 'DATA': None}
DEBUG:__main__:client -> ('54.200.52.112', 4650) (return 100):
b'Type:2;TID:3740;SEQ:11;DATA:ictum convallis. Nullam eros turpis, scelerisque sed
dui sit amet, dignissim tristique enim. Duis co'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 34, 'DATA': None}
...
DEBUG:__main__:client -> ('54.200.52.112', 4650) (return 100):
b'Type:2;TID:3740;SEQ:28;DATA:sit amet cursus. Praesent efficitur sed lectus eu
ultrices. Cras faucibus enim et tincidunt viverra.'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 28, 'DATA': None}
DEBUG:__main__:client -> ('54.200.52.112', 4650) (return 81):
b'Type:2;TID:3740;SEQ:29;DATA: Nullam quis porta dui, eget aliquet enim. Cras
laoreet lectus vel ligula varius,'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 48, 'DATA': None}
DEBUG:__main__:client -> ('18.134.193.153', 4650) (return 100):
b'Type:2;TID:3740;SEQ:49;DATA:t facilisis enim iaculis. Sed cursus nisi vel lorem
aliquam fermentum. Etiam luctus aliquam tincidun'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 29, 'DATA': None}
INFO:__main__:Timeout! ('177.71.168.45', 4650) | seq: 8
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3740;SEQ:8;DATA:iaculis tempor. Nullam nec egestas quam. Sed cursus
magna a sem lacinia mattis. Mauris augue sem, fa'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 49, 'DATA': None}
DEBUG:__main__:client -> ('18.134.193.153', 4650) (return 56):
b'Type:2;TID:3740;SEQ:50;DATA:t. Maecenas quis varius massa. Nunc ornare ac dui
sit a.'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 50, 'DATA': None}
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 8, 'DATA': None}
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 63):
b'Type:2;TID:3740;SEQ:9;DATA:ucibus eget dui at, efficitur efficitur mauris.
Phasellus tempo'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3740, 'SEQ': 9, 'DATA': None}
INFO:__main__:MDALP: ('177.71.168.45', 4650) closed.
INFO:__main__:MDALP: ('54.200.52.112', 4650) closed.
INFO:__main__:MDALP: ('18.134.193.153', 4650) closed.
```

Finally, all packets are sent. From the time before pinging the receiving servers up to all the packets being acknowledged, it took `26.246762644s`.

```
INFO:__main__:Send took 26.246762644s.
DEBUG:__main__:return: 5000 | data length: 5000
INFO:__main__:MDALP: ('18.139.29.142', 4650) closed.
```

5.2. Non load balancing

We take a quick look at how non load balancing performs. Note that in non load balancing, pinging the receiving servers are not done at all to save on time. But the latencies should be very similar to what we had earlier. To recall,

```
INFO:__main__:addr: ('177.71.168.45', 4650), latency: 335.148, data_len: 10
INFO:__main__:addr: ('54.200.52.112', 4650), latency: 162.844, data_len: 20
INFO:__main__:addr: ('18.134.193.153', 4650), latency: 156.857, data_len: 21
```

Server A

TID	IP Address	Status	Comments
3755	13.250.16.215	False	Transaction failed! Load balancing violation and incomplete data!

This receiving server had the highest latency. When sending data to it, it failed to acknowledge all the data. Note that the log here is shortened for conciseness.

```
python3 mdalp.py -a 18.139.29.142 -p 4650 -f large_payload -vv -m 2 -s 1
INFO:__main__:Parsed args: Namespace(addr='18.139.29.142', file=<_io.TextIOWrapper
name='large_payload' mode='r' encoding='UTF-8'>, mode=2, port=4650, server=1,
verbose=2)
DEBUG:__main__:client -> ('18.139.29.142', 4650) (return 0): b'Type:0;'
INFO:__main__:Intent message sent to ('18.139.29.142', 4650).
DEBUG:__main__:Parsed data: {'Type': 1, 'TID': 3755, 'SEQ': None, 'DATA':
[{'ip_address': '177.71.168.45', 'name': '5th Receiver'}, {'ip_address':
'54.200.52.112', 'name': '4th Receiver'}, {'ip_address': '18.134.193.153', 'name':
'2nd Receiver'}]}
INFO:__main__:Response: {'Type': 1, 'TID': 3755, 'SEQ': None, 'DATA':
[{'ip_address': '177.71.168.45', 'name': '5th Receiver'}, {'ip_address':
'54.200.52.112', 'name': '4th Receiver'}, {'ip_address': '18.134.193.153', 'name':
'2nd Receiver'}]}
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:0;DATA:Lorem ipsum dolor sit amet, consectetur adipiscing
elit. Aliquam viverra quis risus sed luctus. Aliq'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3755, 'SEQ': 0, 'DATA': None}
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:1;DATA:uam erat volutpat. Aliquam eget massa non dolor
finibus pulvinar id vitae metus. Praesent pellentesq'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3755, 'SEQ': 1, 'DATA': None}
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:2;DATA:ue nulla at elit consectetur sollicitudin. Fusce
velit enim, cursus fringilla ante id, sollicitudin '
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3755, 'SEQ': 2, 'DATA': None}
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:3;DATA:gravida odio. Fusce sem neque, consequat vel
fermentum vel, placerat vitae lectus. Aliquam porttitor'
```

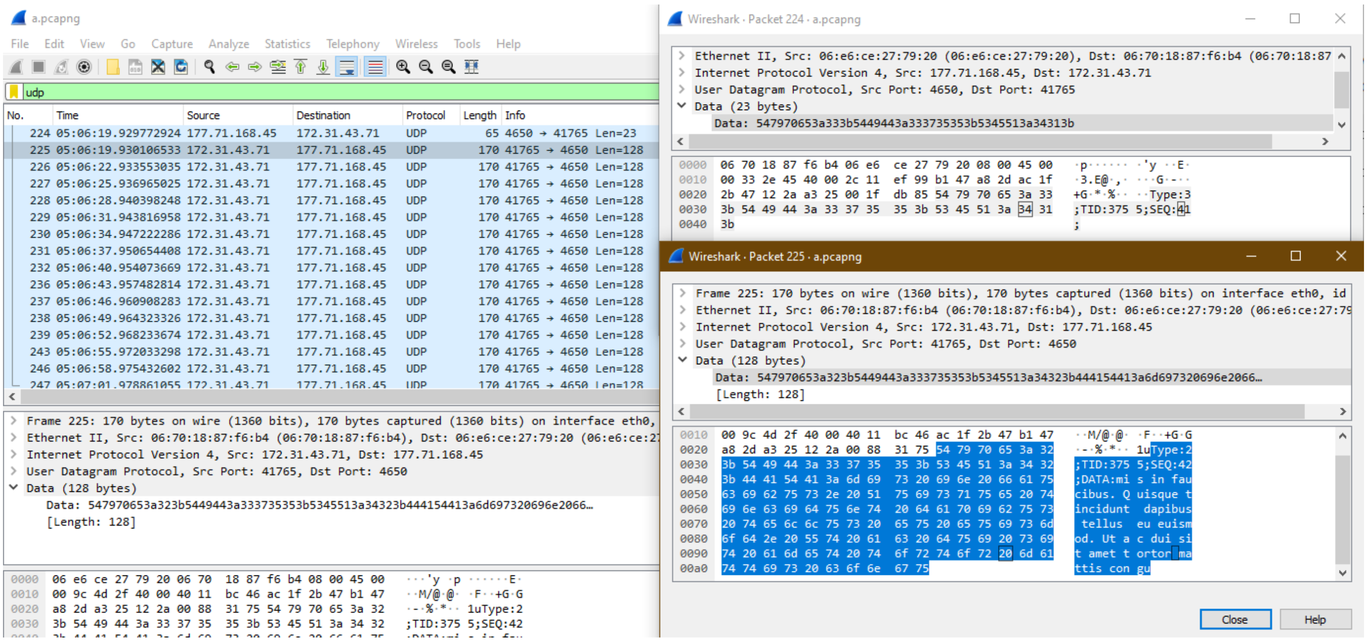
```
...
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3755, 'SEQ': 38, 'DATA': None}
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:39;DATA:nt vehicula lacinia lectus, vel venenatis nisl
aliquam id. Aliquam erat volutpat. Fusce mollis vel l'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3755, 'SEQ': 39, 'DATA': None}
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:40;DATA:ibero a dignissim. Praesent condimentum aliquet
finibus. Nam et elit lorem. Praesent sit amet dolor '
INFO:__main__:Receive timeout!
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:40;DATA:ibero a dignissim. Praesent condimentum aliquet
finibus. Nam et elit lorem. Praesent sit amet dolor '
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3755, 'SEQ': 40, 'DATA': None}
```

After `SEQ = 41` was sent and acknowledged, `SEQ = 42` was sent. However, this was never acknowledged after multiple timeouts. Note that the log is shortened here for conciseness.

```
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:41;DATA:non velit blandit placerat. Aliquam vitae ligula
orci. Interdum et malesuada fames ac ante ipsum pri'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3755, 'SEQ': 41, 'DATA': None}
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:42;DATA:mis in faucibus. Quisque tincidunt dapibus tellus eu
euismod. Ut ac dui sit amet tortor mattis congu'
INFO:__main__:Receive timeout!
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:42;DATA:mis in faucibus. Quisque tincidunt dapibus tellus eu
euismod. Ut ac dui sit amet tortor mattis congu'
INFO:__main__:Receive timeout!
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:42;DATA:mis in faucibus. Quisque tincidunt dapibus tellus eu
euismod. Ut ac dui sit amet tortor mattis congu'
...
INFO:__main__:Receive timeout!
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:42;DATA:mis in faucibus. Quisque tincidunt dapibus tellus eu
euismod. Ut ac dui sit amet tortor mattis congu'
INFO:__main__:Receive timeout!
DEBUG:__main__:client -> ('177.71.168.45', 4650) (return 100):
b'Type:2;TID:3755;SEQ:42;DATA:mis in faucibus. Quisque tincidunt dapibus tellus eu
euismod. Ut ac dui sit amet tortor mattis congu'
^CINFO:__main__:MDALP: ('18.139.29.142', 4650) closed.
Traceback (most recent call last):
  File "mdalp.py", line 660, in <module>
    main(args)
  File "mdalp.py", line 609, in main
    ret = client.send(data, load_balance=False, nth_server=args.server)
  File "mdalp.py", line 587, in send
    ret = self._send_single_server(hosts[nth_server - 1], tid, data)
  File "mdalp.py", line 465, in _send_single_server
```

```
    response = server.recv_packet(timeout=self.TIMEOUT)
  File "mdalp.py", line 271, in recv_packet
    events = self._sel.select(timeout)
  File "/usr/lib/python3.8/selectors.py", line 468, in select
    fd_event_list = self._selector.poll(timeout, max_ev)
KeyboardInterrupt
```

Looking at the packet capture, we observe this series of packets exactly. Packet 224 is the acknowledgement for `SEQ = 41` then the next packets are packets for `SEQ = 42` which are never acknowledged.



Server B

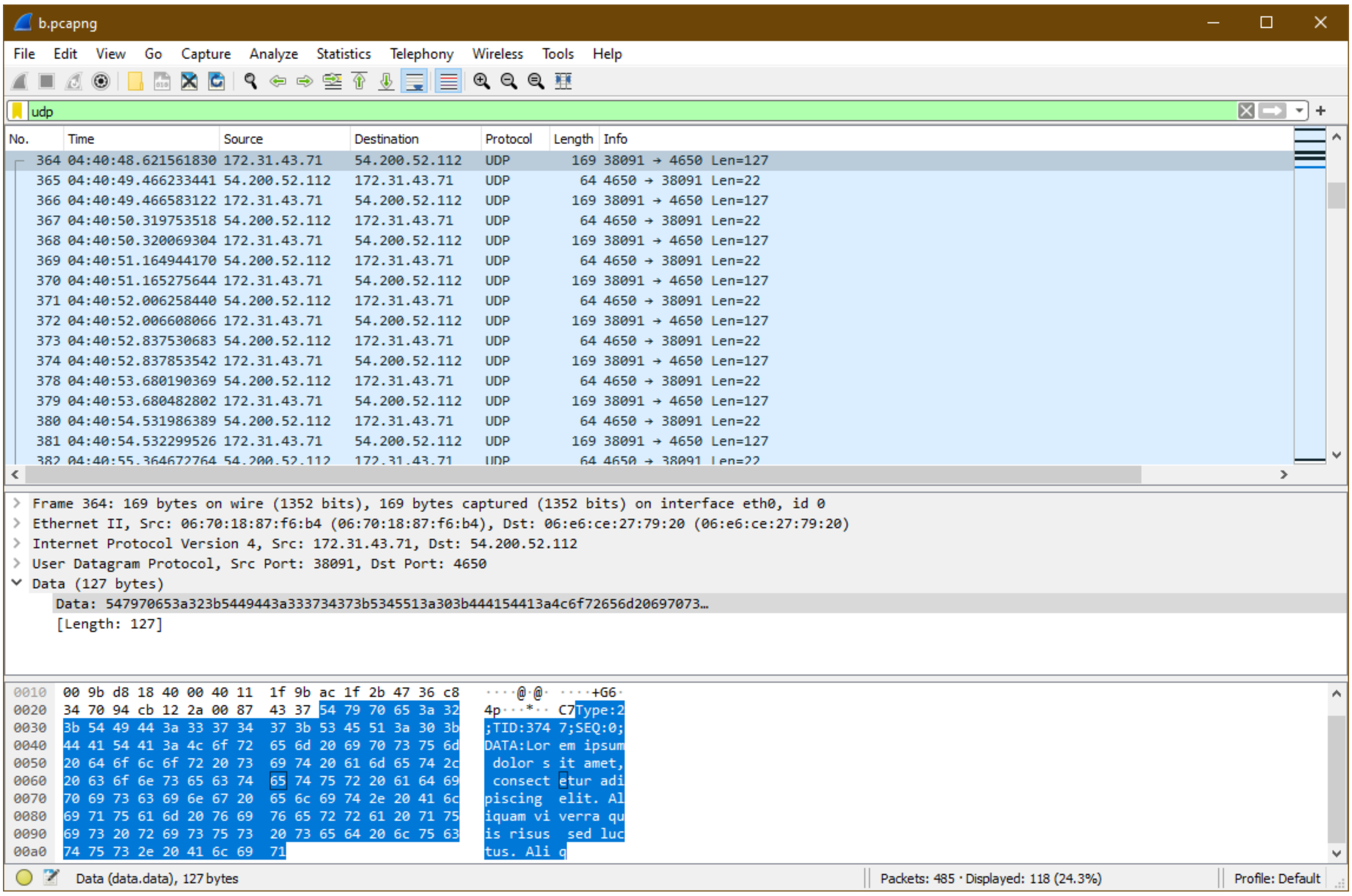
TID	IP Address	Status	Comments
3747	13.250.16.215	False	Transaction failed! Complete data but load balancing violation!

This server successfully completed the transaction.

```
python3 mdalp.py -a 18.139.29.142 -p 4650 -f large_payload -vv -m 2 -s 2
INFO:__main__:Parsed args: Namespace(addr='18.139.29.142', file=<_io.TextIOWrapper
name='large_payload' mode='r' encoding='UTF-8'>, mode=2, port=4650, server=2,
verbose=2)
DEBUG:__main__:client -> ('18.139.29.142', 4650) (return 0): b'Type:0;'
INFO:__main__:Intent message sent to ('18.139.29.142', 4650).
DEBUG:__main__:Parsed data: {'Type': 1, 'TID': 3747, 'SEQ': None, 'DATA':
[{'ip_address': '177.71.168.45', 'name': '5th Receiver'}, {'ip_address':
'54.200.52.112', 'name': '4th Receiver'}, {'ip_address': '18.134.193.153', 'name':
'2nd Receiver'}]}
INFO:__main__:Response: {'Type': 1, 'TID': 3747, 'SEQ': None, 'DATA':
[{'ip_address': '177.71.168.45', 'name': '5th Receiver'}, {'ip_address':
'54.200.52.112', 'name': '4th Receiver'}, {'ip_address': '18.134.193.153', 'name':
'2nd Receiver'}]}
DEBUG:__main__:client -> ('54.200.52.112', 4650) (return 100):
b'Type:2;TID:3747;SEQ:0;DATA:Lorem ipsum dolor sit amet, consectetur adipiscing
```

```
elit. Aliquam viverra quis risus sed luctus. Aliq'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3747, 'SEQ': 0, 'DATA': None}
DEBUG:__main__:client -> ('54.200.52.112', 4650) (return 100):
b'Type:2;TID:3747;SEQ:1;DATA:uam erat volutpat. Aliquam eget massa non dolor
finibus pulvinar id vitae metus. Praesent pellentesq'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3747, 'SEQ': 1, 'DATA': None}
DEBUG:__main__:client -> ('54.200.52.112', 4650) (return 100):
b'Type:2;TID:3747;SEQ:2;DATA:ue nulla at elit consectetur sollicitudin. Fusce
velit enim, cursus fringilla ante id, sollicitudin '
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3747, 'SEQ': 2, 'DATA': None}
...
DEBUG:__main__:client -> ('54.200.52.112', 4650) (return 100):
b'Type:2;TID:3747;SEQ:47;DATA:um nibh, vitae malesuada risus ligula faucibus
turpis. Curabitur ultricies ut metus vitae malesuada.'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3747, 'SEQ': 47, 'DATA': None}
DEBUG:__main__:client -> ('54.200.52.112', 4650) (return 100):
b'Type:2;TID:3747;SEQ:48;DATA: Mauris imperdiet mauris ac eros bibendum, ut
facilisis enim iaculis. Sed cursus nisi vel lorem aliq'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3747, 'SEQ': 48, 'DATA': None}
DEBUG:__main__:client -> ('54.200.52.112', 4650) (return 100):
b'Type:2;TID:3747;SEQ:49;DATA:uam fermentum. Etiam luctus aliquam tincidunt.
Maecenas quis varius massa. Nunc ornare ac dui sit a.'
DEBUG:__main__:Parsed data: {'Type': 3, 'TID': 3747, 'SEQ': 49, 'DATA': None}
```

Looking at the packet capture, observe that the client is exchanging messages with only one receiving server which is `Server B`.



From the time before the first packet is sent up to the last packet was acknowledged, it took `48.36496986100019s` to complete the transaction.

```
INFO:__main__:Send took 48.36496986100019s.
DEBUG:__main__:return: 5000 | data length: 5000
INFO:__main__:MDALP: ('18.139.29.142', 4650) closed.
```

Server C

TID	IP Address	Status	Comments
3752	13.250.16.215	False	Transaction failed! Complete data but load balancing violation!

In this case, it is very similar to `Server B`. Thus, it would not be discussed any further but all logs and tracefiles are still provided as proof. Note that for this server, it took `53.899554123000144s`.

5.3. Comparison

Recall the following and take note of the summary:

Mode	Server	Server latency (ms)	Timeouts	Elapsed Time (s)
Load balance	-	-	4	26.246
Non load balance	A	335.148	inf	failed
Non load balance	B	162.844	2	48.364
Non load balance	C	156.857	4	53.899

Observe that sending with load balancing is significantly faster. Although the specific amount by how much faster could not be established as this is a single test case, it is expected to be at most `n` times quicker where `n = number of receiving servers`. This is because sending the data to multiple receiving servers asynchronously wastes less time in waiting for an acknowledgement. Of course, there will be a trade-off for pinging the receiving servers first, but this should not be very significant because it is done asynchronously. Thus, it can scale to increasing number of receiving servers.