# Reticulum Network Stack

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This manual aims to provide you with all the information you need to understand Reticulum, build networks or develop programs using it, or to participate in the development of Reticulum itself.

CHAPTER

ONE

# WHAT IS RETICULUM?

Reticulum is a cryptography-based networking stack for wide-area networks built on readily available hardware, that can operate even with very high latency and extremely low bandwidth.

Reticulum allows you to build very wide-area networks with off-the-shelf tools, and offers end-to-end encryption, auto-configuring cryptographically backed multi-hop transport, efficient addressing, unforgeable packet acknowledgements and more.

Reticulum is a complete networking stack, and does not need IP or higher layers, although it is easy to utilise IP (with TCP or UDP) as the underlying carrier for Reticulum. It is therefore trivial to tunnel Reticulum over the Internet or private IP networks. Reticulum is built directly on cryptographic principles, allowing resilience and stable functionality in open and trustless networks.

No kernel modules or drivers are required. Reticulum runs completely in userland, and can run on practically any system that runs Python 3. Reticulum runs well even on small single-board computers like the Pi Zero.

## 1.1 Current Status

Reticulum should currently be considered beta software. All core protocol features are implemented and functioning, but additions will probably occur as real-world use is explored. There will be bugs. The API and wire-format can be considered relatively stable at the moment, but could change if warranted.

## 1.2 What does Reticulum Offer?

- Coordination-less globally unique adressing and identification
- Fully self-configuring multi-hop routing
- Complete initiator anonymity, communicate without revealing your identity
- Asymmetric X25519 encryption and Ed25519 signatures as a basis for all communication
- Forward Secrecy with ephemereal Elliptic Curve Diffie-Hellman keys on Curve25519
- Reticulum uses the Fernet specification for on-the-wire / over-the-air encryption
  - All keys are ephemeral and derived from an ECDH key exchange on Curve25519
  - AES-128 in CBC mode with PKCS7 padding
  - HMAC using SHA256 for authentication
  - IVs are generated through os.urandom()
- Unforgeable packet delivery confirmations

- A variety of supported interface types
- An intuitive and developer-friendly API
- Reliable and efficient transfer of arbitrary amounts of data
  - Reticulum can handle a few bytes of data or files of many gigabytes
  - Sequencing, transfer coordination and checksumming is automatic
  - The API is very easy to use, and provides transfer progress
- Efficient link establishment
  - Total bandwidth cost of setting up a link is only 3 packets, totalling 237 bytes
  - Low cost of keeping links open at only 0.62 bits per second

## 1.3 Where can Reticulum be Used?

Over practically any medium that can support at least a half-duplex channel with 500 bits per second throughput, and an MTU of 500 bytes. Data radios, modems, LoRa radios, serial lines, AX.25 TNCs, amateur radio digital modes, ad-hoc WiFi, free-space optical links and similar systems are all examples of the types of interfaces Reticulum was designed for.

An open-source LoRa-based interface called RNode has been designed specifically for use with Reticulum. It is possible to build yourself, or it can be purchased as a complete transceiver that just needs a USB connection to the host.

Reticulum can also be encapsulated over existing IP networks, so there's nothing stopping you from using it over wired ethernet or your local WiFi network, where it'll work just as well. In fact, one of the strengths of Reticulum is how easily it allows you to connect different mediums into a self-configuring, resilient and encrypted mesh.

As an example, it's possible to set up a Raspberry Pi connected to both a LoRa radio, a packet radio TNC and a WiFi network. Once the interfaces are configured, Reticulum will take care of the rest, and any device on the WiFi network can communicate with nodes on the LoRa and packet radio sides of the network, and vice versa.

## 1.4 Interface Types and Devices

Reticulum implements a range of generalised interface types that covers most of the communications hardware that Reticulum can run over. If your hardware is not supported, it's relatively simple to implement an interface class. Currently, the following interfaces are supported:

- Any ethernet device
- LoRa using RNode
- Packet Radio TNCs, such as OpenModem
- Any device with a serial port
- TCP over IP networks
- UDP over IP networks

For a full list and more details, see the *Supported Interfaces* chapter.

## 1.5 Caveat Emptor

Reticulum is an experimental networking stack, and should be considered as such. While it has been built with cryptography best-practices very foremost in mind, it has not been externally security audited, and there could very well be privacy-breaking bugs. To be considered secure, Reticulum needs a thourough security review by independt cryptographers and security researchers. If you want to help out, or help sponsor an audit, please do get in touch.

CHAPTER

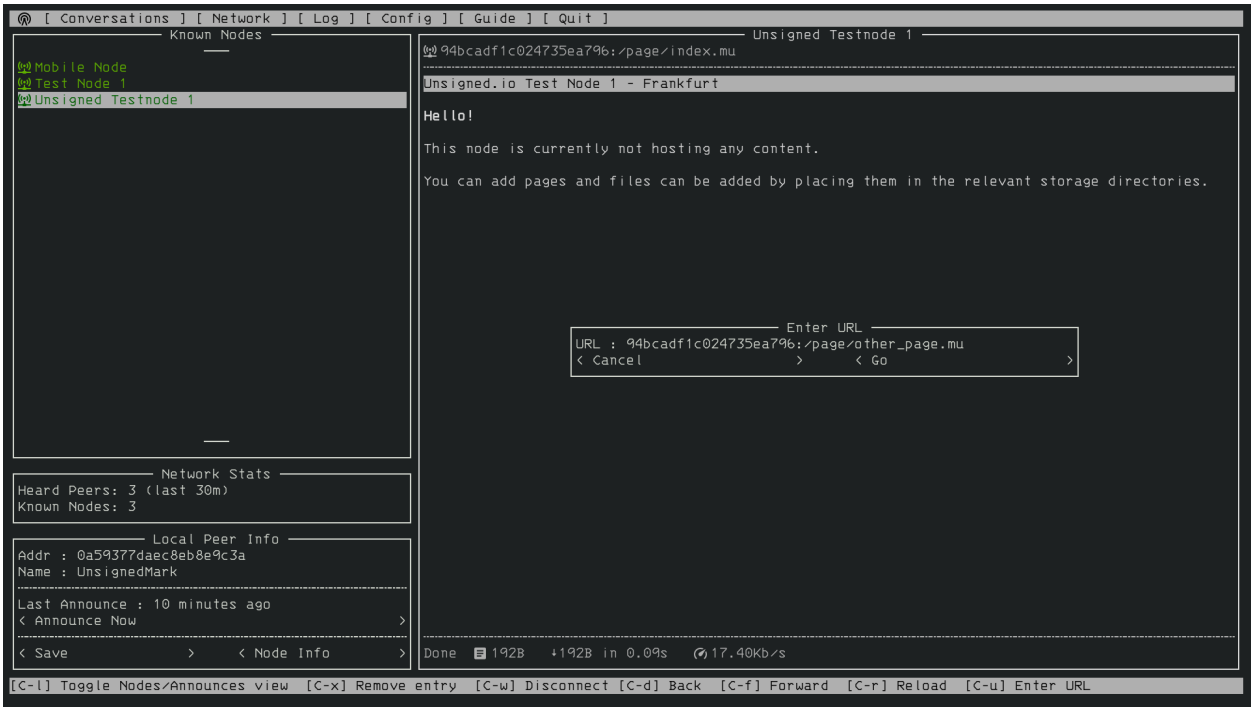
TWO

# GETTING STARTED FAST

The best way to get started with the Reticulum Network Stack depends on what you want to do. This guide will outline sensible starting paths for different scenarios.

## 2.1 Try Using a Reticulum-based Program

If you simply want to try using a program built with Reticulum, you can take a look at Nomad Network, which provides a complete encrypted communications suite built with Reticulum.




Nomad Network is a user-facing client for the messaging and information-sharing protocol LXMF, another project built with Reticulum.

You can install Nomad Network via pip:

```
# Install ...
pip3 install nomadnet
```

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```
# ... and run
nomadnet
```

**Please Note**: If this is the very first time you use pip to install a program on your system, you might need to reboot your system for your program to become available. If you get a "command not found" error or similar when running the program, reboot your system and try again.

## 2.2 Using the Included Utilities

Reticulum comes with a range of included utilities that make it easier to manage your network, check connectivity and make Reticulum available to other programs on your system.

You can use `rnsd` to run Reticulum as a background or foreground service, and the `rnstatus`, `rnpath` and `rnprobe` utilities to view and query network status and connectivity.

To learn more about these utility programs, have a look at the *Using Reticulum on Your System* chapter of this manual.

## 2.3 Creating a Network With Reticulum

To create a network, you will need to specify one or more *interfaces* for Reticulum to use. This is done in the Reticulum configuration file, which by default is located at `~/.reticulum/config`. You can edit this file by hand, or use the interactive `rnsconfig` utility.

When Reticulum is started for the first time, it will create a default configuration file, with one active interface. This default interface uses your existing ethernet network (if there is one), and only allows you to communicate with other Reticulum peers within your local broadcast domain.

To communicate further, you will have to add one or more interfaces. The default configuration includes a number of examples, ranging from using TCP over the internet, to LoRa and Packet Radio interfaces.

Possibly, the examples in the config file are enough to get you started. If you want more information, you can read the *Building Networks* and *Interfaces* chapters of this manual.

## 2.4 Develop a Program with Reticulum

If you want to develop programs that use Reticulum, the easiest way to get started is to install the latest release of Reticulum via pip:

```
pip3 install rns
```

The above command will install Reticulum and dependencies, and you will be ready to import and use RNS in your own programs. The next step will most likely be to look at some *Example Programs*.

For extended functionality, you can install optional dependencies:

```
pip3 install pyserial netifaces
```

Further information can be found in the *API Reference*.

## 2.5 Participate in Reticulum Development

If you want to participate in the development of Reticulum and associated utilities, you'll want to get the latest source from GitHub. In that case, don't use pip, but try this recipe:

```
# Install dependencies
pip3 install cryptography pyserial netifaces

# Clone repository
git clone https://github.com/markqvist/Reticulum.git

# Move into Reticulum folder and symlink library to examples folder
cd Reticulum
ln -s ../RNS ./Examples/

# Run an example
python3 Examples/Echo.py -s

# Unless you've manually created a config file, Reticulum will do so now,
# and immediately exit. Make any necessary changes to the file:
nano ~/.reticulum/config

# ... and launch the example again.
python3 Examples/Echo.py -s

# You can now repeat the process on another computer,
# and run the same example with -h to get command line options.
python3 Examples/Echo.py -h

# Run the example in client mode to "ping" the server.
# Replace the hash below with the actual destination hash of your server.
python3 Examples/Echo.py 3e12fc71692f8ec47bc5

# Have a look at another example
python3 Examples/Filetransfer.py -h
```

When you have experimented with the basic examples, it's time to go read the *Understanding Reticulum* chapter.

## 2.6 Reticulum on ARM64

On some architectures, including ARM64, not all dependencies have precompiled binaries. On such systems, you will need to install `python3-dev` before installing Reticulum or programs that depend on Reticulum.

```
# Install Python and development packages
sudo apt update
sudo apt install python3 python3-pip python3-dev

# Install Reticulum
python3 -m pip install rns
```

## 2.7 Reticulum on Android

Reticulum can be used on Android in different ways. The easiest way to get started is using the Termux app, at the time of writing available on F-droid.

Termux is a terminal emulator and Linux environment for Android based devices, which includes the ability to use many different programs and libraries, including Reticulum.

Since the Python cryptography.io module does not offer pre-built wheels for Android, the standard one-line install of Reticulum does not work on Android, and a few extra commands are required.

From within Termux, execute the following:

```
# First, make sure indexes and packages are up to date.
pkg update
pkg upgrade

# Then install dependencies for the cryptography library.
pkg install python build-essential openssl libffi rust

# Make sure pip is up to date, and install the wheel module.
pip3 install wheel pip --upgrade

# To allow the installer to build the cryptography module,
# we need to let it know what platform we are compiling for:
export CARGO_BUILD_TARGET="aarch64-linux-android"

# Start the install process for the cryptography module.
# Depending on your device, this can take several minutes,
# since the module must be compiled locally on your device.
pip3 install cryptography

# If the above installation succeeds, you can now install
# Reticulum and any related software
pip3 install rns
```

It is also possible to include Reticulum in apps compiled and distributed as Android APKs. A detailed tutorial and example source code will be included here at a later point.

CHAPTER

THREE

# USING RETICULUM ON YOUR SYSTEM

Reticulum is not installed as a driver or kernel module, as one might expect of a networking stack. Instead, Reticulum is distributed as a Python module. This means that no special privileges are required to install or use it. Any program or application that uses Reticulum will automatically load and initialise Reticulum when it starts.

In many cases, this approach is sufficient. When any program needs to use Reticulum, it is loaded, initialised, interfaces are brought up, and the program can now communicate over Reticulum. If another program starts up and also wants access to the same Reticulum network, the instance is simply shared. This works for any number of programs running concurrently, and is very easy to use, but depending on your use case, there are other options.

## 3.1 Included Utility Programs

If you often use Reticulum from several different programs, or simply want Reticulum to stay available all the time, for example if you are hosting a transport node, you might want to run Reticulum as a separate service that other programs, applications and services can utilise.

### 3.1.1 The rnsd Utility

To do so is very easy. Simply run the included `rnsd` command. When `rnsd` is running, it will keep all configured interfaces open, handle transport if it is enabled, and allow any other programs to immediately utilise the Reticulum network it is configured for.

You can even run multiple instances of rnsd with different configurations on the same system.

```
# Install Reticulum
pip3 install rns

# Run rnsd
rnsd
```

```
usage: rnsd [-h] [--config CONFIG] [-v] [-q] [--version]

Reticulum Network Stack Daemon

optional arguments:
  -h, --help       show this help message and exit
  --config CONFIG  path to alternative Reticulum config directory
  -v, --verbose
  -q, --quiet
  --version        show program's version number and exit
```

You can easily add `rnsd` as an always-on service by *configuring a service*.

### 3.1.2 The rnstatus Utility

Using the `rnstatus` utility, you can view the status of configured Reticulum interfaces, similar to the `ifconfig` program.

```
# Run rnstatus
rnstatus

# Example output
Shared Instance[37428]
       Status: Up
       Connected applications: 1
       RX: 1.13 KB
       TX: 1.07 KB

UDPInterface[Default UDP Interface/0.0.0.0:4242]
       Status: Up
       RX: 1.01 KB
       TX: 1.01 KB

TCPInterface[RNS Testnet Frankfurt/frankfurt.rns.unsigned.io:4965]
       Status: Up
       RX: 1.37 KB
       TX: 9.02 KB
```

```
usage: rnsd [-h] [--config CONFIG] [-v] [-q] [--version]

Reticulum Network Stack Daemon

optional arguments:
  -h, --help       show this help message and exit
  --config CONFIG  path to alternative Reticulum config directory
  -v, --verbose
  -q, --quiet
  --version        show program's version number and exit
```

### 3.1.3 The rnpath Utility

With the `rnpath` utility, you can look up and view paths for destinations on the Reticulum network.

```
# Run rnpath
rnpath eca6f4e4dc26ae329e61

# Example output
Path found, destination <eca6f4e4dc26ae329e61> is 4 hops away via <56b115c30cd386cad69c>␣
↪on TCPInterface[Testnet/frankfurt.rns.unsigned.io:4965]
```

```
usage: rnpath.py [-h] [--config CONFIG] [--version] [-v] [destination]
```

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```
Reticulum Path Discovery Utility

positional arguments:
  destination      hexadecimal hash of the destination

optional arguments:
  -h, --help       show this help message and exit
  --config CONFIG  path to alternative Reticulum config directory
  --version        show program's version number and exit
  -v, --verbose
```

### 3.1.4 The rnprobe Utility

The `rnprobe` utility lets you probe a destination for connectivity, similar to the `ping` program. Please note that probes will only be answered if the specified destination is configured to send proofs for received packets. Many destinations will not have this option enabled, and will not be probable.

```
# Run rnprobe
python3 -m RNS.Utilities.rnprobe example_utilities.echo.request 9382f334de63217a4278

# Example output
Sent 16 byte probe to <9382f334de63217a4278>
Valid reply received from <9382f334de63217a4278>
Round-trip time is 38.469 milliseconds over 2 hops
```

```
usage: rnprobe.py [-h] [--config CONFIG] [--version] [-v] [full_name] [destination_hash]

Reticulum Probe Utility

positional arguments:
  full_name         full destination name in dotted notation
  destination_hash  hexadecimal hash of the destination

optional arguments:
  -h, --help        show this help message and exit
  --config CONFIG   path to alternative Reticulum config directory
  --version         show program's version number and exit
  -v, --verbose
```

## 3.2 Improving System Configuration

If you are setting up a system for permanent use with Reticulum, there is a few system configuration changes that can make this easier to administrate. These changes will be detailed here.

### 3.2.1 Fixed Serial Port Names

On a Reticulum node with several serial port based interfaces, it can be beneficial to use the fixed name device nodes for the serial ports, instead of the dynamically allocated shorthands such as `/dev/ttyUSB0`. Under most Debian-based distributions, including Ubuntu and Raspberry Pi OS, these nodes can be found under `/dev/serial/by-id`.

You can use such a device path directly in place of the numbered shorthands. Here is an example of a packet radio TNC configured as such:

```
[[Packet Radio KISS Interface]]
  type = KISSInterface
  interface_enabled = True
  outgoing = true
  port = /dev/serial/by-id/usb-FTDI_FT230X_Basic_UART_43891CKM-if00-port0
  speed = 115200
  databits = 8
  parity = none
  stopbits = 1
  preamble = 150
  txtail = 10
  persistence = 200
  slottime = 20
```

Using this methodology avoids potential naming mix-ups where physical devices might be plugged and unplugged in different orders, or when node name assignment varies from one boot to another.

### 3.2.2 Reticulum as a System Service

Instead of starting Reticulum manually, you can install `rnsd` as a system service and have it start automatically at boot.

If you installed Reticulum with `pip`, the `rnsd` program will most likely be located in a user-local installation path only, which means `systemd` will not be able to execute it. In this case, you can simply symlink the `rnsd` program into a directory that is in systemd's path:

```
sudo ln -s $(which rnsd) /usr/local/bin/
```

You can then create the service file `/etc/systemd/system/rnsd.service` with the following content:

```
[Unit]
Description=Reticulum Network Stack Daemon
After=multi-user.target

[Service]
# If you run Reticulum on WiFi devices,
# or other devices that need some extra
# time to initialise, you might want to
# add a short delay before Reticulum is
# started by systemd:
# ExecStartPre=/bin/sleep 10
Type=simple
Restart=always
RestartSec=3
User=USERNAMEHERE
ExecStart=rnsd --service
```

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

Be sure to replace `USERNAMEHERE` with the user you want to run `rnsd` as.

To manually start `rnsd` run:

```
sudo systemctl start rnsd
```

If you want to automatically start `rnsd` at boot, run:

```
sudo systemctl enable rnsd
```

CHAPTER

FOUR

# BUILDING NETWORKS

This chapter will provide you with the knowledge needed to build networks with Reticulum, which can often be easier than using traditional stacks, since you don't have to worry about coordinating addresses, subnets and routing for an entire network that you might not know how will evolve in the future. With Reticulum, you can simply add more segments to your network when it becomes necesarry, and Reticulum will handle the convergence of the entire network automatically.

## 4.1 Concepts & Overview

There are important points that need to be kept in mind when building networks with Reticulum:

- In a Reticulum network, any node can autonomously generate as many adresses (called *destinations* in Reticulum terminology) as it needs, which become globally reachable to the rest of the network. There is no central point of control over the adress space.
- Reticulum was designed to handle both very small, and very large networks. While the adress space can support billions of endpoints, Reticulum is also very useful when just a few devices needs to communicate.
- Reticulum provides sender/initiator anonymity by default. There is no way to filter traffic or discriminate it based on the source of the traffic.
- All traffic is encrypted using ephemeral keys generated by an Elliptic Curve Diffie-Hellman key exchange on Curve25519. There is no way to inspect traffic contents, and no way to prioritise or throttle certain kinds of traffic. All transport and routing layers are thus completely agnostic to traffic type, and will pass all traffic equally.
- Reticulum can function both with and without infrastructure. When *transport nodes* are available, they can route traffic over multiple hops for other nodes, and will function as a distributed cryptographic keystore. When there is no transport nodes available, all nodes that are within communication range can still communicate.
- Every node can become a transport node, simply by enabling it in it's configuration, but there is no need for every node on the network to be a transport node. Letting every node be a transport node will in most cases degrade the performance and reliability of the network.

  > In general terms, if a node is stationary, well-connected and kept running most of the time, it is a good candidate to be a transport node. For optimal performance, a network should contain the amount of transport nodes that provides connectivity to the intended area / topography, and not many more than that.

Reticulum allows you to mix very different kinds of networking mediums into a unified mesh, or to keep everything within one medium. You could build a "virtual network" running entirely over the Internet, where all nodes communicate over TCP and UDP "channels". You could also build such a network using MQTT or ZeroMQ as the underlying carrier for Reticulum.

However, most real-world networks will probably involve either some form of wireless or direct hardline communications. To allow Reticulum to communicate over any type of medium, you must specify it in the configuration file, by default located at `~/.reticulum/config`. See the *Supported Interfaces* chapter of this manual for interface configuration examples.

Any number of interfaces can be configured, and Reticulum will automatically decide which are suitable to use in any given situation, depending on where traffic needs to flow.

## 4.2 Example Scenarios

This section illustrates a few example scenarios, and how they would, in general terms, be planned, implemented and configured.

### 4.2.1 Interconnected LoRa Sites

An organisation wants to provide communication and information services to it's members, which are located mainly in three separate areas. Three suitable hill-top locations are found, where the organisation can install equipment: Site A, B and C.

Since the amount of data that needs to be exchanged between users is mainly text- based, the bandwidth requirements are low, and LoRa radios are chosen to connect users to the network.

Due to the hill-top locations found, there is radio line-of-sight between site A and B, and also between site B and C. Because of this, the organisation does not need to use the Internet to interconnect the sites, but purchases four Point-to-Point WiFi based radios for interconnecting the sites.

At each site, a Raspberry Pi is installed to function as a gateway. A LoRa radio is connected to the Pi with a USB cable, and the WiFi radio is connected to the ethernet port of the Pi. At site B, two WiFi radios are needed to be able to reach both site A and site C, so an extra ethernet adapter is connected to the Pi in this location.

Once the hardware has been installed, Reticulum is installed on all the Pis, and at site A and C, one interface is added for the LoRa radio, as well as one for the WiFi radio. At site B, an interface for the LoRa radio, and one interface for each WiFi radio is added to the Reticulum configuration file. The transport node option is enabled in the configuration of all three gateways.

The network is now operational, and ready to serve users across all three areas. The organisation prepares a LoRa radio that is supplied to the end users, along with a Reticulum configuration file, that contains the right parameters for communicating with the LoRa radios installed at the gateway sites.

Once users connect to the network, anyone will be able to communicate with anyone else across all three sites.

### 4.2.2 Bridging Over the Internet

As the organisation grows, several new communities form in places too far away from the core network to be reachable over WiFi links. New gateways similar to those previously installed are set up for the new communities at the new sites D and E, but they are islanded from the core network, and only serve the local users.

After investigating the options, it is found that it is possible to install an Internet connection at site A, and an interface on the Internet connection is configured for Reticulum on the Raspberry Pi at site A.

A member of the organisation at site D, named Dori, is willing to help by sharing the Internet connection she already has in her home, and is able to leave a Raspberry Pi running. A new Reticulum interface is configured on her Pi, connecting to the newly enabled Internet interface on the gateway at site A. Dori is now connected to both all the nodes at her own local site (through the hill-top LoRa gateway), and all the combined users of sites A, B and C. She then enables transport on her node, and traffic from site D can now reach everyone at site A, B and C, and vice versa.

### 4.2.3 Growth and Convergence

As the organisation grows, more gateways are added to keep up with the growing user base. Some local gateways even add VHF radios and packet modems to reach outlying users and communities that are out of reach for the LoRa radios and WiFi backhauls.

As more sites, gateways and users are connected, the amount of coordination required is kept to a minimum. If one community wants to add connectivity to the next one over, it can simply be done without having to involve everyone or coordinate address space or routing tables.

With the added geographical coverage, the operators at site A one day find that the original internet bridged interfaces are no longer utilised. The network has converged to be completely self-connected, and the sites that were once poorly connected outliers are now an integral part of the network.

CHAPTER

FIVE

# SUPPORTED INTERFACES

Reticulum supports using many kinds of devices as networking interfaces, and allows you to mix and match them in any way you choose. The number of distinct network topologies you can create with Reticulum is more or less endless, but common to them all is that you will need to define one or more *interfaces* for Reticulum to use.

The following sections describe the interfaces currently available in Reticulum, and gives example configurations for the respective interface types.

For a high-level overview of how networks can be formed over different interface types, have a look at the *Building Networks* chapter of this manual.

## 5.1 Auto Interface

The Auto Interface enables communication with other discoverable Reticulum nodes over autoconfigured IPv6 and UDP. It does not need any functional IP infrastructure like routers or DHCP servers, but will require at least some sort of switching medium between peers (a wired switch, a hub, a WiFi access point or similar), and that link-local IPv6 is enabled in your operating system, which should be enabled by default in almost all OSes.

```
# This example demonstrates a TCP server interface.
# It will listen for incoming connections on the
# specified IP address and port number.

[[Default Interface]]
  type = AutoInterface
  interface_enabled = True

  # You can create multiple isolated Reticulum
  # networks on the same physical LAN by
  # specifying different Group IDs.

  group_id = reticulum

  # You can also select specifically which
  # kernel networking devices to use.

  devices = wlan0,eth1

  # Or let AutoInterface use all suitable
  # devices except for a list of ignored ones.

  ignored_devices = tun0,eth0
```

If you are connected to the Internet with IPv6, and your provider will route IPv6 multicast, you can potentially configure the Auto Interface to globally autodiscover other Reticulum nodes within your selected Group ID. You can specify the discovery scope by setting it to one of `link`, `admin`, `site`, `organisation` or `global`.

```
[[Default Interface]]
  type = AutoInterface
  interface_enabled = True

  # Configure global discovery

  group_id = custom_network_name
  discovery_scope = global

  # Other configuration options

  discovery_port = 48555
  data_port = 49555
```

## 5.2 I2P Interface

The I2P interface lets you connect Reticulum instances over the Invisible Internet Protocol. This can be especially useful in cases where you want to host a globally reachable Reticulum instance, but do not have access to any public IP addresses, have a frequently changing IP address, or have firewalls blocking inbound traffic.

Using the I2P interface, you will get a globally reachable, portable and persistent I2P address that your Reticulum instance can be reached at.

To use the I2P interface, you must have an I2P router running on your system. The easiest way to acheive this is to download and install the latest release of the `i2pd` package. For more details about I2P, see the geti2p.net website.`

When an I2P router is running on your system, you can simply add an I2P interface to reticulum:

```
[[I2P]]
  type = I2PInterface
  interface_enabled = yes
```

On the first start, Reticulum will generate a new I2P address for the interface and start listening for inbound traffic on it. This can take a while the first time, especially if your I2P router was also just started, and is not yet well-connected to the I2P network. When ready, you should see I2P base32 address printed to your log file. You can also inspect the status of the interface using the `rnstatus` utility.

To connect to other Reticulum instances over I2P, just add a comma-separated list of I2P base32 addresses to the `peers` option of the interface:

```
[[I2P]]
  type = I2PInterface
  interface_enabled = yes
  peers = 5urvjicpzi7q3ybztsef4i5ow2aq4soktfj7zedz53s47r54jnqq.b32.i2p
```

It can take anywhere from a few seconds to a few minutes to establish I2P connections to the desired peers, so Reticulum handles the process in the background, and will output relevant events to the log.

**Please Note!** While the I2P interface is the simplest way to use Reticulum over I2P, it is also possible to tunnel the TCP server and client interfaces over I2P manually. This can be useful in situations where more control is needed, but requires manual tunnel setup through the I2P daemon configuration.

It is important to note that the two methods are *interchangably compatible*. You can use the I2PInterface to connect to a TCPServerInterface that was manually tunneled over I2P, for example. This offers a high degree of flexibility in network setup, while retaining ease of use in simpler use-cases.

## 5.3 TCP Server Interface

The TCP Server interface is suitable for allowing other peers to connect over the Internet or private IP networks. When a TCP server interface has been configured, other Reticulum peers can connect to it with a TCP Client interface.

```
# This example demonstrates a TCP server interface.
# It will listen for incoming connections on the
# specified IP address and port number.

[[TCP Server Interface]]
  type = TCPServerInterface
  interface_enabled = True

  # This configuration will listen on all IP
  # interfaces on port 4242

  listen_ip = 0.0.0.0
  listen_port = 4242

  # Alternatively you can bind to a specific IP

  # listen_ip = 10.0.0.88
  # listen_port = 4242

  # Or a specific network device

  # device = eth0
  # port = 4242
```

**Please Note!** The TCP interfaces support tunneling over I2P, but to do so reliably, you must use the i2p_tunneled option:

```
[[TCP Server on I2P]]
    type = TCPServerInterface
    interface_enabled = yes
    listen_ip = 127.0.0.1
    listen_port = 5001
    i2p_tunneled = yes
```

## 5.4 TCP Client Interface

To connect to a TCP server interface, you would naturally use the TCP client interface. Many TCP Client interfaces from different peers can connect to the same TCP Server interface at the same time.

```
# Here's an example of a TCP Client interface. The
# target_host can either be an IP address or a hostname.

[[TCP Client Interface]]
  type = TCPClientInterface
  interface_enabled = True
  target_host = 127.0.0.1
  target_port = 4242
```

It is also possible to use this interface type to connect via other programs or hardware devices that expose a KISS interface on a TCP port, for example software-based soundmodems. To do this, use the `kiss_framing` option:

```
# Here's an example of a TCP Client interface that connects
# to a software TNC soundmodem on a KISS over TCP port.

[[TCP KISS Interface]]
  type = TCPClientInterface
  interface_enabled = True
  kiss_framing = True
  target_host = 127.0.0.1
  target_port = 8001
```

**Caution!** Only use the KISS framing option when connecting to external devices and programs like soundmodems and similar over TCP. When using the `TCPClientInterface` in conjunction with the `TCPServerInterface` you should never enable `kiss_framing`, since this will disable internal reliability and recovery mechanisms that greatly improves performance over unreliable and intermittent TCP links.

**Please Note!** The TCP interfaces support tunneling over I2P, but to do so reliably, you must use the i2p_tunneled option:

```
[[TCP Client over I2P]]
    type = TCPClientInterface
    interface_enabled = yes
    target_host = 127.0.0.1
    target_port = 5001
    i2p_tunneled = yes
```

## 5.5 UDP Interface

A UDP interface can be useful for communicating over IP networks, both private and the internet. It can also allow broadcast communication over IP networks, so it can provide an easy way to enable connectivity with all other peers on a local area network.

*Please Note!* Using broadcast UDP traffic has performance implications, especially on WiFi. If your goal is simply to enable easy communication with all peers in your local ethernet broadcast domain, the *Auto Interface* performs better, and is just as easy to use.

The below example is enabled by default on new Reticulum installations, as it provides an easy way to get started and to test Reticulum on a pre-existing LAN.

```
# This example enables communication with other
# local Reticulum peers over UDP.

[[Default UDP Interface]]
  type = UDPInterface
  interface_enabled = True

  listen_ip = 0.0.0.0
  listen_port = 4242
  forward_ip = 255.255.255.255
  forward_port = 4242

  # The above configuration will allow communication
  # within the local broadcast domains of all local
  # IP interfaces.

  # Instead of specifying listen_ip, listen_port,
  # forward_ip and forward_port, you can also bind
  # to a specific network device like below.

  # device = eth0
  # port = 4242

  # Assuming the eth0 device has the address
  # 10.55.0.72/24, the above configuration would
  # be equivalent to the following manual setup.
  # Note that we are both listening and forwarding to
  # the broadcast address of the network segments.

  # listen_ip = 10.55.0.255
  # listen_port = 4242
  # forward_ip = 10.55.0.255
  # forward_port = 4242

  # You can of course also communicate only with
  # a single IP address

  # listen_ip = 10.55.0.15
  # listen_port = 4242
  # forward_ip = 10.55.0.16
  # forward_port = 4242
```

## 5.6 RNode LoRa Interface

To use Reticulum over LoRa, the RNode interface can be used, and offers full control over LoRa parameters.

```
# Here's an example of how to add a LoRa interface
# using the RNode LoRa transceiver.

[[RNode LoRa Interface]]
  type = RNodeInterface

  # Enable interface if you want use it!
  interface_enabled = True

  # Serial port for the device
  port = /dev/ttyUSB0

  # Set frequency to 867.2 MHz
  frequency = 867200000

  # Set LoRa bandwidth to 125 KHz
  bandwidth = 125000

  # Set TX power to 7 dBm (5 mW)
  txpower = 7

  # Select spreading factor 8. Valid
  # range is 7 through 12, with 7
  # being the fastest and 12 having
  # the longest range.
  spreadingfactor = 8

  # Select coding rate 5. Valid range
  # is 5 throough 8, with 5 being the
  # fastest, and 8 the longest range.
  codingrate = 5

  # You can configure the RNode to send
  # out identification on the channel with
  # a set interval by configuring the
  # following two parameters.
  # id_callsign = MYCALL-0
  # id_interval = 600

  # For certain homebrew RNode interfaces
  # with low amounts of RAM, using packet
  # flow control can be useful. By default
  # it is disabled.
  flow_control = False
```

## 5.7 Serial Interface

Reticulum can be used over serial ports directly, or over any device with a serial port, that will transparently pass data. Useful for communicating directly over a wire-pair, or for using devices such as data radios and lasers.

```
[[Serial Interface]]
  type = SerialInterface
  interface_enabled = True

  # Serial port for the device
  port = /dev/ttyUSB0

  # Set the serial baud-rate and other
  # configuration parameters.
  speed = 115200
  databits = 8
  parity = none
  stopbits = 1
```

## 5.8 KISS Interface

With the KISS interface, you can use Reticulum over a variety of packet radio modems and TNCs, including OpenModem. KISS interfaces can also be configured to periodically send out beacons for station identification purposes.

```
[[Packet Radio KISS Interface]]
  type = KISSInterface
  interface_enabled = True

  # Serial port for the device
  port = /dev/ttyUSB1

  # Set the serial baud-rate and other
  # configuration parameters.
  speed = 115200
  databits = 8
  parity = none
  stopbits = 1

  # Set the modem preamble.
  preamble = 150

  # Set the modem TX tail.
  txtail = 10

  # Configure CDMA parameters. These
  # settings are reasonable defaults.
  persistence = 200
  slottime = 20

  # You can configure the interface to send
  # out identification on the channel with
```

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```
  # a set interval by configuring the
  # following two parameters. The KISS
  # interface will only ID if the set
  # interval has elapsed since it's last
  # actual transmission. The interval is
  # configured in seconds.
  # This option is commented out and not
  # used by default.
  # id_callsign = MYCALL-0
  # id_interval = 600

  # Whether to use KISS flow-control.
  # This is useful for modems that have
  # a small internal packet buffer, but
  # support packet flow control instead.
  flow_control = false
```

## 5.9 AX.25 KISS Interface

If you're using Reticulum on amateur radio spectrum, you might want to use the AX.25 KISS interface. This way, Reticulum will automatically encapsulate it's traffic in AX.25 and also identify your stations transmissions with your callsign and SSID.

Only do this if you really need to! Reticulum doesn't need the AX.25 layer for anything, and it incurs extra overhead on every packet to encapsulate in AX.25.

A more efficient way is to use the plain KISS interface with the beaconing functionality described above.

```
[[Packet Radio AX.25 KISS Interface]]
  type = AX25KISSInterface

  # Set the station callsign and SSID
  callsign = NO1CLL
  ssid = 0

  # Enable interface if you want use it!
  interface_enabled = True

  # Serial port for the device
  port = /dev/ttyUSB2

  # Set the serial baud-rate and other
  # configuration parameters.
  speed = 115200
  databits = 8
  parity = none
  stopbits = 1

  # Set the modem preamble. A 150ms
  # preamble should be a reasonable
  # default, but may need to be
```

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```
  # increased for radios with slow-
  # opening squelch and long TX/RX
  # turnaround
  preamble = 150

  # Set the modem TX tail. In most
  # cases this should be kept as low
  # as possible to not waste airtime.
  txtail = 10

  # Configure CDMA parameters. These
  # settings are reasonable defaults.
  persistence = 200
  slottime = 20

  # Whether to use KISS flow-control.
  # This is useful for modems with a
  # small internal packet buffer.
  flow_control = false
```

## 5.10 Common Interface Options

A number of general options can be used to control various aspects of interface behaviour.

The `interface_enabled` option tells Reticulum whether or not to bring up the interface. Defaults to `False`. For any interface to be brought up, the `interface_enabled` option must be set to `True` or `Yes`.

The `outgoing` option sets whether an interface is allowed to transmit. Defaults to `True`. If set to `False` the interface will only receive data, and never transmit.

The `interface_mode` option allows selecting the high-level behaviour of the interface from a number of options.

- The default value is `full`. In this mode, all discovery, meshing and transpor functionality is available.
- In the `access_point` (or shorthand `ap`) mode, the interface will operate as a network access point. In this mode, announces will not be automatically broadcasted on the interface, and paths to destinations on the interface will have a much shorter expiry time. This mode is useful for creating interfaces that are mostly quiet, unless when someone is actually using them. An example of this could be a radio interface serving a wide area, where users are expected to connect momentarily, use the network, and then disappear again.

CHAPTER

SIX

# UNDERSTANDING RETICULUM

This chapter will briefly describe the overall purpose and operating principles of Reticulum, a networking stack designed for reliable and secure communication over high-latency, low-bandwidth links. It should give you an overview of how the stack works, and an understanding of how to develop networked applications using Reticulum.

This document is not an exhaustive source of information on Reticulum, at least not yet. Currently, the best place to go for such information is the Python reference implementation of Reticulum, along with the code examples and API reference. It is however an essential resource to understanding the general principles of Reticulum, how to apply them when creating your own networks or software.

After reading this document, you should be well-equipped to understand how a Reticulum network operates, what it can achieve, and how you can use it yourself. If you want to help out with the development, this is also the place to start, since it will provide a pretty clear overview of the sentiments and the philosophy behind Reticulum.

## 6.1 Motivation

The primary motivation for designing and implementing Reticulum has been the current lack of reliable, functional and secure minimal-infrastructure modes of digital communication. It is my belief that it is highly desirable to create a cheap and reliable way to set up a wide-range digital communication network that can securely allow exchange of information between people and machines, with no central point of authority, control, censorship or barrier to entry.

Almost all of the various networking systems in use today share a common limitation, namely that they require large amounts of coordination and trust to work, and to join the networks you need approval of gatekeepers in control. This need for coordination and trust inevitably leads to an environment of central control, where it's very easy for infrastructure operators or governments to control or alter traffic, and censor or persecute unwanted actors.

Reticulum aims to require as little coordination and trust as possible. In fact, the only "coordination" required is to know the characteristics of physical medium carrying Reticulum traffic.

Since Reticulum is completely medium agnostic, this could be whatever is best suited to the situation. In some cases, this might be 1200 baud packet radio links over VHF frequencies, in other cases it might be a microwave network using off-the-shelf radios. At the time of release of this document, the recommended setup for development and testing is using LoRa radio modules with an open source firmware (see the section *Reference System Setup*), connected to a small computer like a Raspberry Pi. As an example, the default reference setup provides a channel capacity of 5.4 Kbps, and a usable direct node-to-node range of around 15 kilometers (indefinitely extendable by using multiple hops).

## 6.2 Goals

To be as widely usable and easy to use as possible, the following goals have been used to guide the design of Reticulum:

- **Fully useable as open source software stack** Reticulum must be implemented with, and be able to run using only open source software. This is critical to ensuring the availability, security and transparency of the system.
- **Hardware layer agnosticism** Reticulum shall be fully hardware agnostic, and shall be useable over a wide range physical networking layers, such as data radios, serial lines, modems, handheld transceivers, wired ethernet, wifi, or anything else that can carry a digital data stream. Hardware made for dedicated Reticulum use shall be as cheap as possible and use off-the-shelf components, so it can be easily replicated.
- **Very low bandwidth requirements** Reticulum should be able to function reliably over links with a transmission capacity as low as *500 bps*.
- **Encryption by default** Reticulum must use strong encryption by default for all communication.
- **Initiator Anonymity** It must be possible to communicate over a Reticulum network without revealing any identifying information about oneself.
- **Unlicensed use** Reticulum shall be functional over physical communication mediums that do not require any form of license to use. Reticulum must be designed in a way, so it is usable over ISM radio frequency bands, and can provide functional long distance links in such conditions, for example by connecting a modem to a PMR or CB radio, or by using LoRa or WiFi modules.
- **Supplied software** Apart from the core networking stack and API, that allows a developer to build applications with Reticulum, a basic communication suite using Reticulum must be implemented and released at the same time as Reticulum itself. This shall serve both as a functional communication suite, and as an example and learning resource to others wishing to build applications with Reticulum.
- **Ease of use** The reference implementation of Reticulum is written in Python, to make it easy to use and understand. A programmer with only basic experience should be able to use Reticulum in their own applications.
- **Low cost** It shall be as cheap as possible to deploy a communication system based on Reticulum. This should be achieved by using cheap off-the-shelf hardware that potential users might already own. The cost of setting up a functioning node should be less than $100 even if all parts needs to be purchased.

## 6.3 Introduction & Basic Functionality

Reticulum is a networking stack suited for high-latency, low-bandwidth links. Reticulum is at it's core a *message oriented* system. It is suited for both local point-to-point or point-to-multipoint scenarios where alle nodes are within range of each other, as well as scenarios where packets need to be transported over multiple hops in a complex network to reach the recipient.

Reticulum does away with the idea of addresses and ports known from IP, TCP and UDP. Instead Reticulum uses the singular concept of *destinations*. Any application using Reticulum as it's networking stack will need to create one or more destinations to receive data, and know the destinations it needs to send data to.

All destinations in Reticulum are represented internally as 10 bytes, derived from truncating a full SHA-256 hash of identifying characteristics of the destination. To users, the destination addresses will be displayed as 10 bytes in hexadecimal representation, as in the following example: `<80e29bf7cccaf31431b3>`.

By default Reticulum encrypts all data using elliptic curve cryptography. Any packet sent to a destination is encrypted with a derived ephemeral key. Reticulum can also set up an encrypted channel to a destination with *Forward Secrecy* and *Initiator Anonymity* using a elliptic curve cryptography and ephemeral keys derived from a Diffie Hellman exchange on Curve25519. In Reticulum terminology, this is called a *Link*.

Reticulum also offers symmetric key encryption for group-oriented communications, as well as unencrypted packets for broadcast purposes, or situations where you need the communication to be in plain text. The multi-hop transport, coordination, verification and reliability layers are fully autonomous and based on public key cryptography.

Reticulum can connect to a variety of interfaces such as radio modems, data radios and serial ports, and offers the possibility to easily tunnel Reticulum traffic over IP links such as the Internet or private IP networks.

### 6.3.1 Destinations

To receive and send data with the Reticulum stack, an application needs to create one or more destinations. Reticulum uses three different basic destination types, and one special:

- **Single** The *single* destination type is always identified by a unique public key. Any data sent to this destination will be encrypted using ephemeral keys derived from an ECDH key exchange, and will only be readable by the creator of the destination, who holds the corresponding private key.
- **Group** The *group* destination type defines a symmetrically encrypted destination. Data sent to this destination will be encrypted with a symmetric key, and will be readable by anyone in possession of the key.
- **Plain** A *plain* destination type is unencrypted, and suited for traffic that should be broadcast to a number of users, or should be readable by anyone. Traffic to a *plain* destination is not encrypted. Generally, *plain* destinations can be used for broadcast information intended to be public.
- **Link** A *link* is a special destination type, that serves as an abstract channel to a *single* destination, directly connected or over multiple hops. The *link* also offers reliability and more efficient encryption, forward secrecy, initiator anonymity, and as such can be useful even when a node is directly reachable.

#### Destination Naming

Destinations are created and named in an easy to understand dotted notation of *aspects*, and represented on the network as a hash of this value. The hash is a SHA-256 truncated to 80 bits. The top level aspect should always be a unique identifier for the application using the destination. The next levels of aspects can be defined in any way by the creator of the application.

Aspects can be as long and as plentiful as required, and a resulting long destination name will not impact efficiency, as names are always represented as truncated SHA-256 hashes on the network.

As an example, a destination for a environmental monitoring application could be made up of the application name, a device type and measurement type, like this:

```
app name  : environmentlogger
aspects   : remotesensor, temperature

full name : environmentlogger.remotesensor.temperature
hash      : fa7ddfab5213f916dea
```

For the *single* destination, Reticulum will automatically append the associated public key as a destination aspect before hashing. This is done to ensure only the correct destination is reached, since anyone can listen to any destination name. Appending the public key ensures that a given packet is only directed at the destination that holds the corresponding private key to decrypt the packet.

**Take note!** There is a very important concept to understand here:

- Anyone can use the destination name `environmentlogger.remotesensor.temperature`
- Each destination that does so will still have a unique destination hash, and thus be uniquely addressable, because their public keys will differ.

In actual use of *single* destination naming, it is advisable not to use any uniquely identifying features in aspect naming. Aspect names should be general terms describing what kind of destination is represented. The uniquely identifying aspect is always acheived by the appending the public key, which expands the destination into a uniquely identifyable one.

Any destination on a Reticulum network can be addressed and reached simply by knowning its destination hash (and public key, but if the public key is not known, it can be requested from the network simply by knowing the destination hash). The use of app names and aspects makes it easy to structure Reticulum programs and makes it possible to filter what information and data your program receives.

To recap, the different destination types should be used in the following situations:

- **Single** When private communication between two endpoints is needed. Supports multiple hops.
- **Group** When private communication between two or more endpoints is needed. Supports multiple hops indirectly, but must first be established through a *single* destination.
- **Plain** When plain-text communication is desirable, for example when broadcasting information.

To communicate with a *single* destination, you need to know it's public key. Any method for obtaining the public key is valid, but Reticulum includes a simple mechanism for making other nodes aware of your destinations public key, called the *announce*. It is also possible to request an unknown public key from the network, as all participating nodes serve as a distributed ledger of public keys.

Note that public key information can be shared and verified in many other ways than using the built-in *announce* functionality, and that it is therefore not required to use the announce/request functionality to obtain public keys. It is by far the easiest though, and should definitely be used if there is not a good reason for doing it differently.

### 6.3.2 Public Key Announcements

An *announce* will send a special packet over any configured interfaces, containing all needed information about the destination hash and public key, and can also contain some additional, application specific data. The entire packet is signed by the sender to ensure authenticity. It is not required to use the announce functionality, but in many cases it will be the simplest way to share public keys on the network. As an example, an announce in a simple messenger application might contain the following information:

- The announcers destination hash
- The announcers public key
- Application specific data, in this case the users nickname and availability status
- A random blob, making each new announce unique
- An Ed25519 signature of the above information, verifying authenticity

With this information, any Reticulum node that receives it will be able to reconstruct an outgoing destination to securely communicate with that destination. You might have noticed that there is one piece of information lacking to reconstruct full knowledge of the announced destination, and that is the aspect names of the destination. These are intentionally left out to save bandwidth, since they will be implicit in almost all cases. If a destination name is not entirely implicit, information can be included in the application specific data part that will allow the receiver to infer the naming.

It is important to note that announces will be forwarded throughout the network according to a certain pattern. This will be detailed in the section *The Announce Mechanism in Detail*.

Seeing how *single* destinations are always tied to a private/public key pair leads us to the next topic.

### 6.3.3 Identities

In Reticulum, an *identity* does not necessarily represent a personal identity, but is an abstraction that can represent any kind of *verified entity*. This could very well be a person, but it could also be the control interface of a machine, a program, robot, computer, sensor or something else entirely. In general, any kind of agent that can act, or be acted upon, or store or manipulate information, can be represented as an identity.

As we have seen, a *single* destination will always have an *identity* tied to it, but not *plain* or *group* destinations. Destinations and identities share a multilateral connection. You can create a destination, and if it is not connected to an identity upon creation, it will just create a new one to use automatically. This may be desirable in some situations, but often you will probably want to create the identity first, and then link it to created destinations.

Building upon the simple messenger example, we could use an identity to represent the user of the application. Destinations created will then be linked to this identity to allow communication to reach the user. In all cases it is of great importance to store the private keys associated with any Reticulum Identity securely and privately.

### 6.3.4 Getting Further

The above functions and principles form the core of Reticulum, and would suffice to create functional networked applications in local clusters, for example over radio links where all interested nodes can directly hear each other. But to be truly useful, we need a way to direct traffic over multiple hops in the network.

In the following sections, two concepts that allow this will be introduced, *paths* and *links*.

## 6.4 Reticulum Transport

The term routing has been purposefully avoided until now. The current methods of routing used in IP-based networks are fundamentally incompatible with the physical link types that Reticulum was designed to handle. These routing methodologies assume trust at the physical layer, and often needs a lot more bandwidth than Reticulum can assume is available.

Since Reticulum is designed to run over open radio spectrum, no such trust exists, and bandwidth is often very limited. Existing routing protocols like BGP or OSPF carry too much overhead to be practically useable over bandwidth-limited, high-latency links.

To overcome such challenges, Reticulum's *Transport* system uses public-key cryptography to implement the concept of *paths* that allow discovery of how to get information to a certain destination. It is important to note that no single node in a Reticulum network knows the complete path to a destination. Every Transport node participating in a Reticulum network will only know what the most direct way to get a packet one hop closer to it's destination is.

### 6.4.1 The Announce Mechanism in Detail

When an *announce* is transmitted by a node, it will be forwarded by any node receiving it, but according to some specific rules:

- If this exact announce has already been received before, ignore it.
- If not, record into a table which node the announce was received from, and how many times in total it has been retransmitted to get here.
- If the announce has been retransmitted *m+1* times, it will not be forwarded. By default, *m* is set to 18.
- The announce will be assigned a delay $d = c^h$ seconds, where $c$ is a decay constant, and $h$ is the amount of times this packet has already been forwarded.

- The packet will be given a priority $p = 1/d$.
- If at least $d$ seconds has passed since the announce was received, and no other packets with a priority higher than $p$ are waiting in the queue (see Packet Prioritisation), and the channel is not utilized by other traffic, the announce will be forwarded.
- If no other nodes are heard retransmitting the announce with a greater hop count than when it left this node, transmitting it will be retried $r$ times. By default, $r$ is set to 1. Retries follow same rules as above, with the exception that it must wait for at least $d = c^{h+1} + t + \text{rand}(0, rw)$ seconds. This amount of time is equal to the amount of time it would take the next node to retransmit the packet, plus a random window. By default, $t$ is set to 10 seconds, and the random window $rw$ is set to 10 seconds.
- If a newer announce from the same destination arrives, while an identical one is already in the queue, the newest announce is discarded. If the newest announce contains different application specific data, it will replace the old announce, but will use $d$ and $p$ of the old announce.

Once an announce has reached a node in the network, any other node in direct contact with that node will be able to reach the destination the announce originated from, simply by sending a packet addressed to that destination. Any node with knowledge of the announce will be able to direct the packet towards the destination by looking up the next node with the shortest amount of hops to the destination.

According to these rules and default constants, an announce will propagate throughout the network in a predictable way. In an example network utilising the default constants, and with an average link distance of $Lavg = 15$ kilometers, an announce will be able to propagate outwards to a radius of 180 kilometers in 34 minutes, and a *maximum announce radius* of 270 kilometers in approximately 3 days.

### 6.4.2 Reaching the Destination

In networks with changing topology and trustless connectivity, nodes need a way to establish *verified connectivity* with each other. Since the network is assumed to be trustless, Reticulum must provide a way to guarantee that the peer you are communicating with is actually who you expect. Reticulum offers two ways to do this.

For exchanges of small amounts of information, Reticulum offers the *Packet* API, which works exactly like you would expect - on a per packet level. The following process is employed when sending a packet:

- A packet is always created with an associated destination and some payload data. When the packet is sent to a *single* destination type, Reticulum will automatically create an ephemeral encryption key, perform an ECDH key exchange with the destinations public key, and encrypt the information.
- It is important to note that this key exchange does not require any network traffic. The sender already knows the public key of the destination from an earlier received *announce*, and can thus perform the ECDH key exchange locally, before sending the packet.
- The public part of the newly generated ephemeral key-pair is included with the encrypted token, and sent along with the encrypted payload data in the packet.
- When the destination receives the packet, it can itself perform an ECDH key exchange and decrypt the packet.
- A new ephemeral key is used for every packet sent in this way, and forward secrecy is guaranteed on a per packet level.
- Once the packet has been received and decrypted by the addressed destination, that destination can opt to *prove* its receipt of the packet. It does this by calculating the SHA-256 hash of the received packet, and signing this hash with it's Ed25519 signing key. Transport nodes in the network can then direct this *proof* back to the packets origin, where the signature can be verified against the destinations known public signing key.
- In case the packet is addressed to a *group* destination type, the packet will be encrypted with the pre-shared AES-128 key associated with the destination. In case the packet is addressed to a *plain* destination type, the payload data will not be encrypted. Neither of these two destination types offer forward secrecy. In general, it is recommended to always use the *single* destination type, unless it is strictly necessary to use one of the others.

For exchanges of larger amounts of data, or when longer sessions of bidirectional communication is desired, Reticulum offers the *Link* API. To establish a *link*, the following process is employed:

- First, the node that wishes to establish a link will send out a special packet, that traverses the network and locates the desired destination. Along the way, the nodes that forward the packet will take note of this *link request*.
- Second, if the destination accepts the *link request* , it will send back a packet that proves the authenticity of it's identity (and the receipt of the link request) to the initiating node. All nodes that initially forwarded the packet will also be able to verify this proof, and thus accept the validity of the *link* throughout the network.
- When the validity of the *link* has been accepted by forwarding nodes, these nodes will remember the *link* , and it can subsequently be used by referring to a hash representing it.
- As a part of the *link request* , a Diffie-Hellman key exchange takes place, that sets up an efficiently encrypted tunnel between the two nodes, using elliptic curve cryptography. As such, this mode of communication is preferred, even for situations when nodes can directly communicate, when the amount of data to be exchanged numbers in the tens of packets.
- When a *link* has been set up, it automatically provides message receipt functionality, through the same *proof* mechanism discussed before, so the sending node can obtain verified confirmation that the information reached the intended recipient.

In a moment, we will discuss the details of how this methodology is implemented, but let's first recap what purposes this methodology serves. We first ensure that the node answering our request is actually the one we want to communicate with, and not a malicious actor pretending to be so. At the same time we establish an efficient encrypted channel. The setup of this is relatively cheap in terms of bandwidth, so it can be used just for a short exchange, and then recreated as needed, which will also rotate encryption keys. The link can also be kept alive for longer periods of time, if this is more suitable to the application. The procedure also inserts the *link id* , a hash calculated from the link request packet, into the memory of forwarding nodes, which means that the communicating nodes can thereafter reach each other simply by referring to this *link id*.

The combined bandwidth cost of setting up a link is 3 packets totalling 237 bytes (more info in the *Binary Packet Format* section). The amount of bandwidth used on keeping a link open is practically negligible, at 0.62 bits per second. Even on a slow 1200 bits per second packet radio channel, 100 concurrent links will still leave 95% channel capacity for actual data.

### Link Establishment in Detail

After exploring the basics of the announce mechanism, finding a path through the network, and an overview of the link establishment procedure, this section will go into greater detail about the Reticulum link establishment process.

The *link* in Reticulum terminology should not be viewed as a direct node-to-node link on the physical layer, but as an abstract channel, that can be open for any amount of time, and can span an arbitrary number of hops, where information will be exchanged between two nodes.

- When a node in the network wants to establish verified connectivity with another node, it will randomly generate a new X25519 private/public key pair. It then creates a *link request* packet, and broadcast it.

  *It should be noted that the X25519 public/private keypair mentioned above is two separate keypairs: An encryption key pair, used for derivation of a shared symmetric key, and a signing key pair, used for signing and verifying messages on the link. They are sent together over the wire, and can be considered as single public key for simplicity in this explanation.*

- The *link request* is addressed to the destination hash of the desired destination, and contains the following data: The newly generated X25519 public key *LKi*.
- The broadcasted packet will be directed through the network according to the rules laid out previously.

- Any node that forwards the link request will store a *link id* in it's *link table* , along with the amount of hops the packet had taken when received. The link id is a hash of the entire link request packet. If the link request packet is not *proven* by the addressed destination within some set amount of time, the entry will be dropped from the *link table* again.
- When the destination receives the link request packet, it will decide whether to accept the request. If it is accepted, the destination will also generate a new X25519 private/public key pair, and perform a Diffie Hellman Key Exchange, deriving a new symmetric key that will be used to encrypt the channel, once it has been established.
- A *link proof* packet is now constructed and transmitted over the network. This packet is addressed to the *link id* of the *link*. It contains the following data: The newly generated X25519 public key *LKr* and an Ed25519 signature of the *link id* and *LKr* made by the signing key of the addressed destination.
- By verifying this *link proof* packet, all nodes that originally transported the *link request* packet to the destination from the originator can now verify that the intended destination received the request and accepted it, and that the path they chose for forwarding the request was valid. In sucessfully carrying out this verification, the transporting nodes marks the link as active. An abstract bi-directional communication channel has now been established along a path in the network.
- When the source receives the *proof* , it will know unequivocally that a verified path has been established to the destination. It can now also use the X25519 public key contained in the *link proof* to perform it's own Diffie Hellman Key Exchange and derive the symmetric key that is used to encrypt the channel. Information can now be exchanged reliably and securely.

It's important to note that this methodology ensures that the source of the request does not need to reveal any identifying information about itself. The link initiator remains completely anonymous.

When using *links*, Reticulum will automatically verify all data sent over the link, and can also automate retransmissions if *Resources* are used.

### 6.4.3 Resources

For exchanging small amounts of data over a Reticulum network, the *Packet* interface is sufficient, but for exchanging data that would require many packets, an efficient way to coordinate the transfer is needed.

This is the purpose of the Reticulum *Resource*. A *Resource* can automatically handle the reliable transfer of an arbitrary amount of data over an established *Link*. Resources can auto-compress data, will handle breaking the data into individual packets, sequencing the transfer, integrity verification and reassembling the data on the other end.

*Resources* are programmatically very simple to use, and only requires a few lines of codes to reliably transfer any amount of data. They can be used to transfer data stored in memory, or stream data directly from files.

## 6.5 Reference System Setup

This section will detail the recommended *Reference System Setup* for Reticulum. It is important to note that Reticulum is designed to be usable over more or less any medium that allows you to send and receive data in a digital form, and satisfies some very low minimum requirements. The communication channel must support at least half-duplex operation, and provide an average throughput of around 1000 bits per second, and supports a physical layer MTU of 500 bytes. The Reticulum software should be able to run on more or less any hardware that can provide a Python 3.x runtime environment.

That being said, the reference setup has been outlined to provide a common platform for anyone who wants to help in the development of Reticulum, and for everyone who wants to know a recommended setup to get started. A reference system consists of three parts:

- **A channel access device** Or *CAD* , in short, provides access to the physical medium whereupon the communication takes place, for example a radio with an integrated modem. A setup with a separate modem connected to a radio would also be termed a "channel access device".
- **A host device** Some sort of computing device that can run the necessary software, communicates with the channel access device, and provides user interaction.
- **A software stack** The software implementing the Reticulum protocol and applications using it.

The reference setup can be considered a relatively stable platform to develop on, and also to start building networks on. While details of the implementation might change at the current stage of development, it is the goal to maintain hardware compatibility for as long as entirely possible, and the current reference setup has been determined to provide a functional platform for many years into the future. The current Reference System Setup is as follows:

- **Channel Access Device** A data radio consisting of a LoRa radio module, and a microcontroller with open source firmware, that can connect to host devices via USB. It operates in either the 430, 868 or 900 MHz frequency bands. More details can be found on the RNode Page.
- **Host device** Any computer device running Linux and Python. A Raspberry Pi with a Debian based OS is recommended.
- **Software stack** The current Reference Implementation Release of Reticulum, running on a Debian based operating system.

It is very important to note, that the reference channel access device **does not** use the LoRaWAN standard, but uses a custom MAC layer on top of the plain LoRa modulation! As such, you will need a plain LoRa radio module connected to an MCU with the correct firmware. Full details on how to get or make such a device is available on the RNode Page.

With the current reference setup, it should be possible to get on a Reticulum network for around 100$ even if you have none of the hardware already, and need to purchase everything.

## 6.6 Protocol Specifics

This chapter will detail protocol specific information that is essential to the implementation of Reticulum, but non critical in understanding how the protocol works on a general level. It should be treated more as a reference than as essential reading.

### 6.6.1 Node Types

Currently Reticulum defines two node types, the *Station* and the *Peer*. A node is a *station* if it fixed in one place, and if it is intended to be kept online most of the time. Otherwise the node is a *peer*.

This distinction is made by the user configuring the node, and is used to determine what nodes on the network will help forward traffic, and what nodes rely on other nodes for connectivity.

If a node is a *Peer* it should be given the configuration directive `enable_transport = No`.

If it is a *Station*, it should be given the configuration directive `enable_transport = Yes`.

### 6.6.2 Packet Prioritisation

Currently, Reticulum is completely priority-agnostic regarding general traffic. All traffic is handled on a first-come, first-serve basis. Announce re-transmission are handled according to the re-transmission times and priorities described earlier in this chapter.

### 6.6.3 Binary Packet Format

```
== Reticulum Wire Format ======

A Reticulum packet is composed of the following fields:

[HEADER 2 bytes] [ADDRESSES 10/20 bytes] [CONTEXT 1 byte] [DATA 0-477 bytes]

* The HEADER field is 2 bytes long.
  * Byte 1: [Header Type], [Propagation Type], [Destination Type] and [Packet Type]
  * Byte 2: Number of hops

* The ADDRESSES field contains either 1 or 2 addresses.
  * Each address is 10 bytes long.
  * The Header Type flag in the HEADER field determines
    whether the ADDRESSES field contains 1 or 2 addresses.
  * Addresses are Reticulum hashes truncated to 10 bytes.

* The CONTEXT field is 1 byte.
  * It is used by Reticulum to determine packet context.

* The DATA field is between 0 and 477 bytes.
  * It contains the packets data payload.

Header Types
-----------------
type 1          00  Two byte header, one 10 byte address field
type 2          01  Two byte header, two 10 byte address fields
type 3          10  Reserved
type 4          11  Reserved


Propagation Types
-----------------
broadcast       00
transport       01
reserved        10
reserved        11


Destination Types
-----------------
single          00
group           01
plain           10
link            11
```

(continues on next page)

(continued from previous page)

```
Packet Types
-----------------
data            00
announce        01
link request    10
proof           11


+- Packet Example -+

   HEADER FIELD             ADDRESSES FIELD             CONTEXT FIELD  DATA FIELD
 ________|________   ___________________|___________________   _________|_______   __|_
|                 | |                                     | |                 | |    |
01010000 00000100 [ADDR1, 10 bytes] [ADDR2, 10 bytes] [CONTEXT, 1 byte] [DATA]
 | | | |    |
 | | | |    +-- Hops             = 4
 | | | +------- Packet Type      = DATA
 | | +--------- Destination Type = SINGLE
 | +----------- Propagation Type = TRANSPORT
 +------------- Header Type      = HEADER_2 (two byte header, two address fields)


 +- Packet Example -+

   HEADER FIELD    ADDRESSES FIELD    CONTEXT FIELD  DATA FIELD
 ________|________   ________|________   _________|_______   __|_
|                 | |                 | |                 | |    |
00000000 00000111 [ADDR1, 10 bytes] [CONTEXT, 1 byte] [DATA]
 | | | |    |
 | | | |    +-- Hops             = 7
 | | | +------- Packet Type      = DATA
 | | +--------- Destination Type = SINGLE
 | +----------- Propagation Type = BROADCAST
 +------------- Header Type      = HEADER_1 (two byte header, one address field)


 Size examples of different packet types
 ---------------------------------------

 The following table lists example sizes of various
 packet types. The size listed are the complete on-
 wire size including all fields.

 - Path Request    :    33  bytes
 - Announce        :    151 bytes
 - Link Request    :    77  bytes
 - Link Proof      :    77  bytes
 - Link RTT packet :    83  bytes
 - Link keepalive  :    14  bytes
```

CHAPTER

SEVEN

# API REFERENCE

This reference guide lists and explains all classes exposed by the RNS API.

## 7.1 Classes

Communication over a Reticulum network is achieved using a set of classes exposed by RNS.

### 7.1.1 Reticulum

**class** RNS.**Reticulum**(*configdir=None*, *loglevel=None*)

This class is used to initialise access to Reticulum within a program. You must create exactly one instance of this class before carrying out any other RNS operations, such as creating destinations or sending traffic. Every independently executed program must create their own instance of the Reticulum class, but Reticulum will automatically handle inter-program communication on the same system, and expose all connected programs to external interfaces as well.

As soon as an instance of this class is created, Reticulum will start opening and configuring any hardware devices specified in the supplied configuration.

Currently the first running instance must be kept running while other local instances are connected, as the first created instance will act as a master instance that directly communicates with external hardware such as modems, TNCs and radios. If a master instance is asked to exit, it will not exit until all client processes have terminated (unless killed forcibly).

If you are running Reticulum on a system with several different programs that use RNS starting and terminating at different times, it will be advantageous to run a master RNS instance as a daemon for other programs to use on demand.

**MTU = 500**

The MTU that Reticulum adheres to, and will expect other peers to adhere to. By default, the MTU is 500 bytes. In custom RNS network implementations, it is possible to change this value, but doing so will completely break compatibility with all other RNS networks. An identical MTU is a prerequisite for peers to communicate in the same network.

Unless you really know what you are doing, the MTU should be left at the default value.

**static should_use_implicit_proof**()

Returns whether proofs sent are explicit or implicit.

**Returns** True if the current running configuration specifies to use implicit proofs. False if not.

**static transport_enabled**()

Returns whether Transport is enabled for the running instance.

When Transport is enabled, Reticulum will route traffic for other peers, respond to path requests and pass announces over the network.

**Returns** True if Transport is enabled, False if not.

### 7.1.2 Identity

**class** RNS.**Identity**(*create_keys=True*)

This class is used to manage identities in Reticulum. It provides methods for encryption, decryption, signatures and verification, and is the basis for all encrypted communication over Reticulum networks.

**Parameters** **create_keys** – Specifies whether new encryption and signing keys should be generated.

**CURVE = 'Curve25519'**

The curve used for Elliptic Curve DH key exchanges

**KEYSIZE = 512**

X25519 key size in bits. A complete key is the concatenation of a 256 bit encryption key, and a 256 bit signing key.

**TRUNCATED_HASHLENGTH = 80**

Constant specifying the truncated hash length (in bits) used by Reticulum for addressable hashes and other purposes. Non-configurable.

**static recall**(*destination_hash*)

Recall identity for a destination hash.

**Parameters** **destination_hash** – Destination hash as *bytes*.

**Returns** An *RNS.Identity* instance that can be used to create an outgoing *RNS.Destination*, or *None* if the destination is unknown.

**static recall_app_data**(*destination_hash*)

Recall last heard app_data for a destination hash.

**Parameters** **destination_hash** – Destination hash as *bytes*.

**Returns** *Bytes* containing app_data, or *None* if the destination is unknown.

**static full_hash**(*data*)

Get a SHA-256 hash of passed data.

**Parameters** **data** – Data to be hashed as *bytes*.

**Returns** SHA-256 hash as *bytes*

**static truncated_hash**(*data*)

Get a truncated SHA-256 hash of passed data.

**Parameters** **data** – Data to be hashed as *bytes*.

**Returns** Truncated SHA-256 hash as *bytes*

**static get_random_hash**()

Get a random SHA-256 hash.

**Parameters** **data** – Data to be hashed as *bytes*.

**Returns** Truncated SHA-256 hash of random data as *bytes*

**static from_bytes**(*prv_bytes*)
Create a new *RNS.Identity* instance from *bytes* of private key. Can be used to load previously created and saved identities into Reticulum.

**Parameters** **prv_bytes** – The *bytes* of private a saved private key. **HAZARD!** Never use this to generate a new key by feeding random data in prv_bytes.

**Returns** A *RNS.Identity* instance, or *None* if the *bytes* data was invalid.

**static from_file**(*path*)
Create a new *RNS.Identity* instance from a file. Can be used to load previously created and saved identities into Reticulum.

**Parameters** **path** – The full path to the saved *RNS.Identity* data

**Returns** A *RNS.Identity* instance, or *None* if the loaded data was invalid.

**to_file**(*path*)
Saves the identity to a file. This will write the private key to disk, and anyone with access to this file will be able to decrypt all communication for the identity. Be very careful with this method.

**Parameters** **path** – The full path specifying where to save the identity.

**Returns** True if the file was saved, otherwise False.

**get_private_key**()

**Returns** The private key as *bytes*

**get_public_key**()

**Returns** The public key as *bytes*

**load_private_key**(*prv_bytes*)
Load a private key into the instance.

**Parameters** **prv_bytes** – The private key as *bytes*.

**Returns** True if the key was loaded, otherwise False.

**load_public_key**(*pub_bytes*)
Load a public key into the instance.

**Parameters** **pub_bytes** – The public key as *bytes*.

**Returns** True if the key was loaded, otherwise False.

**encrypt**(*plaintext*)
Encrypts information for the identity.

**Parameters** **plaintext** – The plaintext to be encrypted as *bytes*.

**Returns** Ciphertext token as *bytes*.

**Raises** *KeyError* if the instance does not hold a public key.

**decrypt**(*ciphertext_token*)
Decrypts information for the identity.

**Parameters** **ciphertext** – The ciphertext to be decrypted as *bytes*.

**Returns** Plaintext as *bytes*, or *None* if decryption fails.

**Raises** *KeyError* if the instance does not hold a private key.

**sign**(*message*)
Signs information by the identity.

**Parameters** **message** – The message to be signed as *bytes*.

**Returns** Signature as *bytes*.

**Raises** *KeyError* if the instance does not hold a private key.

**validate**(*signature*, *message*)
Validates the signature of a signed message.

**Parameters**

- **signature** – The signature to be validated as *bytes*.
- **message** – The message to be validated as *bytes*.

**Returns** True if the signature is valid, otherwise False.

**Raises** *KeyError* if the instance does not hold a public key.

### 7.1.3 Destination

**class** RNS.**Destination**(*identity*, *direction*, *type*, *app_name*, **aspects*)
A class used to describe endpoints in a Reticulum Network. Destination instances are used both to create outgoing and incoming endpoints. The destination type will decide if encryption, and what type, is used in communication with the endpoint. A destination can also announce its presence on the network, which will also distribute necessary keys for encrypted communication with it.

**Parameters**

- **identity** – An instance of *RNS.Identity*. Can hold only public keys for an outgoing destination, or holding private keys for an ingoing.
- **direction** – RNS.Destination.IN or RNS.Destination.OUT.
- **type** – RNS.Destination.SINGLE, RNS.Destination.GROUP or RNS.Destination.PLAIN.
- **app_name** – A string specifying the app name.
- ***aspects** – Any non-zero number of string arguments.

**static full_name**(*app_name*, **aspects*)

**Returns** A string containing the full human-readable name of the destination, for an app_name and a number of aspects.

**static app_and_aspects_from_name**(*full_name*)

**Returns** A tuple containing the app name and a list of aspects, for a full-name string.

**static hash_from_name_and_identity**(*full_name*, *identity*)

**Returns** A destination name in adressable hash form, for a full name string and Identity instance.

**static hash**(*app_name*, **aspects*)

**Returns** A destination name in adressable hash form, for an app_name and a number of aspects.

**announce**(*app_data=None*, *path_response=False*)
Creates an announce packet for this destination and broadcasts it on all relevant interfaces. Application specific data can be added to the announce.

**Parameters**

- **app_data** – *bytes* containing the app_data.
- **path_response** – Internal flag used by *RNS.Transport*. Ignore.

**set_link_established_callback**(*callback*)
Registers a function to be called when a link has been established to this destination.

**Parameters** **callback** – A function or method to be called.

**set_packet_callback**(*callback*)
Registers a function to be called when a packet has been received by this destination.

**Parameters** **callback** – A function or method to be called.

**set_proof_requested_callback**(*callback*)
Registers a function to be called when a proof has been requested for a packet sent to this destination. Allows control over when and if proofs should be returned for received packets.

**Parameters** **callback** – A function or method to be called. The callback must return one of True or False. If the callback returns True, a proof will be sent. If it returns False, a proof will not be sent.

**set_proof_strategy**(*proof_strategy*)
Sets the destinations proof strategy.

**Parameters** **proof_strategy** – One of `RNS.Destination.PROVE_NONE`, `RNS.Destination.PROVE_ALL` or `RNS.Destination.PROVE_APP`. If `RNS.Destination.PROVE_APP` is set, the *proof_requested_callback* will be called to determine whether a proof should be sent or not.

**register_request_handler**(*path*, *response_generator=None*, *allow=0*, *allowed_list=None*)
Registers a request handler.

**Parameters**

- **path** – The path for the request handler to be registered.
- **response_generator** – A function or method with the signature *response_generator(path, data, request_id, remote_identity, requested_at)* to be called. Whatever this funcion returns will be sent as a response to the requester. If the function returns `None`, no response will be sent.
- **allow** – One of `RNS.Destination.ALLOW_NONE`, `RNS.Destination.ALLOW_ALL` or `RNS.Destination.ALLOW_LIST`. If `RNS.Destination.ALLOW_LIST` is set, the request handler will only respond to requests for identified peers in the supplied list.
- **allowed_list** – A list of *bytes-like RNS.Identity* hashes.

**Raises** `ValueError` if any of the supplied arguments are invalid.

**deregister_request_handler**(*path*)
Deregisters a request handler.

**Parameters** **path** – The path for the request handler to be deregistered.

**Returns** True if the handler was deregistered, otherwise False.

**create_keys**()
For a `RNS.Destination.GROUP` type destination, creates a new symmetric key.

**Raises** `TypeError` if called on an incompatible type of destination.

`get_private_key()`
For a `RNS.Destination.GROUP` type destination, returns the symmetric private key.

**Raises** `TypeError` if called on an incompatible type of destination.

`load_private_key(key)`
For a `RNS.Destination.GROUP` type destination, loads a symmetric private key.

**Parameters** **key** – A *bytes-like* containing the symmetric key.

**Raises** `TypeError` if called on an incompatible type of destination.

`encrypt(plaintext)`
Encrypts information for `RNS.Destination.SINGLE` or `RNS.Destination.GROUP` type destination.

**Parameters** **plaintext** – A *bytes-like* containing the plaintext to be encrypted.

**Raises** `ValueError` if destination does not hold a necessary key for encryption.

`decrypt(ciphertext)`
Decrypts information for `RNS.Destination.SINGLE` or `RNS.Destination.GROUP` type destination.

**Parameters** **ciphertext** – *Bytes* containing the ciphertext to be decrypted.

**Raises** `ValueError` if destination does not hold a necessary key for decryption.

`sign(message)`
Signs information for `RNS.Destination.SINGLE` type destination.

**Parameters** **message** – *Bytes* containing the message to be signed.

**Returns** A *bytes-like* containing the message signature, or *None* if the destination could not sign the message.

`set_default_app_data(app_data=None)`
Sets the default app_data for the destination. If set, the default app_data will be included in every announce sent by the destination, unless other app_data is specified in the *announce* method.

**Parameters** **app_data** – A *bytes-like* containing the default app_data, or a *callable* returning a *bytes-like* containing the app_data.

`clear_default_app_data()`
Clears default app_data previously set for the destination.

### 7.1.4 Packet

`class RNS.Packet(destination, data, create_receipt=True)`
The Packet class is used to create packet instances that can be sent over a Reticulum network. Packets to will automatically be encrypted if they are adressed to a `RNS.Destination.SINGLE` destination, `RNS.Destination.GROUP` destination or a *RNS.Link*.

For `RNS.Destination.GROUP` destinations, Reticulum will use the pre-shared key configured for the destination.

For `RNS.Destination.SINGLE` destinations and *RNS.Link* destinations, reticulum will use ephemeral keys, and offers **Forward Secrecy**.

**Parameters**

- **destination** – A *RNS.Destination* instance to which the packet will be sent.
- **data** – The data payload to be included in the packet as *bytes*.

- **create_receipt** – Specifies whether a *RNS.PacketReceipt* should be created when instantiating the packet.

**ENCRYPTED_MDU = 383**
The maximum size of the payload data in a single encrypted packet

**PLAIN_MDU = 477**
The maximum size of the payload data in a single unencrypted packet

**send**()
Sends the packet.

**Returns** A *RNS.PacketReceipt* instance if *create_receipt* was set to *True* when the packet was instantiated, if not returns *None*. If the packet could not be sent *False* is returned.

**resend**()
Re-sends the packet.

**Returns** A *RNS.PacketReceipt* instance if *create_receipt* was set to *True* when the packet was instantiated, if not returns *None*. If the packet could not be sent *False* is returned.

### 7.1.5 Packet Receipt

**class** RNS.**PacketReceipt**
The PacketReceipt class is used to receive notifications about *RNS.Packet* instances sent over the network. Instances of this class are never created manually, but always returned from the *send()* method of a *RNS.Packet* instance.

**get_status**()

**Returns** The status of the associated *RNS.Packet* instance. Can be one of `RNS.PacketReceipt.SENT`, `RNS.PacketReceipt.DELIVERED`, `RNS.PacketReceipt.FAILED` or `RNS.PacketReceipt.CULLED`.

**get_rtt**()

**Returns** The round-trip-time in seconds

**set_timeout**(*timeout*)
Sets a timeout in seconds

**Parameters** **timeout** – The timeout in seconds.

**set_delivery_callback**(*callback*)
Sets a function that gets called if a successfull delivery has been proven.

**Parameters** **callback** – A *callable* with the signature *callback(packet_receipt)*

**set_timeout_callback**(*callback*)
Sets a function that gets called if the delivery times out.

**Parameters** **callback** – A *callable* with the signature *callback(packet_receipt)*

### 7.1.6 Link

**class** RNS.**Link**(*destination*, *established_callback=None*, *closed_callback=None*)

This class is used to establish and manage links to other peers. When a link instance is created, Reticulum will attempt to establish verified connectivity with the specified destination.

**Parameters**

- **destination** – A *RNS.Destination* instance which to establish a link to.
- **established_callback** – An optional function or method with the signature *callback(link)* to be called when the link has been established.
- **closed_callback** – An optional function or method with the signature *callback(link)* to be called when the link is closed.

**CURVE = 'Curve25519'**

The curve used for Elliptic Curve DH key exchanges

**ESTABLISHMENT_TIMEOUT_PER_HOP = 5**

Default timeout for link establishment in seconds per hop to destination.

**KEEPALIVE = 360**

Interval for sending keep-alive packets on established links in seconds.

**identify**(*identity*)

Identifies the initiator of the link to the remote peer. This can only happen once the link has been established, and is carried out over the encrypted link. The identity is only revealed to the remote peer, and initiator anonymity is thus preserved. This method can be used for authentication.

**Parameters** **identity** – An RNS.Identity instance to identify as.

**request**(*path*, *data=None*, *response_callback=None*, *failed_callback=None*, *progress_callback=None*, *timeout=None*)

Sends a request to the remote peer.

**Parameters**

- **path** – The request path.
- **response_callback** – An optional function or method with the signature *response_callback(request_receipt)* to be called when a response is received. See the *Request Example* for more info.
- **failed_callback** – An optional function or method with the signature *failed_callback(request_receipt)* to be called when a request fails. See the *Request Example* for more info.
- **progress_callback** – An optional function or method with the signature *progress_callback(request_receipt)* to be called when progress is made receiving the response. Progress can be accessed as a float between 0.0 and 1.0 by the *request_receipt.progress* property.
- **timeout** – An optional timeout in seconds for the request. If *None* is supplied it will be calculated based on link RTT.

**Returns** A *RNS.RequestReceipt* instance if the request was sent, or *False* if it was not.

**no_inbound_for**()

**Returns** The time in seconds since last inbound packet on the link.

no_outbound_for()

**Returns** The time in seconds since last outbound packet on the link.

inactive_for()

**Returns** The time in seconds since activity on the link.

get_remote_identity()

**Returns** The identity of the remote peer, if it is known

teardown()
Closes the link and purges encryption keys. New keys will be used if a new link to the same destination is established.

set_packet_callback(*callback*)
Registers a function to be called when a packet has been received over this link.

**Parameters** **callback** – A function or method with the signature *callback(message, packet)* to be called.

set_resource_callback(*callback*)
Registers a function to be called when a resource has been advertised over this link. If the function returns *True* the resource will be accepted. If it returns *False* it will be ignored.

**Parameters** **callback** – A function or method with the signature *callback(resource)* to be called.

set_resource_started_callback(*callback*)
Registers a function to be called when a resource has begun transferring over this link.

**Parameters** **callback** – A function or method with the signature *callback(resource)* to be called.

set_resource_concluded_callback(*callback*)
Registers a function to be called when a resource has concluded transferring over this link.

**Parameters** **callback** – A function or method with the signature *callback(resource)* to be called.

set_remote_identified_callback(*callback*)
Registers a function to be called when an initiating peer has identified over this link.

**Parameters** **callback** – A function or method with the signature *callback(identity)* to be called.

set_resource_strategy(*resource_strategy*)
Sets the resource strategy for the link.

**Parameters** **resource_strategy** – One of RNS.Link.ACCEPT_NONE, RNS.Link.ACCEPT_ALL or RNS.Link.ACCEPT_APP. If RNS.Link.ACCEPT_APP is set, the *resource_callback* will be called to determine whether the resource should be accepted or not.

**Raises** *TypeError* if the resource strategy is unsupported.

### 7.1.7 Request Receipt

**class** RNS.**RequestReceipt**

An instance of this class is returned by the `request` method of `RNS.Link` instances. It should never be instantiated manually. It provides methods to check status, response time and response data when the request concludes.

**get_request_id**()

**Returns** The request ID as *bytes*.

**get_status**()

**Returns** The current status of the request, one of `RNS.RequestReceipt.FAILED`, `RNS.RequestReceipt.SENT`, `RNS.RequestReceipt.DELIVERED`, `RNS.RequestReceipt.READY`.

**get_progress**()

**Returns** The progress of a response being received as a *float* between 0.0 and 1.0.

**get_response**()

**Returns** The response as *bytes* if it is ready, otherwise *None*.

**get_response_time**()

**Returns** The response time of the request in seconds.

### 7.1.8 Resource

**class** RNS.**Resource**(*data*, *link*, *advertise=True*, *auto_compress=True*, *callback=None*, *progress_callback=None*, *timeout=None*)

The Resource class allows transferring arbitrary amounts of data over a link. It will automatically handle sequencing, compression, coordination and checksumming.

**Parameters**

- **data** – The data to be transferred. Can be *bytes* or an open *file handle*. See the *Filetransfer Example* for details.
- **link** – The *RNS.Link* instance on which to transfer the data.
- **advertise** – Optional. Whether to automatically advertise the resource. Can be *True* or *False*.
- **auto_compress** – Optional. Whether to auto-compress the resource. Can be *True* or *False*.
- **callback** – An optional *callable* with the signature *callback(resource)*. Will be called when the resource transfer concludes.
- **progress_callback** – An optional *callable* with the signature *callback(resource)*. Will be called whenever the resource transfer progress is updated.

**advertise**()

Advertise the resource. If the other end of the link accepts the resource advertisement it will begin transferring.

**cancel**()
Cancels transferring the resource.

**get_progress**()

**Returns** The current progress of the resource transfer as a *float* between 0.0 and 1.0.

### 7.1.9 Transport

**class** RNS.**Transport**
Through static methods of this class you can interact with the Transport system of Reticulum.

**PATHFINDER_M = 128**
Maximum amount of hops that Reticulum will transport a packet.

**static register_announce_handler**(*handler*)
Registers an announce handler.

**Parameters** **handler** – Must be an object with an *aspect_filter* attribute and a *received_announce(destination_hash, announced_identity, app_data)* callable. See the *Announce Example* for more info.

**static deregister_announce_handler**(*handler*)
Deregisters an announce handler.

**Parameters** **handler** – The announce handler to be deregistered.

**static has_path**(*destination_hash*)

**Parameters** **destination_hash** – A destination hash as *bytes*.

**Returns** *True* if a path to the destination is known, otherwise *False*.

**static hops_to**(*destination_hash*)

**Parameters** **destination_hash** – A destination hash as *bytes*.

**Returns** The number of hops to the specified destination, or RNS.Transport.PATHFINDER_M if the number of hops is unknown.

**static next_hop**(*destination_hash*)

**Parameters** **destination_hash** – A destination hash as *bytes*.

**Returns** The destination hash as *bytes* for the next hop to the specified destination, or *None* if the next hop is unknown.

**static next_hop_interface**(*destination_hash*)

**Parameters** **destination_hash** – A destination hash as *bytes*.

**Returns** The interface for the next hop to the specified destination, or *None* if the interface is unknown.

**static request_path**(*destination_hash*)
Requests a path to the destination from the network. If another reachable peer on the network knows a path, it will announce it.

**Parameters** `destination_hash` – A destination hash as *bytes*.

CHAPTER

# EIGHT

# CODE EXAMPLES

A number of examples are included in the source distribution of Reticulum. You can use these examples to learn how to write your own programs.

## 8.1 Minimal

The *Minimal* example demonstrates the bare-minimum setup required to connect to a Reticulum network from your program. In about five lines of code, you will have the Reticulum Network Stack initialised, and ready to pass traffic in your program.

```
##########################################################
# This RNS example demonstrates a minimal setup, that    #
# will start up the Reticulum Network Stack, generate a  #
# new destination, and let the user send an announce.    #
##########################################################

import argparse
import RNS

# Let's define an app name. We'll use this for all
# destinations we create. Since this basic example
# is part of a range of example utilities, we'll put
# them all within the app namespace "example_utilities"
APP_NAME = "example_utilities"

# This initialisation is executed when the program is started
def program_setup(configpath):
    # We must first initialise Reticulum
    reticulum = RNS.Reticulum(configpath)

    # Randomly create a new identity for our example
    identity = RNS.Identity()

    # Using the identity we just created, we create a destination.
    # Destinations are endpoints in Reticulum, that can be addressed
    # and communicated with. Destinations can also announce their
    # existence, which will let the network know they are reachable
    # and autoomatically create paths to them, from anywhere else
    # in the network.
    destination = RNS.Destination(
```

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```
        identity,
        RNS.Destination.IN,
        RNS.Destination.SINGLE,
        APP_NAME,
        "minimalsample"
    )

    # We configure the destination to automatically prove all
    # packets adressed to it. By doing this, RNS will automatically
    # generate a proof for each incoming packet and transmit it
    # back to the sender of that packet. This will let anyone that
    # tries to communicate with the destination know whether their
    # communication was received correctly.
    destination.set_proof_strategy(RNS.Destination.PROVE_ALL)

    # Everything's ready!
    # Let's hand over control to the announce loop
    announceLoop(destination)


def announceLoop(destination):
    # Let the user know that everything is ready
    RNS.log(
        "Minimal example "+
        RNS.prettyhexrep(destination.hash)+
        " running, hit enter to manually send an announce (Ctrl-C to quit)"
    )

    # We enter a loop that runs until the users exits.
    # If the user hits enter, we will announce our server
    # destination on the network, which will let clients
    # know how to create messages directed towards it.
    while True:
        entered = input()
        destination.announce()
        RNS.log("Sent announce from "+RNS.prettyhexrep(destination.hash))


##########################################################
#### Program Startup #####################################
##########################################################

# This part of the program gets run at startup,
# and parses input from the user, and then starts
# the desired program mode.
if __name__ == "__main__":
    try:
        parser = argparse.ArgumentParser(
            description="Minimal example to start Reticulum and create a destination"
        )

        parser.add_argument(
```

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```
            "--config",
            action="store",
            default=None,
            help="path to alternative Reticulum config directory",
            type=str
        )

        args = parser.parse_args()

        if args.config:
            configarg = args.config
        else:
            configarg = None

        program_setup(configarg)

    except KeyboardInterrupt:
        print("")
        exit()
```

This example can also be found at https://github.com/markqvist/Reticulum/blob/master/Examples/Minimal.py.

## 8.2 Announce

The *Announce* example builds upon the previous example by exploring how to announce a destination on the network, and how to let your program receive notifications about announces from relevant destinations.

```
##########################################################
# This RNS example demonstrates setting up announce      #
# callbacks, which will let an application receive a     #
# notification when an announce relevant for it arrives  #
##########################################################

import argparse
import random
import RNS

# Let's define an app name. We'll use this for all
# destinations we create. Since this basic example
# is part of a range of example utilities, we'll put
# them all within the app namespace "example_utilities"
APP_NAME = "example_utilities"

# We initialise two lists of strings to use as app_data
fruits = ["Peach", "Quince", "Date", "Tangerine", "Pomelo", "Carambola", "Grape"]
noble_gases = ["Helium", "Neon", "Argon", "Krypton", "Xenon", "Radon", "Oganesson"]

# This initialisation is executed when the program is started
def program_setup(configpath):
    # We must first initialise Reticulum
```

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```
    reticulum = RNS.Reticulum(configpath)

    # Randomly create a new identity for our example
    identity = RNS.Identity()

    # Using the identity we just created, we create two destinations
    # in the "example_utilities.announcesample" application space.
    #
    # Destinations are endpoints in Reticulum, that can be addressed
    # and communicated with. Destinations can also announce their
    # existence, which will let the network know they are reachable
    # and autoomatically create paths to them, from anywhere else
    # in the network.
    destination_1 = RNS.Destination(
        identity,
        RNS.Destination.IN,
        RNS.Destination.SINGLE,
        APP_NAME,
        "announcesample",
        "fruits"
    )

    destination_2 = RNS.Destination(
        identity,
        RNS.Destination.IN,
        RNS.Destination.SINGLE,
        APP_NAME,
        "announcesample",
        "noble_gases"
    )

    # We configure the destinations to automatically prove all
    # packets adressed to it. By doing this, RNS will automatically
    # generate a proof for each incoming packet and transmit it
    # back to the sender of that packet. This will let anyone that
    # tries to communicate with the destination know whether their
    # communication was received correctly.
    destination_1.set_proof_strategy(RNS.Destination.PROVE_ALL)
    destination_2.set_proof_strategy(RNS.Destination.PROVE_ALL)

    # We create an announce handler and configure it to only ask for
    # announces from "example_utilities.announcesample.fruits".
    # Try changing the filter and see what happens.
    announce_handler = ExampleAnnounceHandler(
        aspect_filter="example_utilities.announcesample.fruits"
    )

    # We register the announce handler with Reticulum
    RNS.Transport.register_announce_handler(announce_handler)

    # Everything's ready!
    # Let's hand over control to the announce loop
```

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```
    announceLoop(destination_1, destination_2)


def announceLoop(destination_1, destination_2):
    # Let the user know that everything is ready
    RNS.log("Announce example running, hit enter to manually send an announce (Ctrl-C to␣
↪quit)")

    # We enter a loop that runs until the users exits.
    # If the user hits enter, we will announce our server
    # destination on the network, which will let clients
    # know how to create messages directed towards it.
    while True:
        entered = input()

        # Randomly select a fruit
        fruit = fruits[random.randint(0,len(fruits)-1)]

        # Send the announce including the app data
        destination_1.announce(app_data=fruit.encode("utf-8"))
        RNS.log(
            "Sent announce from "+
            RNS.prettyhexrep(destination_1.hash)+
            " ("+destination_1.name+")"
        )

        # Randomly select a noble gas
        noble_gas = noble_gases[random.randint(0,len(noble_gases)-1)]

        # Send the announce including the app data
        destination_2.announce(app_data=noble_gas.encode("utf-8"))
        RNS.log(
            "Sent announce from "+
            RNS.prettyhexrep(destination_2.hash)+
            " ("+destination_2.name+")"
        )

# We will need to define an announce handler class that
# Reticulum can message when an announce arrives.
class ExampleAnnounceHandler:
    # The initialisation method takes the optional
    # aspect_filter argument. If aspect_filter is set to
    # None, all announces will be passed to the instance.
    # If only some announces are wanted, it can be set to
    # an aspect string.
    def __init__(self, aspect_filter=None):
        self.aspect_filter = aspect_filter

    # This method will be called by Reticulums Transport
    # system when an announce arrives that matches the
    # configured aspect filter. Filters must be specific,
    # and cannot use wildcards.
```

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```
    def received_announce(self, destination_hash, announced_identity, app_data):
        RNS.log(
            "Received an announce from "+
            RNS.prettyhexrep(destination_hash)
        )

        RNS.log(
            "The announce contained the following app data: "+
            app_data.decode("utf-8")
        )

##########################################################
#### Program Startup #####################################
##########################################################

# This part of the program gets run at startup,
# and parses input from the user, and then starts
# the desired program mode.
if __name__ == "__main__":
    try:
        parser = argparse.ArgumentParser(
            description="Reticulum example that demonstrates announces and announce␣
↪handlers"
        )

        parser.add_argument(
            "--config",
            action="store",
            default=None,
            help="path to alternative Reticulum config directory",
            type=str
        )

        args = parser.parse_args()

        if args.config:
            configarg = args.config
        else:
            configarg = None

        program_setup(configarg)

    except KeyboardInterrupt:
        print("")
        exit()
```

This example can also be found at https://github.com/markqvist/Reticulum/blob/master/Examples/Announce.py.

## 8.3 Broadcast

The *Broadcast* example explores how to transmit plaintext broadcast messages over the network.

```
##########################################################
# This RNS example demonstrates broadcasting unencrypted #
# information to any listening destinations.             #
##########################################################

import sys
import argparse
import RNS

# Let's define an app name. We'll use this for all
# destinations we create. Since this basic example
# is part of a range of example utilities, we'll put
# them all within the app namespace "example_utilities"
APP_NAME = "example_utilities"

# This initialisation is executed when the program is started
def program_setup(configpath, channel=None):
    # We must first initialise Reticulum
    reticulum = RNS.Reticulum(configpath)

    # If the user did not select a "channel" we use
    # a default one called "public_information".
    # This "channel" is added to the destination name-
    # space, so the user can select different broadcast
    # channels.
    if channel == None:
        channel = "public_information"

    # We create a PLAIN destination. This is an uncencrypted endpoint
    # that anyone can listen to and send information to.
    broadcast_destination = RNS.Destination(
        None,
        RNS.Destination.IN,
        RNS.Destination.PLAIN,
        APP_NAME,
        "broadcast",
        channel
    )

    # We specify a callback that will get called every time
    # the destination receives data.
    broadcast_destination.set_packet_callback(packet_callback)

    # Everything's ready!
    # Let's hand over control to the main loop
    broadcastLoop(broadcast_destination)

def packet_callback(data, packet):
    # Simply print out the received data
```

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```
    print("")
    print("Received data: "+data.decode("utf-8")+"\r\n> ", end="")
    sys.stdout.flush()

def broadcastLoop(destination):
    # Let the user know that everything is ready
    RNS.log(
        "Broadcast example "+
        RNS.prettyhexrep(destination.hash)+
        " running, enter text and hit enter to broadcast (Ctrl-C to quit)"
    )

    # We enter a loop that runs until the users exits.
    # If the user hits enter, we will send the information
    # that the user entered into the prompt.
    while True:
        print("> ", end="")
        entered = input()

        if entered != "":
            data    = entered.encode("utf-8")
            packet  = RNS.Packet(destination, data)
            packet.send()



#############################################################
#### Program Startup ########################################
#############################################################

# This part of the program gets run at startup,
# and parses input from the user, and then starts
# the program.
if __name__ == "__main__":
    try:
        parser = argparse.ArgumentParser(
            description="Reticulum example demonstrating sending and receiving broadcasts
↪"
        )

        parser.add_argument(
            "--config",
            action="store",
            default=None,
            help="path to alternative Reticulum config directory",
            type=str
        )

        parser.add_argument(
            "--channel",
            action="store",
            default=None,
```

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```
            help="broadcast channel name",
            type=str
        )

        args = parser.parse_args()

        if args.config:
            configarg = args.config
        else:
            configarg = None

        if args.channel:
            channelarg = args.channel
        else:
            channelarg = None

        program_setup(configarg, channelarg)

    except KeyboardInterrupt:
        print("")
        exit()
```

This example can also be found at https://github.com/markqvist/Reticulum/blob/master/Examples/Broadcast.py.

## 8.4 Echo

The *Echo* example demonstrates communication between two destinations using the Packet interface.

```
##########################################################
# This RNS example demonstrates a simple client/server   #
# echo utility. A client can send an echo request to the #
# server, and the server will respond by proving receipt #
# of the packet.                                         #
##########################################################

import argparse
import RNS

# Let's define an app name. We'll use this for all
# destinations we create. Since this echo example
# is part of a range of example utilities, we'll put
# them all within the app namespace "example_utilities"
APP_NAME = "example_utilities"


##########################################################
#### Server Part #########################################
##########################################################

# This initialisation is executed when the users chooses
```

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```
# to run as a server
def server(configpath):
    global reticulum

    # We must first initialise Reticulum
    reticulum = RNS.Reticulum(configpath)

    # Randomly create a new identity for our echo server
    server_identity = RNS.Identity()

    # We create a destination that clients can query. We want
    # to be able to verify echo replies to our clients, so we
    # create a "single" destination that can receive encrypted
    # messages. This way the client can send a request and be
    # certain that no-one else than this destination was able
    # to read it.
    echo_destination = RNS.Destination(
        server_identity,
        RNS.Destination.IN,
        RNS.Destination.SINGLE,
        APP_NAME,
        "echo",
        "request"
    )

    # We configure the destination to automatically prove all
    # packets adressed to it. By doing this, RNS will automatically
    # generate a proof for each incoming packet and transmit it
    # back to the sender of that packet.
    echo_destination.set_proof_strategy(RNS.Destination.PROVE_ALL)

    # Tell the destination which function in our program to
    # run when a packet is received. We do this so we can
    # print a log message when the server receives a request
    echo_destination.set_packet_callback(server_callback)

    # Everything's ready!
    # Let's Wait for client requests or user input
    announceLoop(echo_destination)


def announceLoop(destination):
    # Let the user know that everything is ready
    RNS.log(
        "Echo server "+
        RNS.prettyhexrep(destination.hash)+
        " running, hit enter to manually send an announce (Ctrl-C to quit)"
    )

    # We enter a loop that runs until the users exits.
    # If the user hits enter, we will announce our server
    # destination on the network, which will let clients
```

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```
    # know how to create messages directed towards it.
    while True:
        entered = input()
        destination.announce()
        RNS.log("Sent announce from "+RNS.prettyhexrep(destination.hash))


def server_callback(message, packet):
    global reticulum

    # Tell the user that we received an echo request, and
    # that we are going to send a reply to the requester.
    # Sending the proof is handled automatically, since we
    # set up the destination to prove all incoming packets.

    reception_stats = ""
    if reticulum.is_connected_to_shared_instance:
        reception_rssi = reticulum.get_packet_rssi(packet.packet_hash)
        reception_snr  = reticulum.get_packet_snr(packet.packet_hash)

        if reception_rssi != None:
            reception_stats += " [RSSI "+str(reception_rssi)+" dBm]"

        if reception_snr != None:
            reception_stats += " [SNR "+str(reception_snr)+" dBm]"

    else:
        if packet.rssi != None:
            reception_stats += " [RSSI "+str(packet.rssi)+" dBm]"

        if packet.snr != None:
            reception_stats += " [SNR "+str(packet.snr)+" dB]"

    RNS.log("Received packet from echo client, proof sent"+reception_stats)


##########################################################
#### Client Part #########################################
##########################################################

# This initialisation is executed when the users chooses
# to run as a client
def client(destination_hexhash, configpath, timeout=None):
    global reticulum

    # We need a binary representation of the destination
    # hash that was entered on the command line
    try:
        if len(destination_hexhash) != 20:
            raise ValueError(
                "Destination length is invalid, must be 20 hexadecimal characters (10␣
↪bytes)"
```

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```
            )

        destination_hash = bytes.fromhex(destination_hexhash)
    except:
        RNS.log("Invalid destination entered. Check your input!\n")
        exit()

    # We must first initialise Reticulum
    reticulum = RNS.Reticulum(configpath)

    # We override the loglevel to provide feedback when
    # an announce is received
    if RNS.loglevel < RNS.LOG_INFO:
        RNS.loglevel = RNS.LOG_INFO

    # Tell the user that the client is ready!
    RNS.log(
        "Echo client ready, hit enter to send echo request to "+
        destination_hexhash+
        " (Ctrl-C to quit)"
    )

    # We enter a loop that runs until the user exits.
    # If the user hits enter, we will try to send an
    # echo request to the destination specified on the
    # command line.
    while True:
        input()

        # Let's first check if RNS knows a path to the destination.
        # If it does, we'll load the server identity and create a packet
        if RNS.Transport.has_path(destination_hash):

            # To address the server, we need to know it's public
            # key, so we check if Reticulum knows this destination.
            # This is done by calling the "recall" method of the
            # Identity module. If the destination is known, it will
            # return an Identity instance that can be used in
            # outgoing destinations.
            server_identity = RNS.Identity.recall(destination_hash)

            # We got the correct identity instance from the
            # recall method, so let's create an outgoing
            # destination. We use the naming convention:
            # example_utilities.echo.request
            # This matches the naming we specified in the
            # server part of the code.
            request_destination = RNS.Destination(
                server_identity,
                RNS.Destination.OUT,
                RNS.Destination.SINGLE,
                APP_NAME,
```

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```
                "echo",
                "request"
            )

            # The destination is ready, so let's create a packet.
            # We set the destination to the request_destination
            # that was just created, and the only data we add
            # is a random hash.
            echo_request = RNS.Packet(request_destination, RNS.Identity.get_random_
↪hash())

            # Send the packet! If the packet is successfully
            # sent, it will return a PacketReceipt instance.
            packet_receipt = echo_request.send()

            # If the user specified a timeout, we set this
            # timeout on the packet receipt, and configure
            # a callback function, that will get called if
            # the packet times out.
            if timeout != None:
                packet_receipt.set_timeout(timeout)
                packet_receipt.set_timeout_callback(packet_timed_out)

            # We can then set a delivery callback on the receipt.
            # This will get automatically called when a proof for
            # this specific packet is received from the destination.
            packet_receipt.set_delivery_callback(packet_delivered)

            # Tell the user that the echo request was sent
            RNS.log("Sent echo request to "+RNS.prettyhexrep(request_destination.hash))
        else:
            # If we do not know this destination, tell the
            # user to wait for an announce to arrive.
            RNS.log("Destination is not yet known. Requesting path...")
            RNS.Transport.request_path(destination_hash)

# This function is called when our reply destination
# receives a proof packet.
def packet_delivered(receipt):
    global reticulum

    if receipt.status == RNS.PacketReceipt.DELIVERED:
        rtt = receipt.get_rtt()
        if (rtt >= 1):
            rtt = round(rtt, 3)
            rttstring = str(rtt)+" seconds"
        else:
            rtt = round(rtt*1000, 3)
            rttstring = str(rtt)+" milliseconds"

        reception_stats = ""
        if reticulum.is_connected_to_shared_instance:
```

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```
            reception_rssi = reticulum.get_packet_rssi(receipt.proof_packet.packet_hash)
            reception_snr  = reticulum.get_packet_snr(receipt.proof_packet.packet_hash)

            if reception_rssi != None:
                reception_stats += " [RSSI "+str(reception_rssi)+" dBm]"

            if reception_snr != None:
                reception_stats += " [SNR "+str(reception_snr)+" dB]"

        else:
            if receipt.proof_packet != None:
                if receipt.proof_packet.rssi != None:
                    reception_stats += " [RSSI "+str(receipt.proof_packet.rssi)+" dBm]"

                if receipt.proof_packet.snr != None:
                    reception_stats += " [SNR "+str(receipt.proof_packet.snr)+" dB]"

        RNS.log(
            "Valid reply received from "+
            RNS.prettyhexrep(receipt.destination.hash)+
            ", round-trip time is "+rttstring+
            reception_stats
        )

# This function is called if a packet times out.
def packet_timed_out(receipt):
    if receipt.status == RNS.PacketReceipt.FAILED:
        RNS.log("Packet "+RNS.prettyhexrep(receipt.hash)+" timed out")


##########################################################
#### Program Startup #####################################
##########################################################

# This part of the program gets run at startup,
# and parses input from the user, and then starts
# the desired program mode.
if __name__ == "__main__":
    try:
        parser = argparse.ArgumentParser(description="Simple echo server and client␣
↪utility")

        parser.add_argument(
            "-s",
            "--server",
            action="store_true",
            help="wait for incoming packets from clients"
        )

        parser.add_argument(
            "-t",
            "--timeout",
```

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```
            action="store",
            metavar="s",
            default=None,
            help="set a reply timeout in seconds",
            type=float
        )

        parser.add_argument("--config",
            action="store",
            default=None,
            help="path to alternative Reticulum config directory",
            type=str
        )

        parser.add_argument(
            "destination",
            nargs="?",
            default=None,
            help="hexadecimal hash of the server destination",
            type=str
        )

        args = parser.parse_args()

        if args.server:
            configarg=None
            if args.config:
                configarg = args.config
            server(configarg)
        else:
            if args.config:
                configarg = args.config
            else:
                configarg = None

            if args.timeout:
                timeoutarg = float(args.timeout)
            else:
                timeoutarg = None

            if (args.destination == None):
                print("")
                parser.print_help()
                print("")
            else:
                client(args.destination, configarg, timeout=timeoutarg)
    except KeyboardInterrupt:
        print("")
        exit()
```

This example can also be found at https://github.com/markqvist/Reticulum/blob/master/Examples/Echo.py.

## 8.5 Link

The *Link* example explores establishing an encrypted link to a remote destination, and passing traffic back and forth over the link.

```
##########################################################
# This RNS example demonstrates how to set up a link to  #
# a destination, and pass data back and forth over it.   #
##########################################################

import os
import sys
import time
import argparse
import RNS

# Let's define an app name. We'll use this for all
# destinations we create. Since this echo example
# is part of a range of example utilities, we'll put
# them all within the app namespace "example_utilities"
APP_NAME = "example_utilities"

##########################################################
#### Server Part #########################################
##########################################################

# A reference to the latest client link that connected
latest_client_link = None

# This initialisation is executed when the users chooses
# to run as a server
def server(configpath):
    # We must first initialise Reticulum
    reticulum = RNS.Reticulum(configpath)

    # Randomly create a new identity for our link example
    server_identity = RNS.Identity()

    # We create a destination that clients can connect to. We
    # want clients to create links to this destination, so we
    # need to create a "single" destination type.
    server_destination = RNS.Destination(
        server_identity,
        RNS.Destination.IN,
        RNS.Destination.SINGLE,
        APP_NAME,
        "linkexample"
    )

    # We configure a function that will get called every time
    # a new client creates a link to this destination.
    server_destination.set_link_established_callback(client_connected)
```

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```
    # Everything's ready!
    # Let's Wait for client requests or user input
    server_loop(server_destination)

def server_loop(destination):
    # Let the user know that everything is ready
    RNS.log(
        "Link example "+
        RNS.prettyhexrep(destination.hash)+
        " running, waiting for a connection."
    )

    RNS.log("Hit enter to manually send an announce (Ctrl-C to quit)")

    # We enter a loop that runs until the users exits.
    # If the user hits enter, we will announce our server
    # destination on the network, which will let clients
    # know how to create messages directed towards it.
    while True:
        entered = input()
        destination.announce()
        RNS.log("Sent announce from "+RNS.prettyhexrep(destination.hash))

# When a client establishes a link to our server
# destination, this function will be called with
# a reference to the link.
def client_connected(link):
    global latest_client_link

    RNS.log("Client connected")
    link.set_link_closed_callback(client_disconnected)
    link.set_packet_callback(server_packet_received)
    latest_client_link = link

def client_disconnected(link):
    RNS.log("Client disconnected")

def server_packet_received(message, packet):
    global latest_client_link

    # When data is received over any active link,
    # it will all be directed to the last client
    # that connected.
    text = message.decode("utf-8")
    RNS.log("Received data on the link: "+text)

    reply_text = "I received \""+text+"\" over the link"
    reply_data = reply_text.encode("utf-8")
    RNS.Packet(latest_client_link, reply_data).send()


################################################################
```

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```
#### Client Part ###########################################
############################################################

# A reference to the server link
server_link = None

# This initialisation is executed when the users chooses
# to run as a client
def client(destination_hexhash, configpath):
    # We need a binary representation of the destination
    # hash that was entered on the command line
    try:
        if len(destination_hexhash) != 20:
            raise ValueError("Destination length is invalid, must be 20 hexadecimal␣
↪characters (10 bytes)")
        destination_hash = bytes.fromhex(destination_hexhash)
    except:
        RNS.log("Invalid destination entered. Check your input!\n")
        exit()

    # We must first initialise Reticulum
    reticulum = RNS.Reticulum(configpath)

    # Check if we know a path to the destination
    if not RNS.Transport.has_path(destination_hash):
        RNS.log("Destination is not yet known. Requesting path and waiting for announce␣
↪to arrive...")
        RNS.Transport.request_path(destination_hash)
        while not RNS.Transport.has_path(destination_hash):
            time.sleep(0.1)

    # Recall the server identity
    server_identity = RNS.Identity.recall(destination_hash)

    # Inform the user that we'll begin connecting
    RNS.log("Establishing link with server...")

    # When the server identity is known, we set
    # up a destination
    server_destination = RNS.Destination(
        server_identity,
        RNS.Destination.OUT,
        RNS.Destination.SINGLE,
        APP_NAME,
        "linkexample"
    )

    # And create a link
    link = RNS.Link(server_destination)

    # We set a callback that will get executed
    # every time a packet is received over the
```

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```
    # link
    link.set_packet_callback(client_packet_received)

    # We'll also set up functions to inform the
    # user when the link is established or closed
    link.set_link_established_callback(link_established)
    link.set_link_closed_callback(link_closed)

    # Everything is set up, so let's enter a loop
    # for the user to interact with the example
    client_loop()

def client_loop():
    global server_link

    # Wait for the link to become active
    while not server_link:
        time.sleep(0.1)

    should_quit = False
    while not should_quit:
        try:
            print("> ", end=" ")
            text = input()

            # Check if we should quit the example
            if text == "quit" or text == "q" or text == "exit":
                should_quit = True
                server_link.teardown()

            # If not, send the entered text over the link
            if text != "":
                data = text.encode("utf-8")
                if len(data) <= RNS.Link.MDU:
                    RNS.Packet(server_link, data).send()
                else:
                    RNS.log(
                        "Cannot send this packet, the data size of "+
                        str(len(data))+" bytes exceeds the link packet MDU of "+
                        str(RNS.Link.MDU)+" bytes",
                        RNS.LOG_ERROR
                    )

        except Exception as e:
            RNS.log("Error while sending data over the link: "+str(e))
            should_quit = True
            server_link.teardown()

# This function is called when a link
# has been established with the server
def link_established(link):
    # We store a reference to the link
```

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```
    # instance for later use
    global server_link
    server_link = link

    # Inform the user that the server is
    # connected
    RNS.log("Link established with server, enter some text to send, or \"quit\" to quit")

# When a link is closed, we'll inform the
# user, and exit the program
def link_closed(link):
    if link.teardown_reason == RNS.Link.TIMEOUT:
        RNS.log("The link timed out, exiting now")
    elif link.teardown_reason == RNS.Link.DESTINATION_CLOSED:
        RNS.log("The link was closed by the server, exiting now")
    else:
        RNS.log("Link closed, exiting now")

    RNS.Reticulum.exit_handler()
    time.sleep(1.5)
    os._exit(0)

# When a packet is received over the link, we
# simply print out the data.
def client_packet_received(message, packet):
    text = message.decode("utf-8")
    RNS.log("Received data on the link: "+text)
    print("> ", end=" ")
    sys.stdout.flush()


###########################################################
#### Program Startup ######################################
###########################################################

# This part of the program runs at startup,
# and parses input of from the user, and then
# starts up the desired program mode.
if __name__ == "__main__":
    try:
        parser = argparse.ArgumentParser(description="Simple link example")

        parser.add_argument(
            "-s",
            "--server",
            action="store_true",
            help="wait for incoming link requests from clients"
        )

        parser.add_argument(
            "--config",
            action="store",
```

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```
            default=None,
            help="path to alternative Reticulum config directory",
            type=str
        )

        parser.add_argument(
            "destination",
            nargs="?",
            default=None,
            help="hexadecimal hash of the server destination",
            type=str
        )

        args = parser.parse_args()

        if args.config:
            configarg = args.config
        else:
            configarg = None

        if args.server:
            server(configarg)
        else:
            if (args.destination == None):
                print("")
                parser.print_help()
                print("")
            else:
                client(args.destination, configarg)

    except KeyboardInterrupt:
        print("")
        exit()
```

This example can also be found at https://github.com/markqvist/Reticulum/blob/master/Examples/Link.py.

## 8.6 Identification

The *Identify* example explores identifying an intiator of a link, once the link has been established.

```
##########################################################
# This RNS example demonstrates how to set up a link to  #
# a destination, and identify the initiator to it's peer #
##########################################################

import os
import sys
import time
import argparse
import RNS
```

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```
# Let's define an app name. We'll use this for all
# destinations we create. Since this echo example
# is part of a range of example utilities, we'll put
# them all within the app namespace "example_utilities"
APP_NAME = "example_utilities"

##########################################################
#### Server Part #########################################
##########################################################

# A reference to the latest client link that connected
latest_client_link = None

# This initialisation is executed when the users chooses
# to run as a server
def server(configpath):
    # We must first initialise Reticulum
    reticulum = RNS.Reticulum(configpath)

    # Randomly create a new identity for our link example
    server_identity = RNS.Identity()

    # We create a destination that clients can connect to. We
    # want clients to create links to this destination, so we
    # need to create a "single" destination type.
    server_destination = RNS.Destination(
        server_identity,
        RNS.Destination.IN,
        RNS.Destination.SINGLE,
        APP_NAME,
        "identifyexample"
    )

    # We configure a function that will get called every time
    # a new client creates a link to this destination.
    server_destination.set_link_established_callback(client_connected)

    # Everything's ready!
    # Let's Wait for client requests or user input
    server_loop(server_destination)

def server_loop(destination):
    # Let the user know that everything is ready
    RNS.log(
        "Link identification example "+
        RNS.prettyhexrep(destination.hash)+
        " running, waiting for a connection."
    )

    RNS.log("Hit enter to manually send an announce (Ctrl-C to quit)")
```

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```
    # We enter a loop that runs until the users exits.
    # If the user hits enter, we will announce our server
    # destination on the network, which will let clients
    # know how to create messages directed towards it.
    while True:
        entered = input()
        destination.announce()
        RNS.log("Sent announce from "+RNS.prettyhexrep(destination.hash))

# When a client establishes a link to our server
# destination, this function will be called with
# a reference to the link.
def client_connected(link):
    global latest_client_link

    RNS.log("Client connected")
    link.set_link_closed_callback(client_disconnected)
    link.set_packet_callback(server_packet_received)
    link.set_remote_identified_callback(remote_identified)
    latest_client_link = link

def client_disconnected(link):
    RNS.log("Client disconnected")

def remote_identified(identity):
    RNS.log("Remote identified as: "+str(identity))

def server_packet_received(message, packet):
    global latest_client_link

    # Get the originating identity for display
    remote_peer =  "unidentified peer"
    if packet.link.get_remote_identity() != None:
        remote_peer = str(packet.link.get_remote_identity())

    # When data is received over any active link,
    # it will all be directed to the last client
    # that connected.
    text = message.decode("utf-8")

    RNS.log("Received data from "+remote_peer+": "+text)

    reply_text = "I received \""+text+"\" over the link from "+remote_peer
    reply_data = reply_text.encode("utf-8")
    RNS.Packet(latest_client_link, reply_data).send()


##########################################################
#### Client Part #########################################
##########################################################

# A reference to the server link
```

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```
server_link = None

# A reference to the client identity
client_identity = None

# This initialisation is executed when the users chooses
# to run as a client
def client(destination_hexhash, configpath):
    global client_identity
    # We need a binary representation of the destination
    # hash that was entered on the command line
    try:
        if len(destination_hexhash) != 20:
            raise ValueError("Destination length is invalid, must be 20 hexadecimal␣
↪characters (10 bytes)")
        destination_hash = bytes.fromhex(destination_hexhash)
    except:
        RNS.log("Invalid destination entered. Check your input!\n")
        exit()

    # We must first initialise Reticulum
    reticulum = RNS.Reticulum(configpath)

    # Create a new client identity
    client_identity = RNS.Identity()
    RNS.log(
        "Client created new identity "+
        str(client_identity)
    )

    # Check if we know a path to the destination
    if not RNS.Transport.has_path(destination_hash):
        RNS.log("Destination is not yet known. Requesting path and waiting for announce␣
↪to arrive...")
        RNS.Transport.request_path(destination_hash)
        while not RNS.Transport.has_path(destination_hash):
            time.sleep(0.1)

    # Recall the server identity
    server_identity = RNS.Identity.recall(destination_hash)

    # Inform the user that we'll begin connecting
    RNS.log("Establishing link with server...")

    # When the server identity is known, we set
    # up a destination
    server_destination = RNS.Destination(
        server_identity,
        RNS.Destination.OUT,
        RNS.Destination.SINGLE,
        APP_NAME,
        "identifyexample"
```

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```
    )

    # And create a link
    link = RNS.Link(server_destination)

    # We set a callback that will get executed
    # every time a packet is received over the
    # link
    link.set_packet_callback(client_packet_received)

    # We'll also set up functions to inform the
    # user when the link is established or closed
    link.set_link_established_callback(link_established)
    link.set_link_closed_callback(link_closed)

    # Everything is set up, so let's enter a loop
    # for the user to interact with the example
    client_loop()

def client_loop():
    global server_link

    # Wait for the link to become active
    while not server_link:
        time.sleep(0.1)

    should_quit = False
    while not should_quit:
        try:
            print("> ", end=" ")
            text = input()

            # Check if we should quit the example
            if text == "quit" or text == "q" or text == "exit":
                should_quit = True
                server_link.teardown()

            # If not, send the entered text over the link
            if text != "":
                data = text.encode("utf-8")
                if len(data) <= RNS.Link.MDU:
                    RNS.Packet(server_link, data).send()
                else:
                    RNS.log(
                        "Cannot send this packet, the data size of "+
                        str(len(data))+" bytes exceeds the link packet MDU of "+
                        str(RNS.Link.MDU)+" bytes",
                        RNS.LOG_ERROR
                    )

        except Exception as e:
            RNS.log("Error while sending data over the link: "+str(e))
```

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```
            should_quit = True
            server_link.teardown()

# This function is called when a link
# has been established with the server
def link_established(link):
    # We store a reference to the link
    # instance for later use
    global server_link, client_identity
    server_link = link

    # Inform the user that the server is
    # connected
    RNS.log("Link established with server, identifying to remote peer...")

    link.identify(client_identity)

# When a link is closed, we'll inform the
# user, and exit the program
def link_closed(link):
    if link.teardown_reason == RNS.Link.TIMEOUT:
        RNS.log("The link timed out, exiting now")
    elif link.teardown_reason == RNS.Link.DESTINATION_CLOSED:
        RNS.log("The link was closed by the server, exiting now")
    else:
        RNS.log("Link closed, exiting now")

    RNS.Reticulum.exit_handler()
    time.sleep(1.5)
    os._exit(0)

# When a packet is received over the link, we
# simply print out the data.
def client_packet_received(message, packet):
    text = message.decode("utf-8")
    RNS.log("Received data on the link: "+text)
    print("> ", end=" ")
    sys.stdout.flush()


###########################################################
#### Program Startup ######################################
###########################################################

# This part of the program runs at startup,
# and parses input of from the user, and then
# starts up the desired program mode.
if __name__ == "__main__":
    try:
        parser = argparse.ArgumentParser(description="Simple link example")

        parser.add_argument(
```

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```
            "-s",
            "--server",
            action="store_true",
            help="wait for incoming link requests from clients"
        )

        parser.add_argument(
            "--config",
            action="store",
            default=None,
            help="path to alternative Reticulum config directory",
            type=str
        )

        parser.add_argument(
            "destination",
            nargs="?",
            default=None,
            help="hexadecimal hash of the server destination",
            type=str
        )

        args = parser.parse_args()

        if args.config:
            configarg = args.config
        else:
            configarg = None

        if args.server:
            server(configarg)
        else:
            if (args.destination == None):
                print("")
                parser.print_help()
                print("")
            else:
                client(args.destination, configarg)

    except KeyboardInterrupt:
        print("")
        exit()
```

This example can also be found at https://github.com/markqvist/Reticulum/blob/master/Examples/Identify.py.

## 8.7 Requests & Responses

The *Request* example explores sendig requests and receiving responses.

```
##########################################################
# This RNS example demonstrates how to set perform       #
# requests and receive responses over a link.            #
##########################################################

import os
import sys
import time
import random
import argparse
import RNS

# Let's define an app name. We'll use this for all
# destinations we create. Since this echo example
# is part of a range of example utilities, we'll put
# them all within the app namespace "example_utilities"
APP_NAME = "example_utilities"

##########################################################
#### Server Part #########################################
##########################################################

# A reference to the latest client link that connected
latest_client_link = None

def random_text_generator(path, data, request_id, remote_identity, requested_at):
    RNS.log("Generating response to request "+RNS.prettyhexrep(request_id))
    texts = ["They looked up", "On each full moon", "Becky was upset", "I'll stay away␣
↪from it", "The pet shop stocks everything"]
    return texts[random.randint(0, len(texts)-1)]

# This initialisation is executed when the users chooses
# to run as a server
def server(configpath):
    # We must first initialise Reticulum
    reticulum = RNS.Reticulum(configpath)

    # Randomly create a new identity for our link example
    server_identity = RNS.Identity()

    # We create a destination that clients can connect to. We
    # want clients to create links to this destination, so we
    # need to create a "single" destination type.
    server_destination = RNS.Destination(
        server_identity,
        RNS.Destination.IN,
        RNS.Destination.SINGLE,
        APP_NAME,
        "requestexample"
```

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```
    )

    # We configure a function that will get called every time
    # a new client creates a link to this destination.
    server_destination.set_link_established_callback(client_connected)

    # We register a request handler for handling incoming
    # requests over any established links.
    server_destination.register_request_handler(
        "/random/text",
        response_generator = random_text_generator,
        allow = RNS.Destination.ALLOW_ALL
    )

    # Everything's ready!
    # Let's Wait for client requests or user input
    server_loop(server_destination)

def server_loop(destination):
    # Let the user know that everything is ready
    RNS.log(
        "Request example "+
        RNS.prettyhexrep(destination.hash)+
        " running, waiting for a connection."
    )

    RNS.log("Hit enter to manually send an announce (Ctrl-C to quit)")

    # We enter a loop that runs until the users exits.
    # If the user hits enter, we will announce our server
    # destination on the network, which will let clients
    # know how to create messages directed towards it.
    while True:
        entered = input()
        destination.announce()
        RNS.log("Sent announce from "+RNS.prettyhexrep(destination.hash))

# When a client establishes a link to our server
# destination, this function will be called with
# a reference to the link.
def client_connected(link):
    global latest_client_link

    RNS.log("Client connected")
    link.set_link_closed_callback(client_disconnected)
    latest_client_link = link

def client_disconnected(link):
    RNS.log("Client disconnected")


##########################################################
```

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```
#### Client Part ###########################################
############################################################

# A reference to the server link
server_link = None

# This initialisation is executed when the users chooses
# to run as a client
def client(destination_hexhash, configpath):
    # We need a binary representation of the destination
    # hash that was entered on the command line
    try:
        if len(destination_hexhash) != 20:
            raise ValueError("Destination length is invalid, must be 20 hexadecimal␣
↪characters (10 bytes)")
        destination_hash = bytes.fromhex(destination_hexhash)
    except:
        RNS.log("Invalid destination entered. Check your input!\n")
        exit()

    # We must first initialise Reticulum
    reticulum = RNS.Reticulum(configpath)

    # Check if we know a path to the destination
    if not RNS.Transport.has_path(destination_hash):
        RNS.log("Destination is not yet known. Requesting path and waiting for announce␣
↪to arrive...")
        RNS.Transport.request_path(destination_hash)
        while not RNS.Transport.has_path(destination_hash):
            time.sleep(0.1)

    # Recall the server identity
    server_identity = RNS.Identity.recall(destination_hash)

    # Inform the user that we'll begin connecting
    RNS.log("Establishing link with server...")

    # When the server identity is known, we set
    # up a destination
    server_destination = RNS.Destination(
        server_identity,
        RNS.Destination.OUT,
        RNS.Destination.SINGLE,
        APP_NAME,
        "requestexample"
    )

    # And create a link
    link = RNS.Link(server_destination)

    # We'll set up functions to inform the
    # user when the link is established or closed
```

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```
    link.set_link_established_callback(link_established)
    link.set_link_closed_callback(link_closed)

    # Everything is set up, so let's enter a loop
    # for the user to interact with the example
    client_loop()

def client_loop():
    global server_link

    # Wait for the link to become active
    while not server_link:
        time.sleep(0.1)

    should_quit = False
    while not should_quit:
        try:
            print("> ", end=" ")
            text = input()

            # Check if we should quit the example
            if text == "quit" or text == "q" or text == "exit":
                should_quit = True
                server_link.teardown()

            else:
                server_link.request(
                    "/random/text",
                    data = None,
                    response_callback = got_response,
                    failed_callback = request_failed
                )


        except Exception as e:
            RNS.log("Error while sending request over the link: "+str(e))
            should_quit = True
            server_link.teardown()

def got_response(request_receipt):
    request_id = request_receipt.request_id
    response = request_receipt.response

    RNS.log("Got response for request "+RNS.prettyhexrep(request_id)+": "+str(response))

def request_received(request_receipt):
    RNS.log("The request "+RNS.prettyhexrep(request_receipt.request_id)+" was received␣
↪by the remote peer.")

def request_failed(request_receipt):
    RNS.log("The request "+RNS.prettyhexrep(request_receipt.request_id)+" failed.")
```

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```
# This function is called when a link
# has been established with the server
def link_established(link):
    # We store a reference to the link
    # instance for later use
    global server_link
    server_link = link

    # Inform the user that the server is
    # connected
    RNS.log("Link established with server, hit enter to perform a request, or type in \
↪"quit\" to quit")

# When a link is closed, we'll inform the
# user, and exit the program
def link_closed(link):
    if link.teardown_reason == RNS.Link.TIMEOUT:
        RNS.log("The link timed out, exiting now")
    elif link.teardown_reason == RNS.Link.DESTINATION_CLOSED:
        RNS.log("The link was closed by the server, exiting now")
    else:
        RNS.log("Link closed, exiting now")

    RNS.Reticulum.exit_handler()
    time.sleep(1.5)
    os._exit(0)


###########################################################
#### Program Startup ######################################
###########################################################

# This part of the program runs at startup,
# and parses input of from the user, and then
# starts up the desired program mode.
if __name__ == "__main__":
    try:
        parser = argparse.ArgumentParser(description="Simple request/response example")

        parser.add_argument(
            "-s",
            "--server",
            action="store_true",
            help="wait for incoming requests from clients"
        )

        parser.add_argument(
            "--config",
            action="store",
            default=None,
            help="path to alternative Reticulum config directory",
```

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```
            type=str
        )

        parser.add_argument(
            "destination",
            nargs="?",
            default=None,
            help="hexadecimal hash of the server destination",
            type=str
        )

        args = parser.parse_args()

        if args.config:
            configarg = args.config
        else:
            configarg = None

        if args.server:
            server(configarg)
        else:
            if (args.destination == None):
                print("")
                parser.print_help()
                print("")
            else:
                client(args.destination, configarg)

    except KeyboardInterrupt:
        print("")
        exit()
```

This example can also be found at https://github.com/markqvist/Reticulum/blob/master/Examples/Request.py.

## 8.8 Filetransfer

The *Filetransfer* example implements a basic file-server program that allow clients to connect and download files. The program uses the Resource interface to efficiently pass files of any size over a Reticulum *Link*.

```
##########################################################
# This RNS example demonstrates a simple filetransfer    #
# server and client program. The server will serve a      #
# directory of files, and the clients can list and        #
# download files from the server.                         #
#                                                         #
# Please note that using RNS Resources for large file     #
# transfers is not recommended, since compression,        #
# encryption and hashmap sequencing can take a long time  #
# on systems with slow CPUs, which will probably result   #
# in the client timing out before the resource sender     #
```

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```
# can complete preparing the resource.                    #
#                                                         #
# If you need to transfer large files, use the Bundle     #
# class instead, which will automatically slice the data  #
# into chunks suitable for packing as a Resource.         #
###########################################################

import os
import sys
import time
import threading
import argparse
import RNS
import RNS.vendor.umsgpack as umsgpack

# Let's define an app name. We'll use this for all
# destinations we create. Since this echo example
# is part of a range of example utilities, we'll put
# them all within the app namespace "example_utilities"
APP_NAME = "example_utilities"

# We'll also define a default timeout, in seconds
APP_TIMEOUT = 45.0

###########################################################
#### Server Part ##########################################
###########################################################

serve_path = None

# This initialisation is executed when the users chooses
# to run as a server
def server(configpath, path):
    # We must first initialise Reticulum
    reticulum = RNS.Reticulum(configpath)

    # Randomly create a new identity for our file server
    server_identity = RNS.Identity()

    global serve_path
    serve_path = path

    # We create a destination that clients can connect to. We
    # want clients to create links to this destination, so we
    # need to create a "single" destination type.
    server_destination = RNS.Destination(
        server_identity,
        RNS.Destination.IN,
        RNS.Destination.SINGLE,
        APP_NAME,
        "filetransfer",
        "server"
```

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```
    )

    # We configure a function that will get called every time
    # a new client creates a link to this destination.
    server_destination.set_link_established_callback(client_connected)

    # Everything's ready!
    # Let's Wait for client requests or user input
    announceLoop(server_destination)

def announceLoop(destination):
    # Let the user know that everything is ready
    RNS.log("File server "+RNS.prettyhexrep(destination.hash)+" running")
    RNS.log("Hit enter to manually send an announce (Ctrl-C to quit)")

    # We enter a loop that runs until the users exits.
    # If the user hits enter, we will announce our server
    # destination on the network, which will let clients
    # know how to create messages directed towards it.
    while True:
        entered = input()
        destination.announce()
        RNS.log("Sent announce from "+RNS.prettyhexrep(destination.hash))

# Here's a convenience function for listing all files
# in our served directory
def list_files():
    # We add all entries from the directory that are
    # actual files, and does not start with "."
    global serve_path
    return [file for file in os.listdir(serve_path) if os.path.isfile(os.path.join(serve_
↪path, file)) and file[:1] != "."]

# When a client establishes a link to our server
# destination, this function will be called with
# a reference to the link. We then send the client
# a list of files hosted on the server.
def client_connected(link):
    # Check if the served directory still exists
    if os.path.isdir(serve_path):
        RNS.log("Client connected, sending file list...")

        link.set_link_closed_callback(client_disconnected)

        # We pack a list of files for sending in a packet
        data = umsgpack.packb(list_files())

        # Check the size of the packed data
        if len(data) <= RNS.Link.MDU:
            # If it fits in one packet, we will just
            # send it as a single packet over the link.
            list_packet = RNS.Packet(link, data)
```

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```
            list_receipt = list_packet.send()
            list_receipt.set_timeout(APP_TIMEOUT)
            list_receipt.set_delivery_callback(list_delivered)
            list_receipt.set_timeout_callback(list_timeout)
        else:
            RNS.log("Too many files in served directory!", RNS.LOG_ERROR)
            RNS.log("You should implement a function to split the filelist over multiple␣
↪packets.", RNS.LOG_ERROR)
            RNS.log("Hint: The client already supports it :)", RNS.LOG_ERROR)

        # After this, we're just going to keep the link
        # open until the client requests a file. We'll
        # configure a function that get's called when
        # the client sends a packet with a file request.
        link.set_packet_callback(client_request)
    else:
        RNS.log("Client connected, but served path no longer exists!", RNS.LOG_ERROR)
        link.teardown()

def client_disconnected(link):
    RNS.log("Client disconnected")

def client_request(message, packet):
    global serve_path

    try:
        filename = message.decode("utf-8")
    except Exception as e:
        filename = None

    if filename in list_files():
        try:
            # If we have the requested file, we'll
            # read it and pack it as a resource
            RNS.log("Client requested \""+filename+"\"")
            file = open(os.path.join(serve_path, filename), "rb")

            file_resource = RNS.Resource(
                file,
                packet.link,
                callback=resource_sending_concluded
            )

            file_resource.filename = filename
        except Exception as e:
            # If somethign went wrong, we close
            # the link
            RNS.log("Error while reading file \""+filename+"\"", RNS.LOG_ERROR)
            packet.link.teardown()
            raise e
    else:
        # If we don't have it, we close the link
```

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```
        RNS.log("Client requested an unknown file")
        packet.link.teardown()

# This function is called on the server when a
# resource transfer concludes.
def resource_sending_concluded(resource):
    if hasattr(resource, "filename"):
        name = resource.filename
    else:
        name = "resource"

    if resource.status == RNS.Resource.COMPLETE:
        RNS.log("Done sending \""+name+"\" to client")
    elif resource.status == RNS.Resource.FAILED:
        RNS.log("Sending \""+name+"\" to client failed")

def list_delivered(receipt):
    RNS.log("The file list was received by the client")

def list_timeout(receipt):
    RNS.log("Sending list to client timed out, closing this link")
    link = receipt.destination
    link.teardown()

################################################################
#### Client Part ###############################################
################################################################

# We store a global list of files available on the server
server_files      = []

# A reference to the server link
server_link       = None

# And a reference to the current download
current_download  = None
current_filename  = None

# Variables to store download statistics
download_started  = 0
download_finished = 0
download_time     = 0
transfer_size     = 0
file_size         = 0


# This initialisation is executed when the users chooses
# to run as a client
def client(destination_hexhash, configpath):
    # We need a binary representation of the destination
    # hash that was entered on the command line
    try:
```

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```
        if len(destination_hexhash) != 20:
            raise ValueError("Destination length is invalid, must be 20 hexadecimal␣
↪characters (10 bytes)")
        destination_hash = bytes.fromhex(destination_hexhash)
    except:
        RNS.log("Invalid destination entered. Check your input!\n")
        exit()

    # We must first initialise Reticulum
    reticulum = RNS.Reticulum(configpath)


    # Check if we know a path to the destination
    if not RNS.Transport.has_path(destination_hash):
        RNS.log("Destination is not yet known. Requesting path and waiting for announce␣
↪to arrive...")
        RNS.Transport.request_path(destination_hash)
        while not RNS.Transport.has_path(destination_hash):
            time.sleep(0.1)

    # Recall the server identity
    server_identity = RNS.Identity.recall(destination_hash)

    # Inform the user that we'll begin connecting
    RNS.log("Establishing link with server...")

    # When the server identity is known, we set
    # up a destination
    server_destination = RNS.Destination(
        server_identity,
        RNS.Destination.OUT,
        RNS.Destination.SINGLE,
        APP_NAME,
        "filetransfer",
        "server"
    )

    # We also want to automatically prove incoming packets
    server_destination.set_proof_strategy(RNS.Destination.PROVE_ALL)

    # And create a link
    link = RNS.Link(server_destination)

    # We expect any normal data packets on the link
    # to contain a list of served files, so we set
    # a callback accordingly
    link.set_packet_callback(filelist_received)

    # We'll also set up functions to inform the
    # user when the link is established or closed
    link.set_link_established_callback(link_established)
    link.set_link_closed_callback(link_closed)
```

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```
    # And set the link to automatically begin
    # downloading advertised resources
    link.set_resource_strategy(RNS.Link.ACCEPT_ALL)
    link.set_resource_started_callback(download_began)
    link.set_resource_concluded_callback(download_concluded)

    menu()

# Requests the specified file from the server
def download(filename):
    global server_link, menu_mode, current_filename, transfer_size, download_started
    current_filename = filename
    download_started = 0
    transfer_size    = 0

    # We just create a packet containing the
    # requested filename, and send it down the
    # link. We also specify we don't need a
    # packet receipt.
    request_packet = RNS.Packet(server_link, filename.encode("utf-8"), create_
↪receipt=False)
    request_packet.send()

    print("")
    print(("Requested \""+filename+"\" from server, waiting for download to begin..."))
    menu_mode = "download_started"

# This function runs a simple menu for the user
# to select which files to download, or quit
menu_mode = None
def menu():
    global server_files, server_link
    # Wait until we have a filelist
    while len(server_files) == 0:
        time.sleep(0.1)
    RNS.log("Ready!")
    time.sleep(0.5)

    global menu_mode
    menu_mode = "main"
    should_quit = False
    while (not should_quit):
        print_menu()

        while not menu_mode == "main":
            # Wait
            time.sleep(0.25)

        user_input = input()
        if user_input == "q" or user_input == "quit" or user_input == "exit":
            should_quit = True
```

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```
            print("")
        else:
            if user_input in server_files:
                download(user_input)
            else:
                try:
                    if 0 <= int(user_input) < len(server_files):
                        download(server_files[int(user_input)])
                except:
                    pass

    if should_quit:
        server_link.teardown()

# Prints out menus or screens for the
# various states of the client program.
# It's simple and quite uninteresting.
# I won't go into detail here. Just
# strings basically.
def print_menu():
    global menu_mode, download_time, download_started, download_finished, transfer_size,␣
↪file_size

    if menu_mode == "main":
        clear_screen()
        print_filelist()
        print("")
        print("Select a file to download by entering name or number, or q to quit")
        print(("> "), end=' ')
    elif menu_mode == "download_started":
        download_began = time.time()
        while menu_mode == "download_started":
            time.sleep(0.1)
            if time.time() > download_began+APP_TIMEOUT:
                print("The download timed out")
                time.sleep(1)
                server_link.teardown()

    if menu_mode == "downloading":
        print("Download started")
        print("")
        while menu_mode == "downloading":
            global current_download
            percent = round(current_download.get_progress() * 100.0, 1)
            print(("\rProgress: "+str(percent)+" %   "), end=' ')
            sys.stdout.flush()
            time.sleep(0.1)

    if menu_mode == "save_error":
        print(("\rProgress: 100.0 %"), end=' ')
        sys.stdout.flush()
        print("")
```

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```
        print("Could not write downloaded file to disk")
        current_download.status = RNS.Resource.FAILED
        menu_mode = "download_concluded"

    if menu_mode == "download_concluded":
        if current_download.status == RNS.Resource.COMPLETE:
            print(("\rProgress: 100.0 %"), end=' ')
            sys.stdout.flush()

            # Print statistics
            hours, rem = divmod(download_time, 3600)
            minutes, seconds = divmod(rem, 60)
            timestring = "{:0>2}:{:0>2}:{:05.2f}".format(int(hours),int(minutes),seconds)
            print("")
            print("")
            print("--- Statistics -----")
            print("\tTime taken       : "+timestring)
            print("\tFile size        : "+size_str(file_size))
            print("\tData transferred : "+size_str(transfer_size))
            print("\tEffective rate   : "+size_str(file_size/download_time, suffix='b')+
↪"/s")
            print("\tTransfer rate    : "+size_str(transfer_size/download_time, suffix='b
↪')+"/s")
            print("")
            print("The download completed! Press enter to return to the menu.")
            print("")
            input()

        else:
            print("")
            print("The download failed! Press enter to return to the menu.")
            input()

        current_download = None
        menu_mode = "main"
        print_menu()

# This function prints out a list of files
# on the connected server.
def print_filelist():
    global server_files
    print("Files on server:")
    for index,file in enumerate(server_files):
        print("\t("+str(index)+")\t"+file)

def filelist_received(filelist_data, packet):
    global server_files, menu_mode
    try:
        # Unpack the list and extend our
        # local list of available files
        filelist = umsgpack.unpackb(filelist_data)
        for file in filelist:
```

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```
            if not file in server_files:
                server_files.append(file)

        # If the menu is already visible,
        # we'll update it with what was
        # just received
        if menu_mode == "main":
            print_menu()
    except:
        RNS.log("Invalid file list data received, closing link")
        packet.link.teardown()

# This function is called when a link
# has been established with the server
def link_established(link):
    # We store a reference to the link
    # instance for later use
    global server_link
    server_link = link

    # Inform the user that the server is
    # connected
    RNS.log("Link established with server")
    RNS.log("Waiting for filelist...")

    # And set up a small job to check for
    # a potential timeout in receiving the
    # file list
    thread = threading.Thread(target=filelist_timeout_job)
    thread.setDaemon(True)
    thread.start()

# This job just sleeps for the specified
# time, and then checks if the file list
# was received. If not, the program will
# exit.
def filelist_timeout_job():
    time.sleep(APP_TIMEOUT)

    global server_files
    if len(server_files) == 0:
        RNS.log("Timed out waiting for filelist, exiting")
        os._exit(0)


# When a link is closed, we'll inform the
# user, and exit the program
def link_closed(link):
    if link.teardown_reason == RNS.Link.TIMEOUT:
        RNS.log("The link timed out, exiting now")
    elif link.teardown_reason == RNS.Link.DESTINATION_CLOSED:
        RNS.log("The link was closed by the server, exiting now")
```

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```
    else:
        RNS.log("Link closed, exiting now")

    RNS.Reticulum.exit_handler()
    time.sleep(1.5)
    os._exit(0)

# When RNS detects that the download has
# started, we'll update our menu state
# so the user can be shown a progress of
# the download.
def download_began(resource):
    global menu_mode, current_download, download_started, transfer_size, file_size
    current_download = resource

    if download_started == 0:
        download_started = time.time()

    transfer_size += resource.size
    file_size = resource.total_size

    menu_mode = "downloading"

# When the download concludes, successfully
# or not, we'll update our menu state and
# inform the user about how it all went.
def download_concluded(resource):
    global menu_mode, current_filename, download_started, download_finished, download_
↪time
    download_finished = time.time()
    download_time = download_finished - download_started

    saved_filename = current_filename

    if resource.status == RNS.Resource.COMPLETE:
        counter = 0
        while os.path.isfile(saved_filename):
            counter += 1
            saved_filename = current_filename+"."+str(counter)

        try:
            file = open(saved_filename, "wb")
            file.write(resource.data.read())
            file.close()
            menu_mode = "download_concluded"
        except:
            menu_mode = "save_error"
    else:
        menu_mode = "download_concluded"

# A convenience function for printing a human-
# readable file size
```

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```
def size_str(num, suffix='B'):
    units = ['','Ki','Mi','Gi','Ti','Pi','Ei','Zi']
    last_unit = 'Yi'

    if suffix == 'b':
        num *= 8
        units = ['','K','M','G','T','P','E','Z']
        last_unit = 'Y'

    for unit in units:
        if abs(num) < 1024.0:
            return "%3.2f %s%s" % (num, unit, suffix)
        num /= 1024.0
    return "%.2f %s%s" % (num, last_unit, suffix)

# A convenience function for clearing the screen
def clear_screen():
    os.system('cls' if os.name=='nt' else 'clear')

###########################################################
#### Program Startup #####################################
###########################################################

# This part of the program runs at startup,
# and parses input of from the user, and then
# starts up the desired program mode.
if __name__ == "__main__":
    try:
        parser = argparse.ArgumentParser(
            description="Simple file transfer server and client utility"
        )

        parser.add_argument(
            "-s",
            "--serve",
            action="store",
            metavar="dir",
            help="serve a directory of files to clients"
        )

        parser.add_argument(
            "--config",
            action="store",
            default=None,
            help="path to alternative Reticulum config directory",
            type=str
        )

        parser.add_argument(
            "destination",
            nargs="?",
            default=None,
```

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```
            help="hexadecimal hash of the server destination",
            type=str
        )

        args = parser.parse_args()

        if args.config:
            configarg = args.config
        else:
            configarg = None

        if args.serve:
            if os.path.isdir(args.serve):
                server(configarg, args.serve)
            else:
                RNS.log("The specified directory does not exist")
        else:
            if (args.destination == None):
                print("")
                parser.print_help()
                print("")
            else:
                client(args.destination, configarg)

    except KeyboardInterrupt:
        print("")
        exit()
```

This example can also be found at https://github.com/markqvist/Reticulum/blob/master/Examples/Filetransfer.py.

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