Towards Modernising Data Collection and Archive for the Tor Network

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Contents

Abstract

CollecTor is developed by Tor Project's Metrics Team for the purpose of archiving data relating to the public Tor network and applications developed by Tor Project. This report distills the requirements for a prototype modernized replacement of the CollecTor service, and evaluates frameworks and libraries that are available to reduce code maintenance costs for the CollecTor service.

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1 Introduction

The Tor anonymity system [3] protects Internet users from tracking, surveillance, and censorship. The Tor network is made up of thousands of volunteer-run *relays*—servers that are usually located in data centers—distributed across the world that enable users to make private connections to services on the Internet. Currently, the vast majority of connections to the Tor network are made using the Tor Browser. But a growing number of applications use the Tor network, and we expect that many more will do so in the future.

Ongoing, robust network measurement is essential in order to respond to censorship events, to adapt Tor Browser and other applications to respond to changing network conditions, and to validate changes to the Tor network software.

In the field of Internet Engineering and Privacy Enhancing Technologies it is not common to come across large open datasets. Often this can be due difficulties balancing utility goals with privacy risks. CAIDA, one example of an organization that does make anonymised Internet Engineering datasets available[1], has performed a detailed analysis of the potential issues [2]. In the field of medicine and bio-informatics however, there has been a longer history of open data and data re-use across studies. In one analysis, it was found that investment in the archive and curation of open datasets had vastly greater research output returns than solely investing in original research [10].

By collecting data about the Tor network it becomes possible to create accurate emulations or simulations of the network [6] [7] [17]. This in turn allows for researchers to perform experiments on private testbeds as opposed to on the public network where the experiment may harm the security or anonymity properties of the Tor network. By collecting data over time, it is possible to see trends in the data. For example, the blocking of Tor in China can be identified from the data [9]. Data collection can then also be used to validate whether or not a particular circumvention technique is working in a particular country.

The CollecTor service fetches data from various servers in the public Tor network and related services and makes it available to the world[2]. The CollecTor service provides network data collected since 2004, and has existed in its current form as a Java application since 2010. Over time new modules have been added to collect new data and other modules have been retired as the services they downloaded data from no longer exist.

As the CollecTor codebase has grown, technical debt has emerged as we have added new features without refactoring existing code. This results in it becoming increasingly difficult to add new data sources to CollecTor as the complexity of the application increases. Some of the requirements of CollecTor, such as concurrency or scheduling, are common to many applications and frameworks exist implementing best practices for these components that could be used in place of the current bespoke implementations.

This report details the core requirements for a data collection application for the Tor network (§2) and the specific requirements for two modules of the application: `relaydescs` (§3) and `onionperf` (§4). Library frameworks that might be used for development of this application are then evaluated against these requirements (§5) and an initial prototype is introduced (§6). Finally, next steps are identified for progressing the development of the application (§7).

[1] An index of public datasets can be found at: https://www.caida.org/data/overview/.

[2] Documentation for the current implementation of the CollecTor service can be found at: https://metrics.torproject.org/collector.html.

2 Core Requirements

2.1 Collect

Tor Relay Descriptors `(relaydescs)`

Relays and directory authorities publish relay descriptors, so that clients can select relays for their paths through the Tor network. This module is discussed in more detail in §3.

Bridge Descriptors `(bridgedescs)`

Bridges and the bridge authority publish bridge descriptors that are used by censored clients to connect to the Tor network. We cannot, however, make bridge descriptors available as we do with relay descriptors, because that would defeat the purpose of making bridges hard to enumerate for censors. We therefore sanitize bridge descriptors by removing all potentially identifying information and publish sanitized versions here.

Bridge Pool Assignments `(bridgepools)`

The bridge distribution service BridgeDB publishes bridge pool assignments describing which bridges it has assigned to which distribution pool. BridgeDB receives bridge network statuses from the bridge authority, assigns these bridges to persistent distribution rings, and hands them out to bridge users. BridgeDB periodically dumps the list of running bridges with information about the rings, subrings, and file buckets to which they are assigned to a local file. The sanitized versions of these lists containing SHA-1 hashes of bridge fingerprints instead of the original fingerprints are available for statistical analysis. This module has not been used since 2016, however may be reintroduced in the future.

Web Server Logs `(webstats)`

Tor's web servers, like most web servers, keep request logs for maintenance and informational purposes. However, unlike most other web servers, Tor's web servers use a privacy-aware log format that avoids logging too sensitive data about their users. Also unlike most other web server logs, Tor's logs are neither archived nor analyzed before performing a number of post-processing steps to further reduce any privacy-sensitive parts.

Exit Lists `(exitlists)`

The exit list service *TorDNSEL* publishes exit lists containing the IP addresses of relays that it found when exiting through them.

Torperf's and OnionPerf's Performance Data `(onionperf)`

The performance measurement services Torperf and OnionPerf publish performance data from making simple HTTP requests over the Tor network. Torperf/OnionPerf use a SOCKS client to download files of various sizes over the Tor network and notes how long substeps take. This module is discussed in more detail in §4.

Future Active Measurement Modules

Active measurement, from a perspective of user privacy, can be considerably safer than passive measurement. As the Tor network continues to grow, we may wish to expand the use of active measurement using tools such as *PATHspider* [8] or *exitmap* [19].

2.2 Archive

While it is important for clients and servers in the Tor network to have strict validation of documents and their signatures, the CollecTor service does not want to just drop documents that fail validation. It may be that a descriptor is using a new format that we don't yet understand, or perhaps it is malformed due to a bug and having the documents archived will help in debugging the issue.

The archive should be able to verify its own integrity, ensuring that descriptors have not been truncated or altered. It should also be possible to determine the amount of descriptors that are missing, either through timestamps where a descriptor/status should have been made available or by a descriptor being referenced from another descriptor, and warn if the amount of missing descriptors exceeds a predefined threshold.

Archiving cryptographic signatures can present challenges as the signatures themselves use algorithms that over time will either be broken due to design or implementation flaws, or simply due to the increase in available computing power. A number of systems provide archive timestamps [1] [5] where it is possible to prove that a data object existed at a given time and so if an algorithm is considered to not be broken at that time then the original signature can be trusted.

2.3 Serve

CollecTor does not only collect and archive documents, but also makes them available to other applications. These may be other services run by Tor Metrics such as Onionoo[3], or external applications run by researchers.

For services that would like to consume all descriptors of a particular type as they become known, CollecTor needs to make available recently obtained descriptors. This is currently done by providing descriptors in a concatenated form with one file per download run, however we may in the future only provide an index to the recently downloaded descriptors to allow for applications to fetch only the descriptors they need.

To facilitate the use of other CollecTor instances as data sources, and to offset load generated on the network by CollecTor, a modern CollecTor may implement parts of the Tor directory protocol version 3 [13]. If this protocol were extended to provide index functionality then the current system of providing concatenated files for recent documents could be replaced. This would also be of benefit for those debugging issues with the network as individual descriptors could be easily downloaded for manual examination.

Currently the Onionoo service begins to download data from CollecTor between :15 and :20 past the hour. If it were possible to download data sooner than this, this would be of benefit to those monitoring the health of the Tor network and individual relay operators as they would be

[3]This service is described at: https://metrics.torproject.org/onionoo.html.

Document	Created by†	Served by†	per hour	size ea.	size per hour
Detached Signature	A	A	9	1276B	11.48KB
Status Consensus "ns"	A	C	1	2.17MB	2.17MB
Status Consensus "microdesc"	A	C	1	2.00MB	2.00MB
Status Vote	A	A	9	4.34MB	39.02MB
Bandwidth List‡	A	A	6	2.60MB	15.60MB
Server Descriptor	R	C	707	2829B	2.00MB
Extra Info Descriptor	R	E	705	2100B	1.48MB
Microdescriptor	A	C	35	506B	17.70KB
Total	—	—	1473	—	62.30MB

† A is the set of directory authorities, E is the set of extra info caches, C is the set of directory caches, and R is the set of all relays. $A \subseteq E \subseteq C \subseteq R$.

‡ These numbers are estimates of the numbers we will see once bandwidth lists are advertised from all planned bandwidth authorities. They were not advertised by any authority in September 2018.

Table 1: Summary of document types collected by the `relaydescs` module. Counts per hour and average sizes are determined by the descriptors that were archived by CollecTor for September 2018.

able to detect problems sooner. If CollecTor could also provide status information about the times at which it had completed its latest download tasks, then services could consume this in order to improve the timeliness of downloads.

For services that would like to perform historical analysis of the collected documents, all documents must be available for download. Currently this is done by providing monthly compressed tarballs containing the documents.

An index file that references the filenames for these concatenated files and archives is generated to assist applications in discovering documents, but it currently does not index the specific documents contained within the concatenated files or tarballs.

3 The `relaydescs` module

The `relaydescs` module is the primary module for data about the public Tor network. This module collects network status votes and consensuses, certificates, microdescriptors, and server and extra-info descriptors. The format and purpose of each of these documents is described in version 3 of the Tor directory protocol specification [13].

In the past, this module would also collect version 2 network statuses and version 1 directories from the network. While we will not implement collecting these from a live network, they should be importable via the local filesystem.

A summary of the documents collected by this module is shown in table 1. The counts and sizes of each document type are expected to increase over time, though some more than others. The bandwidth list document type is still under development with new features being added,

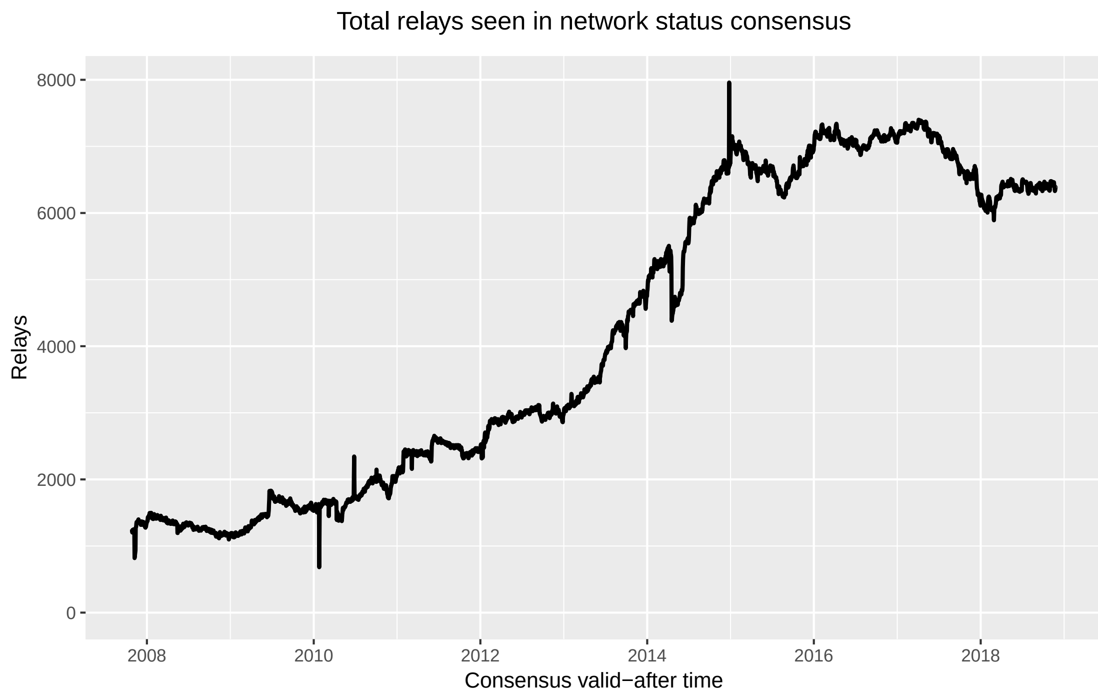


Figure 1: Number of relays seen running in each consensus between September 2007 and November 2018.

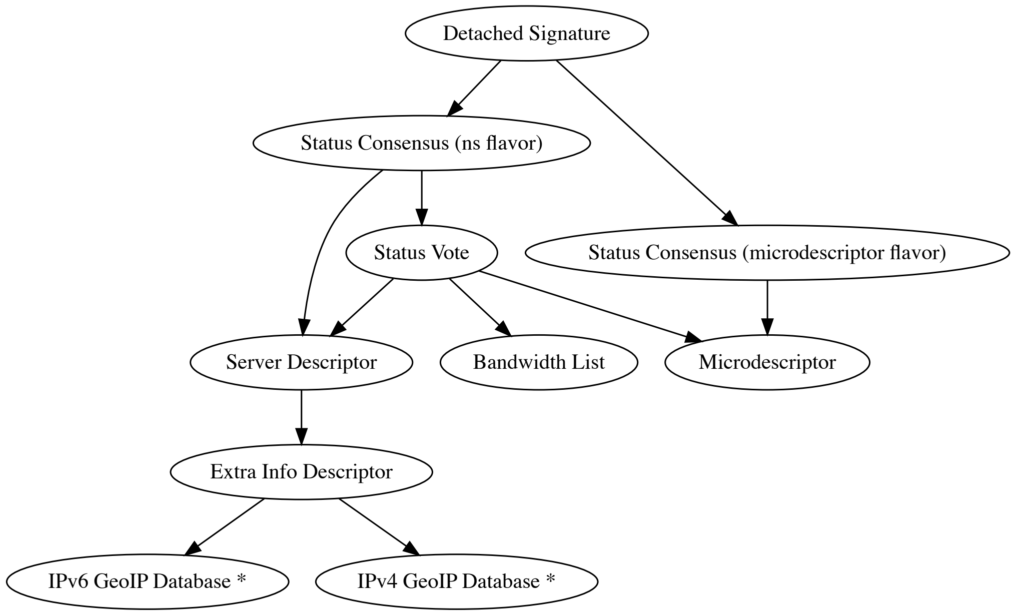
for example, while microdescriptors are intentionally minimal containing as little information as possible for clients to still be able to function. Figure 1 shows the number of relays seen running in consensuses since 2007, which directly influences the number of server, extra-info and microdescriptors seen and also the sizes of other documents. This number has remained relatively stable in recent years with network growth coming from more capable relays as opposed to increased numbers of individual relays.

While most documents are served by caches, they are not instantly available from every cache and timing must be carefully considered. References between documents are shown in figure 2. All document types can be collected by fetching the detached signatures and recursively downloading the referenced documents.

Unfortunately, detached signatures are only available for (typically) 5 minutes per voting period and only from the authority that generated them[4]. While there are currently only two consensus flavors, there may be more in the future and missing a detached signature means that we would not discover it. As these documents are so tricky to get hold of, an example is presented in appendix A.

Without detatched signatures it is still possible to guess that a new consensus is available when the currently known consensus is no longer “fresh”, as determined by the fresh-until time in the known consensus. The known consensus flavors can then be downloaded.

[4]The Tor directory protocol §3.11 does specify a URL for the detached signature that relates to the current consensus, but this URL has not been implemented in `tor`.



*The GeoIP databases are referenced here but not archived themselves in CollecTor.

Figure 2: Document references within documents collected by the `relaydescs` module.

3.1 Document Sources

This module will need to fetch data from both the network, and the local file system. Depending on how old a descriptor is, it may be available from different locations on the network.

Network locations include:

- Directory Authorities (using version 3 of the Tor directory protocol)
  - Connections might use DirPorts or tunnel over the relay's ORPort using the mechanism described in §2.6.1 of the Tor protocol specification [14].
- Directory Caches (using version 3 of the Tor directory protocol)
  - As above. Additionally, directory caches that do not set "caches-extra-info" in their server descriptors, as described in §2.1.1 of the Tor directory protocol, may not make extra-info descriptors available.
  - Future versions of CollecTor may additionally implement the Tor directory protocol to allow for code reuse in fetching from other CollecTor instances. This is discussed further in §3.4.
- CollecTor instances (using CollecTor's File Structure Protocol [11])

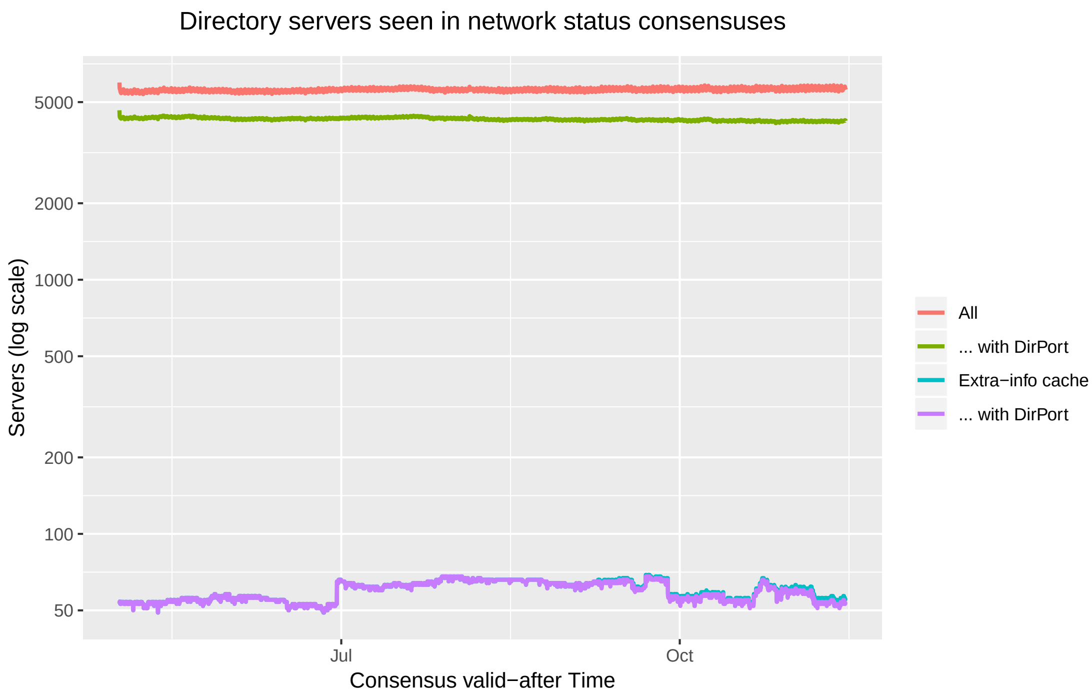


Figure 3: Number of directory servers and extra-info caches seen running in each consensus between May 2018 and November 2018.

This report is written with the assumption that the Tor directory protocol exists as-is, although conclusions from this report may influence work in improving or extending the protocol later to improve performance, archive rate (ratio of documents archived compared to documents missed), or to reduce bandwidth cost.

At the time of writing there are 9 directory authorities and 2 CollecTor instances. Figure 3 shows the numbers of directory caches and extra-info caches seen in each consensus recently. In the time period shown, there was an average of 5591 directory caches in each consensus. There are some directory caches however that we are not currently able to use as they do not advertise a DirPort. The *stem* library has initial support for using ORPort tunnelling to retrieve descriptors, but it is not yet reliable. There does not exist a Java implementation that the current implementation of CollecTor could use to download descriptors via an ORPort. This leaves an average of 4286 usable directory caches in each consensus.

When it comes to fetching extra-info descriptors, there are an average of 59.6 extra-info caches in each consensus. Of these, 59.2 on average advertise a DirPort. By default extra-info descriptors are not cached by directory caches as the descriptors are not of use to clients. If numbers are maintained at their current levels then this should provide adequate fallback to allow collection of descriptors if the directory authorities become unreachable.

For both directory caches and extra-info caches the trend is that the number of caches advertising a DirPort is decreasing and so it is important to think about how a modern CollecTor would be able to fetch via an ORPort instead.

In addition to fetching from the network, documents may also be imported from the local file system. These formats include:

- CollecTor's File Structure Protocol
- Cached descriptors from a `tor` client's data directory

3.2 Download Scheduling

The timing of document download tasks is determined by the valid-after (t_{VA}) and fresh-until (t_{FU}) lines found in the latest consensus. DistSeconds (d_{dist}) and VoteSeconds (d_{vote}) are determined by the voting-delay line in the latest consensus. t_0 is defined as the time that the module is started. More information on these timings can be found in §1.4 of the Tor directory protocol.

For all documents downloaded, the descriptors are annotated with their type and other metadata before being saved in the archive. Each time a task is run, the new descriptors collected should be made available either as a concatenated file or as an index of descriptors to be downloaded by applications that would like to consume all of a particular type of descriptor.

Task 0: Bootstrap $t = t_0$

Download the latest current consensus from a directory authority if we do not already have one. If a download fails, try another directory authority until all have been tried.

Task 1: Eager Vote Fetching $t = t_{FU} - d_{dist} - \frac{d_{vote}}{2}$

Download the next votes from each directory authority concurrently. During this time the votes have not yet been computed into a consensus, but we are able to parse the votes to get a head start on discovering new descriptors. Server descriptors, extra-info descriptors and microdescriptors are all available to fetch at this stage.

Task 2: Eager Consensus Fetching $t = t_{FU} - \frac{d_{dist}}{2}$

Download the detached signatures from each authority. This allows us to discover all consensuses that have been generated.

If authorities have computed different consensuses, this is the only time at which they can be retrieved. Archiving these alternate consensuses may prove to be useful in debugging bugs in computing consensuses[5]. A consensus requires $\frac{n}{2} + 1$ signatures, where n is the total number of known directory authorities, in order to be served via the directory protocol as the current consensus. The voting protocol does not preclude the existence of more than one valid consensus.

[5] In July 2018, a bug occurred in the sorting of version numbers leading to 5 authorities voting one way, and 4 voting another. Comparing the consensuses allowed the root cause to be quickly discovered. See https://bugs.torproject.org/26485 for more information.

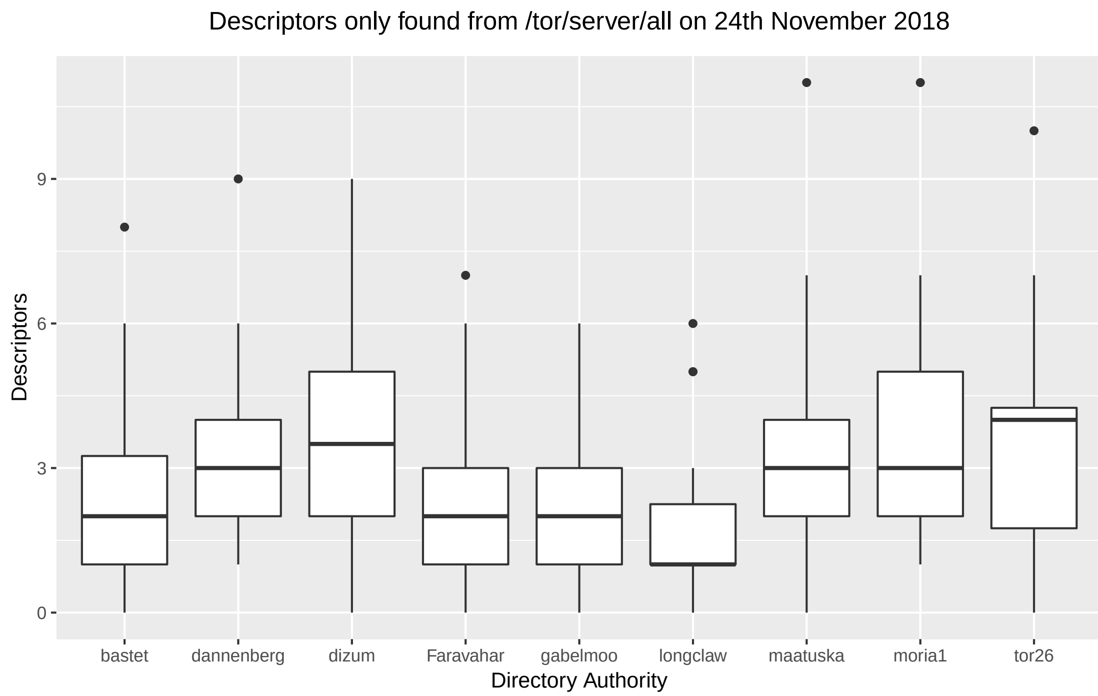


Figure 4: Number of server descriptors that are found by requesting the URL of all known server descriptors from directory authorities at :35 to :40 minutes past the hour, every hour, on the 24th November 2018, that were not referenced by the vote generated prior to, or after the download.

Task 3: Greedy Discovery ⚠

While not bandwidth-friendly, directory authorities provide a method for downloading a concatenated set of the most recent descriptors for all known servers. This can include descriptors that have not been included in votes, but almost certainly includes many descriptors we already know about. The current CollecTor implementation has support for this feature and would run this task every 24-hours if enabled. The official Tor Metrics instances do not have this enabled.

Download the full list of extra-info descriptors from every authority. If a request for an authority fails, do not repeat the request. Once complete, download the full list of server descriptors from every authority. Again, if a request for an authority fails, do not repeat the request. The extra-info descriptors are requested first to avoid the reference checker discovering the extra-info descriptors from the server-descriptors and enqueueing download tasks to retrieve them.

An experiment performed during the preparation of this report has shown that this is incredibly wasteful with a mean average of 2.9 descriptors discovered by downloading all known descriptors compared to those discovered through references in the votes prior to and after the download. Figure 4 shows the distributions across the directory authorities. Each analysis considered only a single directory authority.

Only two instances were seen across all directory authorities in the 24 hour period of a descriptor being available in two consecutive downloads of all known descriptors without being referenced by the vote in between. In both cases, the authority was "dizum". Upon investigation, one descriptor is for a relay that appears to have a dynamic IP address and non-continuous uptime. The second descriptor is for a relay that is running `tor` version 0.2.4.20, a no longer recommended version. It is not clear why these descriptors were retained but not used in a vote. The authority may have not found the relays to be reachable before the vote was generated.

As each download during the experiment was approximately 17 megabytes (uncompressed), there does not appear to be any compelling reason to enable this feature. In order to avoid missing descriptors it would have to run every hour, and not every 24 hours as the current implementation does.

A future extension to the Tor directory protocol may enable collecting these descriptors by providing a URL that only serves descriptors that were not present in the last vote. The timing to use for this request would need to be considered unless authorities were also to make available multiple descriptors for a single relay in this new URL instead of just the latest.

Task 4: Continuous Reference Checking ↻

This task runs continuously. It holds a collection of "starting point" documents that have been fetched by tasks 0–2. At startup, the last 3 hours of available "starting point" documents will be loaded from the archive on disk if available.

This task keeps a list of documents that have been requested since the downloader last changed phase (described in §3.3). If a download is attempted, it won't be attempted again until the next phase.

The reference checker follows a fixed process. It first guesses at new consensuses, consensus flavors, consensus signatures, or votes that might exist based on the current time and fetches these, adding them to the "starting point" documents. Using these:

1. From each vote, bandwidth files are identified and fetched.
2. From each vote and consensus, server descriptors and microdescriptors are identified and fetched.
3. From each server descriptor, extra-info descriptors are identified and fetched.

When fetching server descriptors, extra-info descriptors, and microdescriptors, these are batched to reduce the number of requests that must be made. After each download attempt, the descriptor digests that were received are removed from the request and it is then repeated against another server until each of the servers available has been tried.

Following each run, starting points that are older than 3 hours are removed.

3.3 Downloader Operation

The downloader will fetch descriptors in two phases. This modifies the behavior of the reference checker. Until a consensus is known, the downloader will operate in phase α. The main motivation behind the phases is to allow a second chance for the reference checker, described in the previous section, to locate any missing descriptors. It will also allow for load balancing in the event that downloads are triggered for descriptors that would now be available from directory caches.

Phase α: Directory Cache Mode $t_{FU} - d_{dist} - \frac{d_{vote}}{2} \leqslant t < t_{VA} + \frac{t_{FU} - t_{VA}}{2}$

During this time, downloads occur in a similar manner to directory caches as described in §4 of the Tor directory protocol. If a vote download failed in the previous step, it must be re-attempted now. If a consensus download failed in the previous step it must be re-attempted now. As in phase 2, we should try to collect all available consensus signatures (or alternate consensuses).

If a download for a particular descriptor fails, we will attempt the download again using another authority. Within a single phase period, only one attempt is made per authority per descriptor.

Phase β: Client Mode $t_{VA} + \frac{t_{FU} - t_{VA}}{2} \leqslant t < t_{FU} - d_{dist} - \frac{d_{vote}}{2}$

During this time, downloads occur in a similar manner to clients as described in §5 of the Tor directory protocol. This phase gives a second chance for descriptors that were missed earlier. This mode would also include fetching from other known CollecTor instances via the Tor directory protocol as discussed in the next section.

Directory caches in the network will have retrieved all the descriptors referenced by the latest consensus by the start of this period.

3.4 Directory Server

A server, either as part of CollecTor or as a CollecTor client, implementing the Tor directory protocol would be able to act as a directory cache. All of the necessary documents are already available in the archive, they just need to be returned when requested. Consensus diff[6] functionality would require some additional logic to be provided, but this functionality could also be used to fetch consensus diffs instead of full consensuses to reduce the load on the network created by CollecTor.

As a CollecTor instance retains descriptors for longer than the average directory cache in the Tor network, missing descriptors could be synchronized from other instances once they are no longer available from the caches. While this does introduce the need to add code that serves the descriptors, it reduces the need for alternate code to synchronize with other instances. It is not currently possible to download individual descriptors from another CollecTor instance.

This server would only implement a directory server and would not function as a relay. Currently no such servers exist in the consensus but if one did, it would be compliant with the protocol. There is a risk that such servers may provide poor performance which would degrade client performance, and cause extra bandwidth to be used by clients as requests may need to be retried. Directory authorities would not perform the usual checks as there is no ORPort to use.

The Tor directory protocol previously specified a "BadDir" flag that could be used to mark bad directories, indicating that clients should not attempt to use them. This functionality was removed from `tor` in 2014[7].

[6] This functionality is described in §4.5 of the Tor directory protocol.

[7] More information about the removal of the flag can be found at: `https://bugs.torproject.org/13060`.

4 The `onionperf` module

In comparison to the `relaydescs` module, this module is a lot simpler. OnionPerf[8] uses multiple processes and threads to download random data through Tor while tracking the performance of those downloads. The data is served and fetched on localhost using two TGen (traffic generator) processes, and is transferred through Tor using Tor client processes and an ephemeral Tor Onion Service. Tor control information and TGen performance statistics are logged to disk, analyzed once per day to produce a json stats database and files that use the Torperf results format, and can later be used to visualize changes in Tor client performance over time.

4.1 Document Sources

This module collects the Torperf formatted results files from OnionPerf instances, of which Tor Metrics currently has 3. One result file is produced at midnight each day for each of the file sizes configured to test with. There are three file sizes used for measurements: 50 KiB, 1MiB and 5MiB. This means that we collect $3 \times 3 = 9$ results files each day. The size of the downloads are chosen probabilistically and so it is not easy to predict the sizes of each file. In September 2018, a total of 24 MB of results were collected.

4.2 Download Scheduling

Each day the scheduler should start downloads of the results from the previous day. There are no other sources available, except perhaps other CollecTor instances, for the files and so if a file is unable to be retrieved due to a permanent error it should not be reattempted.

5 Frameworks Evaluated

All of the evaluated frameworks use the Python language, initially targeting version 3.7[9]. Tor Metrics runs its services on Debian stable systems. The next Debian release, Debian 10 "buster", is expected mid-2019 and will include Python 3.7 or later.

The CollecTor service is still well within the limits for operation on a single machine and so while distributed frameworks such as Apache Beam do offer scalability, in this case it is unnecessary and would lead to additional complexity in the codebase. There are four main areas in which we would like to re-use an existing framework: descriptor parsing, concurrency, scheduling and plugin architecture. Each of the frameworks is evaluated for its applicability to the application and its ability to reduce software development and maintenance costs for the CollecTor application.

[8] The source code and documentation for OnionPerf can be found at: `https://github.com/robgjansen/onionperf`.

[9] Should it be necessary to deploy any replacement service before the next Debian release, it would be possible to use lower-level mechanisms to recreate the Python 3.7 language features we use, but this would mean additional code complexity and maintenance costs, which we are trying to reduce.

5.1 Document Parsing

CollecTor needs to work with many document formats that are specific to the Tor ecosystem. The current Java implementation of CollecTor uses metrics-lib[10] which is primarily maintained by Tor Metrics for the use of applications developed by Tor Metrics.

stem

stem[11] is a Python library for parsing Tor-specific data formats, and for interacting with remote Tor servers (i.e. directory servers). It does not support all the current formats supported by metrics-lib although this support can be added. The library is also used as part of Tor Project's `nyx` application and as part of the test-suite for `tor` which means that it is being exercised by more developers than just the Tor Metrics team and hopefully allows for issues to be quickly discovered and fixed.

5.2 Concurrency

The vast majority of the work performed by CollecTor is I/O bound. That is to say that the time it takes to complete a task is determined principally by the period spent waiting for I/O (network or disk) operations, to be completed. When fetching server descriptors, extra-info descriptors, or microdescriptors, there will typically be thousands of descriptors to fetch before moving on to the next stage. Downloads of descriptors of the same type do not depend on each other and so are candidates for concurrent execution.

The current Java implementation of CollecTor uses `java.util.concurrent`[12] to provide concurrency, with the tasks running in threads. All synchronisation between tasks must be performed manually.

asyncio

asyncio[13] [16] is a framework for asynchronous programming in Python. Coroutines declared with `async`/`await` syntax [15] is the preferred way of writing *asyncio* applications. While callbacks are possible, they are not used explicitly in practice. Future objects, which represent an eventual result of an asynchronous operation, are used to bridge low-level callback-based code with high-level `async`/`await` code.

Other language features, for example the ability to delegate to a subgenerator [4], allow for concurrent programming while writing in a sequential fashion. Parallel computing using threads is hard because of race conditions. *asyncio* is explicit about where the event loop may take control of the program. This reduces mental load for developers as resulting programs are easier to follow, which should help to reduce development and maintenance costs directly.

While the *stem* library does not have native support for *asyncio* it does have support for asynchronous requests and a simple wrapper can be written to allow integration. An example is shown in listing 1.

[10]The documentation can be found at: https://metrics.torproject.org/metrics-lib/.

[11]The documentation can be found at: https://stem.torproject.org/.

[12]The documentation can be found at: https://docs.oracle.com/javase/8/docs/api/java/util/concurrent/package-summary.html.

[13]The documentation can be found at: https://docs.python.org/3.7/library/asyncio.html.

```python
async def fetch_consensus():
    """
    Returns the latest consensus.
    """
    loop = asyncio.get_running_loop()
    query = stem.descriptor.remote.Query("/tor/status-vote/current/consensus",
        document_handler=stem.descriptor.DocumentHandler.DOCUMENT)
    result = await loop.run_in_executor(None, query.run)
    for consensus in result:
        return consensus
```

Listing 1: Python *asyncio* wrapper for *stem* to download the latest consensus

```python
async def fetch_consensus():
    """
    Returns the latest consensus.
    """
    query = stem.descriptor.remote.Query("/tor/status-vote/current/consensus",
        document_handler=stem.descriptor.DocumentHandler.DOCUMENT)
    result = await curio.run_in_thread(query.run)
    for consensus in result:
        return consensus
```

Listing 2: Python *curio* wrapper for *stem* to download the latest consensus

asyncio is part of the Python standard library. It may still be quite new but it has momentum.

For modules like the `onionperf` module, that require only to fetch data from a remote HTTP server, the *aiohttp*[14] library provides an *asyncio*-compatible asynchronous HTTP client. This library also includes web server functionality that could be used to serve archived documents.

Local file I/O is blocking, and cannot easily and portably made asynchronous. While there has been efforts to bring asynchronous file I/O to POSIX and Linux it does not seem to have been adopted by developers. To avoid file I/O blocking execution, we can make use of the *aiofiles*[15] library which provides an object with an API identical to an ordinary file. The asynchronous I/O is provided by delegating I/O operations to a thread pool.

curio

curio[16] is a library of building blocks for performing concurrent I/O and common system programming tasks such as launching subprocesses, working with files, and farming work out to thread and process pools. It uses Python coroutines and the explicit `async`/`await` syntax but does not use *asyncio*.

While *curio* is not part of the Python standard library it does not have any third-party dependencies. It is quite low-level however and so there would likely be work in building enough infrastructure on top of it to handle the tasks we would like to perform.

[14] The documentation can be found at: https://docs.aiohttp.org/.
[15] The source code and documentation can be found at: https://github.com/Tinche/aiofiles.
[16] The documentation can be found at: https://curio.readthedocs.io/.

While the *stem* library does not have native support for *curio*, it is again simple to create a wrapper for integration. An example is shown in listing 2. This is very similar to the *asyncio* wrapper as it is using the same concepts.

There is no HTTP support available from *curio*, nor a recommended HTTP library to use. The *asks*[17] library provides a *curio*-compatible HTTP client but does not implement a server.

curio does provide support for asynchronous file operations. Like *aiofiles* it uses threads, however this may change in the future. The use of threads is noted as an implementation detail in the documentation which may indicate that this would change in the future to be the most optimised mechanism for the platform that is in use.

One strong feature of *curio* is that it recognises that asynchronous programming is still new to Python and provides primitives, such as *curio.UniversalQueue*, that allow for communication between `async` tasks and threads. The *asyncio* counterpart, *asyncio.Queue*, will only permit communication between `async` tasks. This allows for transition between legacy libraries and those that support the new language features, however this is a fresh implementation of the application using Python so we do not have problems with legacy dependencies.

Twisted

The *Twisted* framework for Python is very mature event-driven framework and has support for a large number of network protocols. It does not have support for Tor's directory protocol although this could be built on top of a *Twisted* HTTP client for DirPort. For ORPort usage a minimal implementation of the Tor protocol would be required using *Twisted* for the directory protocol client to use, which is a non-trivial piece of work.

There exists a library for Tor's control protocol [12], *txtorcon*[18], however this application is primarily concerned with the directory protocol and the documentation for *txtorcon* points users towards *stem* for this.

Wrapping *stem* is again possible as shown in listing 3, but the reactor pattern used by *Twisted* makes using this more complicated. It is not possible to pause the execution of the calling function as with the `async`/`await` syntax and so a callback must be used. This pattern inverts the flow of control and so makes the code more difficult to debug than the pseudo-procedural pattern made possible by `async`/`await` and other related language features.

Non-blocking file I/O is provided by the *fdesc*[19] module but the API for this is very limited. It also operates directly on file descriptors and does not provide a complete abstraction for files.

5.3 Scheduling

Each module needs to download documents on a schedule. Timing can be very important as there may only be a small window in which documents are available for download before they are discarded. The current Java implementation uses `java.util.concurrent` which provides basic scheduling functionality.

[17] The documentation can be found at: https://asks.readthedocs.io/.

[18] The documentation can be found at: https://txtorcon.readthedocs.io/en/latest/.

[19] The documentation can be found at: https://twistedmatrix.com/documents/current/api/twisted.internet.fdesc.html.

```python
def fetch_consensus():
    """
    Returns the latest consensus.
    """
    query = stem.descriptor.remote.Query("/tor/status-vote/current/consensus",
        document_handler=stem.descriptor.DocumentHandler.DOCUMENT)
    query.run()
    for consensus in result:
        return consensus

def handle_consensus(consensus):
    """
    Do something with the consensus.
    """
    ...

t = reactor.deferToThread(fetch_consensus)
t.addCallback(handle_consensus)
reactor.run()
```

Listing 3: Python *Twisted* wrapper for *stem* to download the latest consensus

The article [18] that inspired *schedule*, evaluated below, describes a wishlist for a scheduling solution. First, it must have a powerful and human-friendly syntax. This is particularly important for CollecTor as there will be a number of scheduled tasks to perform per module and it is important that mistakes are not made. To correctly implement the Tor directory protocol specification, some times must be calculated based on values found in the latest consensus and cannot simply be declared with a crontab-like syntax.

Testing is also important as a means to reduce development costs. By being able to easily validate the scheduling of tasks, and also test tasks themselves in an environment that does not differ from the environment used for scheduled execution, it is possible to catch bugs before software changes are deployed.

The operation of the scheduler must be clear to ensure that tasks are running correctly and to assist in any debugging. This can be achieved by having good visibility into the scheduler through logging and performing as little work in the scheduler as possible with all heavy lifting being performed by individual tasks.

sched

The *sched*[20] module, part of the standard library for Python 3.7, provides a general purpose scheduler. While it is nice to not have external dependencies, it operates on a monotonic clock and does not understand UTC time on which the directory authorities, and other services that CollecTor must interact with, operate. It also provides no facility for recurring tasks or for scheduling tasks to run at a specific time, only to run tasks once after a delay.

schedule

[20]The documentation can be found at: https://docs.python.org/3.7/library/sched.html.

```python
import asyncio
import time
import schedule
from threading import Thread

loop = asyncio.new_event_loop()

def f(loop):
    asyncio.set_event_loop(loop)
    loop.run_forever()

t = Thread(target=f, args=(loop,))
t.start()

def run_async(job_coro):
    job_task = job_coro()
    loop.call_soon_threadsafe(asyncio.async, job_task)

async def job():
    await asyncio.sleep(1)
    print('Hello, world!')

schedule.every(10).seconds.do(run_async, job)

while 1:
    schedule.run_pending()
    time.sleep(1)
```

Listing 4: *schedule* wrapper for *asyncio* tasks

schedule[21] is an in-process scheduler for periodic jobs that uses the builder pattern for configuration. The syntax is easy to understand and so should reduce mistakes. It supports scheduling tasks to run at periodic intervals, or at fixed times. It does not support scheduling a task to run only once without modifying the task to cancel its schedule after its execution.

It expects that programs will either have thread-safe tasks or that the developer will take care of ensuring safe execution of the tasks. Listing 4 shows how a wrapper might be used to run *asyncio* tasks using *schedule*.

The current maintainer has indicated the he does not have the time to properly maintain this package and is seeking to bring on a co-maintainer[22] which indicates a risk that if this library is used, Tor Metrics may become the de-facto maintainers of it.

Advanced Python Scheduler

Advanced Python Scheduler[23], also known as *apscheduler*, is an in-process scheduler for periodic jobs that provides an object to add jobs to at runtime, or permits for scheduled tasks to be added by using a decorator.

[21]The documentation and source code can be found at: https://github.com/dbader/schedule.
[22]More discussion may be found at the GitHub issue: https://github.com/dbader/schedule/issues/219.
[23]The documentation can be found at: https://apscheduler.readthedocs.io/.

It supports scheduling tasks to run at periodic intervals, at fixed times, and also for a single execution at a fixed time or interval. Jobs can be stored persistently on disk, and *apscheduler* will check for misfired jobs (where the job was unable to be executed at the desired time) and run the job immediately if it is configured to do so.

By default, only one instance of each job is allowed to be run at the same time. This means that if the job is about to be run but the previous run hasn't finished yet, then the latest run is considered a misfire. It is possible to set the maximum number of instances for a particular job that the scheduler will let run concurrently.

apscheduler provides a scheduler that runs on an *asyncio* event loop that can run jobs based on native coroutines using the `async/await` syntax. It also provides a scheduler that runs on a *Twisted* reactor that uses the reactor's thread pool to execute jobs.

5.4 Plugin Architecture

By building CollecTor as an extensible application, it allows easy addition of new data sources in the future. It allows for both Tor Metrics and third-party developers to easily enhance your software in a way that is loosely coupled: only the plugin API is required to remain stable. This extensibility is achieved through the definition of one or more APIs and a mechanism for collecting code plugins which implement this API to provide some additional functionality.

twisted.plugin

This is a component of Twisted, which was previously evaluated for its concurrency features, but can also be used as a standalone module. It has a dependency on *zope.interface* which is used to define interfaces for plugins.

It allows new plugins to be discovered flexibly. For example, plugins can be loaded and saved when a program is first run, or re-discovered each time the program starts up, or they can be polled for repeatedly at runtime (allowing the discovery of new plugins installed after the program has started).

Overall this is quite a heavy module and the complexity in its dependencies may cause more trouble than the benefits it brings are worth.

straight.plugin

This module is quite light but also does not have any interface mechanism. Instead, plugins are found from a namespace and can be identified by a parent class. Through namespace packages, plugins can be split up into separate codebases, even managed by different teams, as long as they all implement the same base API.

If interfaces are required the mechanisms in `collections.abc`, part of the standard library, may provide a suitable implementation.

5.5 Discussion

Whatever other frameworks are used, *stem* is the only viable choice for descriptor parsing if targeting Python 3.7. Fortunately it is well maintained and is a mature stable library. During the course of preparing this report, a number of features were included in *stem* to assist in experimentation including:

- Parsing descriptors from a byte-array (#28450)
- Parsing of detached signatures (#28495)
- Generating digests for extra-info descriptors (#28398)
- Generating digests for votes and consensuses (#28398)
- Generating digests for microdescriptors (#28398)

While potential authors of libraries that would compete with *stem* should not be discouraged from implementing alternatives, *stem* does fill all of the requirements of the CollecTor application for the parsing of descriptors.

For concurrency, the *asyncio* framework appears to be the best choice. Moving away from a threading model to an asynchronous model it provides all the functionality required for the CollecTor service requirements. *curio* would also have been a viable option however it has a smaller community than *asyncio* and so less library code is readily available for reuse. There does not appear to be a compelling advantage to using *Twisted* over the more modern frameworks that make use of new language features such as the `async`/`await` syntax despite its maturity.

In the evaluation of these frameworks it became clear that performing file I/O operations in an asynchronous way is not simple. The *asyncio* framework abstracts the complexity by delegating the blocking operations to a thread pool however in the longer term we may wish to explore other storage options.

For scheduling, Advanced Python Scheduler is the only library evaluated that fits the requirements for the CollecTor service. The native support for the *asyncio* event loop means that no custom wrappers will be required. Both *sched* and *schedule* would be useful for other tasks, but for CollecTor are too minimal.

For the plugin architecture, *straight.plugin* is the clear choice as the Twisted module is very heavy in comparison without providing any clear advantages.

6 Prototype Implementation

A prototype of an application implementing the requirements described in §3 has been implemented. This prototype is known as *bushel* and the source code and documentation can be found online[24].

The prototype makes use of *asyncio* for asynchronous I/O. Where using the *stem* library, any calls that would have blocked are delegated to an executor, currently a `concurrent.futures.ThreadPoolExecutor`.

[24] The source code can be found at `https://github.com/irl/bushel` and the documentation at `https://irl.github.io/bushel`.

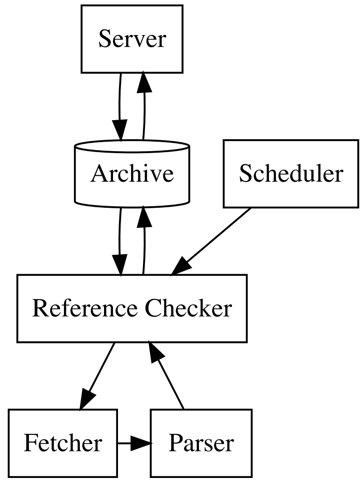


Figure 5: Overview of the architecture for the next-generation CollecTor.

The primary functionality of the `relaydescs` module is implemented in the `DirectoryScraper`. This has functionality for recursively discovering documents that should be archived.

The `DirectoryCache` provides an abstraction layer that forwards requests to a `DirectoryArchive` or a `DirectoryDownloader` instance. When scraping the directory documents are requested from the `DirectoryCache`. If they are not found, and a download is successful, they are stored in the archive as a side-effect.

The `DirectoryArchive` provides methods to retrieve descriptors that have been archived in the local file system. When parsing a consensus there are roughly 6500 server descriptors referenced, and even more for a vote, which is well above the default number of maximum file descriptors for a process[25]. To prevent unbounded use of file descriptors, an `asyncio.BoundedSemaphore` is used to limit concurrency.

7 Next Steps

- Based on the experience of implementing this prototype, a draft plugin API has been specified in appendix B. The prototype will require some refactoring to fit this API and then enable the implementation of the requirements set out in §4.
- Currently the prototype runs only as a command-line tool and not as a service with an in-process scheduler. The scheduler would need to be integrated to the prototype before it could be deployed.

[25]The default maximum file descriptors per process is 1024 on Debian 9 systems, and remains unchanged in Debian 10 at time of writing.

- The API may still require new functions or tweaks to existing functions and would need to be formalised in the documentation. Before it can be considered complete an assessment of suitability for each of the current CollecTor modules would need to be performed.
- In order to improve the archive rate for detached signatures, which currently must be collected during a strict 5 minute interval, it would be useful to have the missing URL that publishes the detached signature for the current consensus implemented in `tor`. The Tor directory protocol could further be extended to support retrieval of recent consensuses, votes and detached signatures and not just those for the current and next periods.
- For server descriptors our archive rate will not be 100% due to relays uploading new descriptors twice between CollecTor polling the directory authorities. One possible solution to this would be to provide a URL to retrieve all known descriptors, not just the most recent. URLs could be provided to limit the descriptors to only those learned within a given time period to help reduce duplicated downloads while maintaining a high archive rate.
- The archive rate will need to be monitored, and to define thresholds for warning the service operators the current CollecTor archives should be analyzed to find a baseline. Any replacement needs to at least maintain this baseline, if not improve on it.
- Synchronization between CollecTor instances has not yet been considered. While the current CollecTor implementation supports this through the CollecTor client interface, it is suboptimal in terms of bandwidth usage and an improved design may help both synchronization and for general client usage.
- Currently there are no efforts to provide trusted timestamps for documents containing signatures that are archived by CollecTor, but in the future we could look into providing this service.
- Finally, alternatives for document storage may be considered. This report assumed that a new implementation would continue to implement the CollecTor File Structure Protocol however this is not a strict requirement for the internal storage. Using the same structure on top of ZFS, using a relational database, or using an object store could provide better performance and reduce application complexity with some tasks delegated to the storage provider.

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A Sample Detached Consensus Signature

```
consensus-digest 1CBD322788FFC841B0DB701C2942EE5750617CFF
valid-after 2018-11-15 19:00:00
fresh-until 2018-11-15 20:00:00
valid-until 2018-11-15 22:00:00
additional-digest microdesc sha256 476993
   E797C51682E95ACEED12B2DD21588847E8E2FF7C49291E64207D8FED53
additional-signature microdesc sha256 D586D18309DED4CD6D57C18FDB97EFA96D330566
    8A45BACC94A6023A90C24FBCD10520C1741828F7
-----BEGIN SIGNATURE-----
1c/vHIqlqdhS8HR+Lps3Tk+VHeJaQ5lL/NxIkARDpVMLhv6fHxCNGlXrKvd9S5KR
MvOzblmrVt3TV/iJTvOmMwHuziRjzrZeHpeeK81zQ/z6QGvheooaxa8jsYuANgA0
GK4agnsCI4JTKz/47SGpIDjY3VtXbns58TUPYHHUQY82khLqWvj1nL5djWdnnm9l
yyU4od4mv6JJz9XdCNN+qDTzEA0QE10Y0lUV+K2Ipqplrb/zd9pzJS9GUf82cNOj
GYLvBMzuSr/aL0UIeQgiI0BRDw2MPqXd/KA04dOFCiqnDhKqh0PR6SMD3ulgxxhs
R0du41KYQC/eDqeRhxZF4g==
-----END SIGNATURE-----
directory-signature D586D18309DED4CD6D57C18FDB97EFA96D330566 8
   A45BACC94A6023A90C24FBCD10520C1741828F7
-----BEGIN SIGNATURE-----
ITaD0D5CmuobYi3G5LbuWmbIe5Vpt3o+5d1XOtKaBhRxmC10c9WWMXCVJ7K6Ezb5
dzX6CsEKpop1+V8eqPRTyAZ7H4VvxNS5j6yPsgrMlahgQjcaOpxZY8p+dmzEluPe
E45/+qlXoNfxwF4jv1t1+NLM0jIJRwHErNgJXzFRZ/q/MUZxn/LuN68mcBqzdLD4
L/D9bKNmvIAkcfTedk0x/zmwaXNMV6N9kN3kmUqeAvFLNOM/oP46ktj+B5Ch/2et
lFy4MEf1iHXKiLzq2uuCkMN2pfVtmga8j/BHE47ne5paMHnDwaTrEmBM2ws8n4mK
E/RAIUlD8COyEUImjcns6w==
-----END SIGNATURE-----
```

Listing 5: Sample detached consensus signature

B Initial Plugin API

The following documents a draft API to be implemented by plugins. These functions will be called by the reference checker. While plugins may keep state internally, it is expected that any state they do keep is not required to be persistent.

The latest version of this API will be found at https://irl.github.io/bushel/plugins.html.

```
class DocumentIdentifier(doctype, subject, datetime, digests):

   Represents a document that is expected to exist.

   **Attributes:**

   doctype

      The "type" of the document.

   subject

      The subject of the document. This is usually a string containing
      an opaque identifier. Examples include the fingerprint of a
      relay for a server descriptor, or the hostname of an OnionPerf
      vantage point.

   datetime

      A "datetime" related to the document. The exact meaning of this
      will be document dependent. Example include the published time
      for a server descriptor, or the valid-after time for a network
      status consensus.

   digests

      A "dict" containing mappings of "DigestHash" to "tuple"s. Each
      tuple contains a "str" representation of the digest
      and a "stem.descriptor.DigestEncoding".
```

```
class ExamplePlugin:

   An example plugin for bushel.

   expectations()

      Returns:
         A "list" of "DocumentIdentifier" for documents that are
         expected to be available for fetching.

   fetch(docid)

      Fetches a document from a remote location.

      Parameters:
         **docid** (*DocumentIdentifier*)  Identifier for the
         document to be fetched.

   parse(document)

      Parses a retrieved document for any documents that are
      referenced and should be fetched.

      Parameters:
         **document** (*Document*)  A retrieved document.

      Returns:
         A "list" of "DocumentIdentifier" for documents that are
         expected to be available for fetching.
```