Identifying and Managing Technical Debt in Complex Distributed Systems

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by

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Abstract

The term *technical debt* has been used to described the increased cost of changing or maintaining a system due to expedient shortcuts taken during development, possibly due to budget or time constraints. The term has gained significant attention in the agile and academic community and several scientific models have been proposed to keep track of and solve technical debt.

Tribler, a platform to share and discover content in a complete decentralized way, has accumulated a tremendous amount of technical debt over the last ten years of scientific research in the area of peer-to-peer networking. The platform suffers from a complex architecture, unintuitive user interface, an incomplete, unstable testing framework and a significant amount of unmaintained code. A new simple, flexible and component-based architecture that readies Tribler for the next decade of research, is proposed and discussed. We lay the foundations for this new architecture by implementing a flexible, convenient RESTful API and a new graphical user interface.

Additional work includes paying off various kind of technical debt by the means of a major refactoring in the testing framework, several heavy modifications within the core of Tribler and improvements to the infrastructure to make it more usable and robust. With the deletion of 12.581 lines, the modification of 765 lines and addition of 12.429 lines, we show that we contributed to the increase of several important software metrics and paid off a huge amount of technical debt. Raising awareness about the accumulated debt is of uttermost importance if we wish to prevent the deterioration of the system.

Our experiments will demonstrate that the performance of Tribler has not significantly degraded due to the invasive modifications as performed in this thesis work. We perform some static analysis to verify the usability of various components in the system and propose future work for the components that require more attention.

Preface

There are some people that contributed to this thesis I would like to thank. First, I would like to thank Johan Pouwelse for his supervision. Next, I would like to thank Elric Milon who taught me much about Python, Twisted and Linux and provided me with the necessary infrastructure. I would like to thank Laurens, Hans, Ernst, Niels and the rest of the Tribler development team for their help and support during this thesis by providing feedback and advise and by making this thesis a much more enjoyable experience.

Last but not least, I would like to thank my friends and family for their support and motivation.

M.A. de Vos
August 11, 2016

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Introduction

The resources, budget and time frame of software engineering projects are often constrained[24]. This requires software engineers to analyse trade-offs that have to be made in order to meet deadlines and budgets. Making decisions that are beneficial on the short term, might lead to significantly increased maintenance costs in the long run. The phenomenon of favouring short-term development goals over longer term requirements is often referred to as *technical debt*. While technical debt might not have implicit consequences on the user experience, it dramatically impacts quality and maintainability of software. Research has confirmed that there exists a correlation between the amount of design flaws and vulnerabilities in a system[35]. A high amount of technical debt also leads to a greater likelihood of defects, unintended re-engineering efforts[30] and increased development time when implementing new functionalities.

The term technical debt was first introduced by Ward Cunningham in 1992 as writing "not quite right" code in order to ship a new product or feature to market faster[17]. Since then, the term has gained progressively more attention in the software engineering research and agile community. Effective management of such debt is considered critical to achieve and to maintain an adequate level of software quality. In 2007, Steve McConnell created the technical debt taxonomy where he refined and expanded the definition[1]. He points out that some kind of engineering practices are not considered technical debt, such as deferred features, incomplete work that is not shipped and other features where one does not have to 'pay' the debt for. Martin Fowler considers technical debt more as a metaphor to use when communicating with non-technical people and introduced the technical debt quadrant in 2009[3]. According to his work, technical debt can be categorized in distinct types, separating issues arising from recklessness from those decisions that are made strategically. Figure 1.1 presents this distinction in more detail, together with some examples.

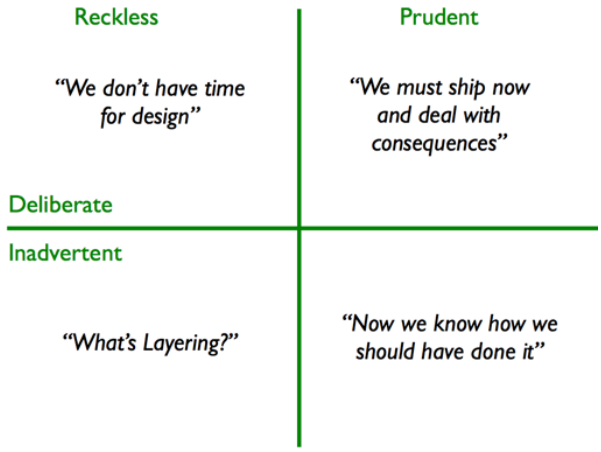


Figure 1.1: The technical debt quadrant, as proposed by Martin Fowler.

Technical debt has several interesting properties, explored and defined in the work of Brown et al[14].

Whether the debt is visible or not is an important factor during software engineering as significant problems can arise when the debt is not clearly visible to other developers. The value of technical debt is the economic difference between the system as it is and the system in an ideal state for the assumed environment. The technical debt is relative to a given or assumed environment. The phenomena has an origin which can be traced back to strategic decisions taken earlier in the development process. Otherwise, the debt could be accumulated in a more unintentional way, either due to recklessness or a lack of knowledge. Finally, we consider the impact of the technical debt: for instance, what are the required changes we have to perform in order to pay off the debt?

From the perspective of end users, technical debt can be both invisible and visible[29]. Examples of invisible technical debt includes code smells, coding style violations, low internal quality and high code complexity, issues developers should deal with. Visible debt is expressed in defects that are affecting users but can also be identified by user-unfriendly, cluttered Graphical User Interfaces (GUIs) that has been subject to various reckless modifications: decisions to extend and evolve the user interface with new visual elements, can lead to a high amount of technical debt and a poor user experience.

The term itself is borrowed from the finance domain[23]. There is however one important distinction between financial debt and technical debt: when dealing with financial debt, the costs that the debtor has to pay is usually clear. This is not always the case with technical debt since there might be some situations where no technical debt is incurred. For instance, if it is known for a part of the system to never be updated or maintained in the future, development time and budget can be saved by not updating the related documentation. Software engineers need to be carefully with the consideration what technical debt they wish to incur and when this debt will be paid off at specific points in time.

There are several causes that contribute to the amount of accumulated technical debt during the software development process[32]. Time pressure can cause developers to think reckless about their design and architecture. Uncertainty in decision making during an early stage of development might lead to higher technical debt later on. Finally, in an agile environment, software requirements might change more often, causing the underlying architecture and code base to change to a certain extent. Not properly managing such changes can lead to significant technical debt.

Technical debt often becomes a noticeable problem in large systems that are built and maintained by many contributors. Tribler is an example of such a system: the software is the result of ten ongoing years of scientific research in the area of decentralized network technology and has incurred a serious amount of technical debt, both visible and invisible for users. The software is the combination of four disruptive techniques in one large code base: *BitTorrent*, allowing users to download files in a decentralized matter, *Tor*, providing anonymity and strong encryption, *Bitcoin*, offering a way to introduce the notion of trustworthiness inside a decentralized network and *Wikipedia*, allowing collaborative editing of content. These components are depicted in Figure 1.2.

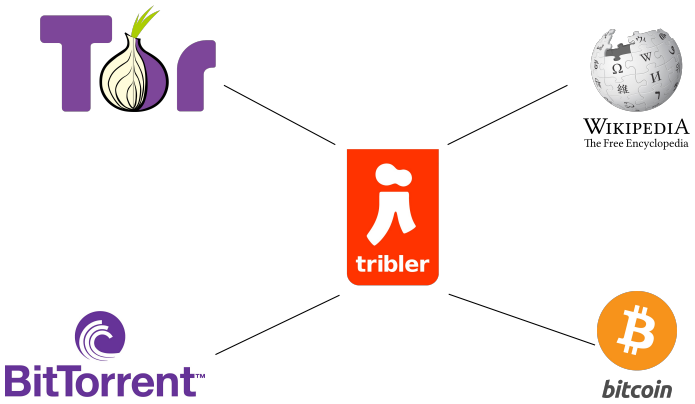


Figure 1.2: The four disruptive technologies as integrated in Tribler.

Anonymity by the utilization of a Tor-like protocol has been added In 2014 by the work of R. Plak[36] and J.H. Tanaskoski[45]. In 2015, the protocol has been extended to support anonymous seeding of torrents[39]. The graphical user interface of Tribler is shown in figure 1.3.

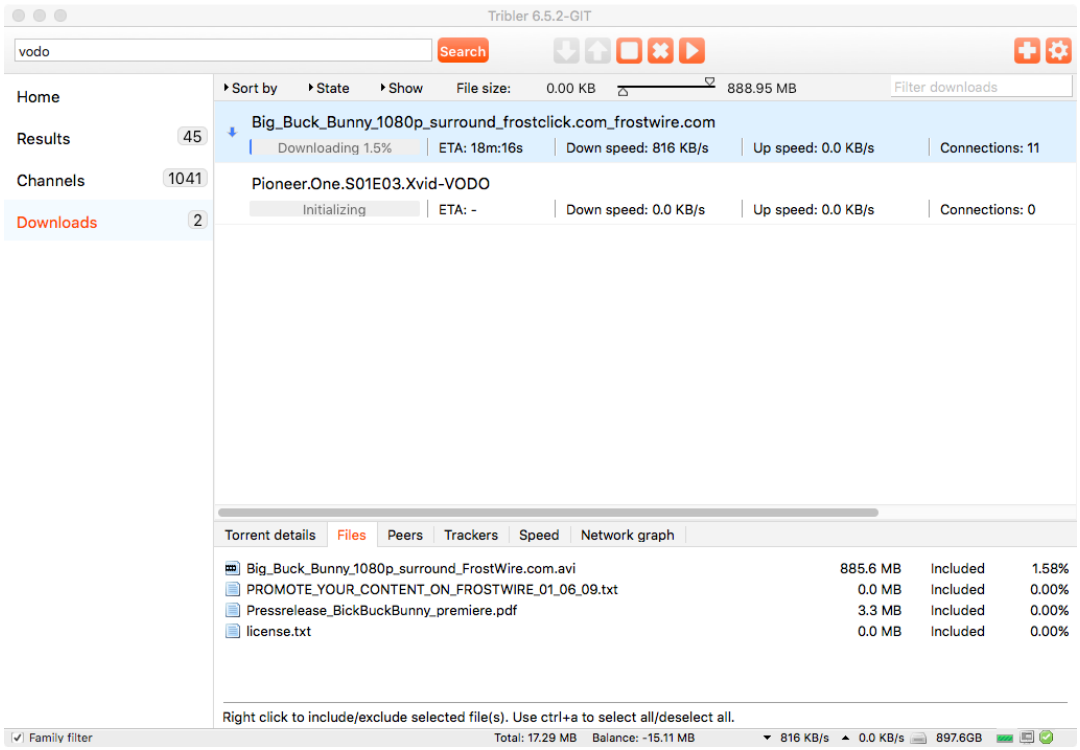


Figure 1.3: The graphical user interface of Tribler v6.5.2.

This thesis work will be centred around identification and management of the accumulated technical debt within the code base of Tribler. With this in mind, we can be formulated the following research question:

How can we track, manage and prevent technical debt within Tribler?

This question can be divided into several sub questions:

1. What are the adequate tools to identity the amount of technical debt within Tribler?
2. What is the right approach to pay off each identified kind of technical debt?
3. What are the adequate requirements in the software development process to prevent decisions that are leading to a high amount of debt later in the development process?

The rest of this document is outlined as follows: in Chapter 2, the current state of the system will be elaborated, highlighting flaws and impurity in the design and code base. In Chapter 3, the evolution of Tribler over the past ten years will be presented and we lay the foundations for a next decade of scientific research with Tribler by proposing a new future-proof and robust architecture. The first efforts towards a realisation of this new architecture will be discussed in Chapter 4 by the implementation of a RESTful API and a new user interface. Next, in Chapter 5, we will focus on the question whether we should pay off the debt in the core of Tribler and how we can do that. We will discuss efforts to improve code quality, architecture, infrastructure and the testing framework. The performance of Tribler after our refactoring efforts will be discussed in Chapter 6. By conduction various benchmarks and performance measurements, the user experience of Tribler will be assessed. We will end with the conclusions and propose future work in Chapter 8.

2

Problem Description

The goal of this thesis project is to help Tribler mature from an experimental research prototype into production-level code with potentially reliable usage by millions of users.

After careful analysis it was decided that within the context of a nine month project the strongest contribution to the future of Tribler would be a step forward in technical debt. At this point we believe the project does not need a particular focus on feature improvements, novel additional features, or boosting performance. After over ten years of software development by 44 unique contributors the amount of accumulated technical debt is worrying.

Tribler suffers from all kinds of technical debt, including instability issues, race conditions, coding style violations, code complexity and feature pollution in the graphical user interface. To illustrate, there is even a dedicated file, called *hacks.py* that facilitates some workarounds caused by incompatible software.

This thesis is focussed on a round of invasive maintenance and cleaning of the code and all other infrastructure such as installers and testing environment. Our work aims to ensure that it is possible to conduct another decade of experimental distributed systems research with the Tribler code base. The alternative is continued usage and expansion of the code, which are likely to lead to a forced clean slate approach.

The structural problem is the lack of maintenance capacity. Each contributor to the Tribler research in the form of a bachelor, master, or PhD student needs to be primarily focussed on their thesis work. A thesis requires concrete experimental results, contribution to theory, or both. We believe the lack of student enthusiasm for fixing bugs and writing documentation is the root cause of current state of the code base.

In this remaining of this Chapter, various problems within the Tribler project will be highlighted.

2.1. A large code base

Tribler has a large, complex code base. This makes Tribler an unattractive open-source project for external developers since the process to get familiar with the code base takes a long time. Figure 2.1 illustrates the number of commits over the past 10 years. The evolution of number of source code lines is shown in Figure 2.2. The magnitude of the project is also presented by Figure 2.3. From these figures, it is clear that Tribler has continued to grow to a project with an unmaintainable amount of code. According to the basic COCOMO[28] model, the established costs of the project is $2,371,403 with an estimated effort of 43 person-years.

This continue growth can be explained by the fact that Tribler is a research-oriented prototype. Students often contribute to Tribler by implementing a specific feature of the system, such as anonymous downloads, credit mining mechanisms or an adult filter to filter out explicit content. After completions of these features, the student leaves the project and the knowledge about the specific part of Tribler he or she contributed to, is lost. Afterwards, that part of Tribler is not maintained any more, due to lack of knowledge and manpower constraints.

Continuous expansion of a system inevitably leads to feature pollution. During the past 10 years, no single effort has been made to do a proper clean up of the current code. The code base contains a huge amount of technical debt. If this trend continues, Tribler will evolve into an tremendously complex system where the choice to use a clean-slate approach is favoured over continued usage of the current code base.

Figure 2.1: A history of commits per month on the Tribler project, as reported by Open Hub.

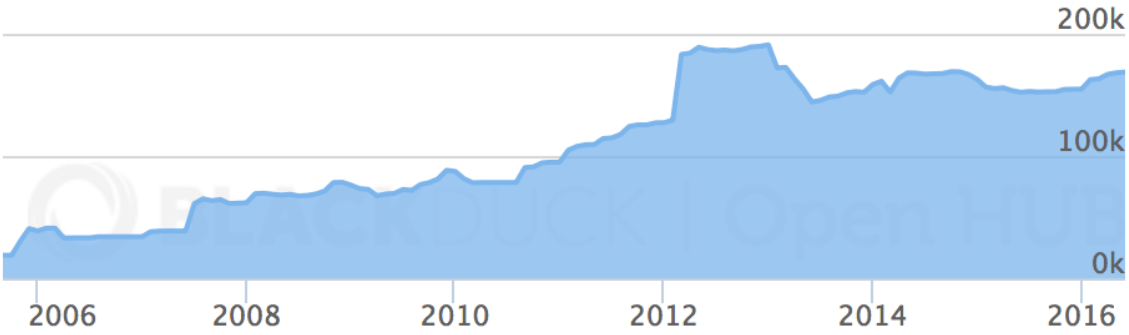


Figure 2.2: The evolution of lines of code in the Tribler project, as reported by Open Hub.

	All Time	12 Month	30 Day
Commits:	17175	1670	390
Contributors:	111	38	16
Files Modified:	10190	1048	270
Lines Added:	2223864	93098	27490
Lines Removed	2037749	57019	11508

Figure 2.3: Statistics about modifications to the code base, as reported by Open Hub.

2.2. Lack of Maintenance

Many features of Tribler are completely unmaintained, due to lack of knowledge or resource constraints. There are even some experimental features that are not working anymore and could be removed.

The lack of maintenance is clearly visible in the synchronization system of Tribler, called *Dispersy*. Dispersy is a platform to simplify the design of distributed communities and is mostly designed and written by N. Zeilemaker and B. Schoon[47]. After these two developers left the project, knowledge of the Dispersy system disappeared and the system transited to an unmaintained state where the process of fixing new failures is being deferred.

Most researchers working with Tribler have a specific feature to deliver. This means that defects in unmaintained parts of Tribler are not prioritized, causing long outstanding issues on GitHub that are not resolved

and delayed for many major or minor release. Of the 300 total issues on GitHub, 100 issues are older than one year.

2.3. Architectural Impurity

During the lifetime of Tribler, the architecture has been subject to various minor and major modifications, leading to a high amount of *architectural debt*. Starting as a fork from ABC, a BitTorrent client based on BitTornado, Tribler has evolved to a platform that allows users to discover, share and download content. The evolution of the Tribler architecture will be explained in-depth in Chapter 3.

On the highest code-base level, two main components in Tribler can be identified: the module with code providing the graphical user interface and the code that contains the core of Tribler. These modules have a mutual dependency on each other which is considered bad design since the Tribler core should never be dependent on the user interface. Splitting this dependency is a high priority issue.

Overall, the code base feels like a bunch of glued together research works whereby every developer maintained his own code style and practices. No clear design patterns can be identified throughout the code and there is a staggering amount of legacy code that is either unused or can be removed. After more analysis of the core module, we managed to identify some other issues. Code that facilitates a video player is present in the core package while this is clearly related to the user interface. We have two files with configuration parameters that can easily be merged to reduce complexity and increase maintainability.

The code related to the graphical user interface is of poor quality and plague with many cyclic dependencies. Having two files being dependent on each other, makes testing of the classes that these files contains, significantly harder. To better see where the main problems are located, we created an import graph of the code base that is related to the user interface, visible in Figure 2.4 where a red edge indicates that this import dependency is part of a cycle. Having many cyclic imports indicates a bad design. Besides the huge amount of cyclic references, we notice that there are various files which seems to have a huge number of incoming references, possibly indicating that these classes have too much responsibilities and should be split into smaller components.

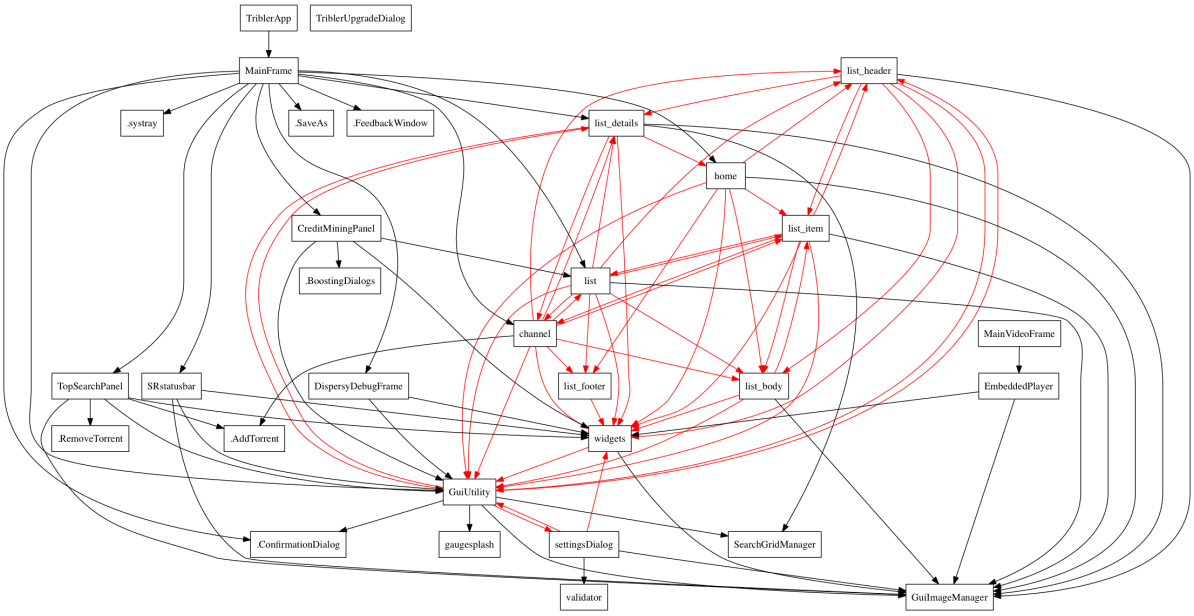


Figure 2.4: A generated import graph of the user interface code package. A red edge indicates that this edge is part of an import cycle.

While the current decade of software engineering provides a plethora of visual designers that requires barely any hand-written code, our whole graphical user interface is built with code that's unmaintained and hard to read. Many features and visual elements in the graphical user interface are unnecessary and unin-

tuitive, contributing to the technical debt. Finally, the user interface has been written with the *wxPython* framework which is not maintained anymore since late 2014. The library builds upon native APIs, i.e. Cocoa on OS X and Win32 on Windows. While the library claims to be cross-platform with a native look and feel, various features in Tribler are limited to a subset of the supported platforms.

2.4. Unstable and incomplete testing framework

Proper testing is the responsibility of every developer. Over the past 10 years, this responsibility has been completely neglected by the majority of contributors, leading to a significant amount of *testing debt*. This is clearly visible in Figure 2.5 where we plot the ratio between the amount of code lines in the tests package (TLC) and the number of code lines related to production code in Tribler (PLC). Tribler has a structural lack of proper designed (unit) tests. Currently, around 100 tests are available that cover 71,2% of the source lines of code located in the Tribler core. Many of these tests are taking over half a minute to complete and are initializing an extensive Tribler session. Only a small fraction of the test suite has the characteristics of unit tests. Having tests that are doing a broad range of operations, inevitably leads to undesired side-effect and failing tests. No single attempt has been made to mock components of the system to simplify tests and focus on the part of the system that has to be verified.

There is one more factor that contributes to the instability of the current test suite. A significant part of the test suite is depending on external network resources, ranging from trackers and seeders for a specific torrent to other peers in the decentralized network. This fragile architecture gives rise to failing tests due to unavailable nodes, unexpected responses from external peers and other unpredicted circumstances.

In general, well designed tests exclude any dependency on external resource that is outside the control of the developer. This can be achieved by mocking method calls to return dummy data. Additionally, one can make sure that the external resource is available in the local testing environment. For instance, when a test is dependent on a specific torrent seeder, a local *libtorrent* session can be started that seeds this torrent.

While Tribler is packaged and distributed for multiple platforms, unit tests in our continuous integration environment are only executed on a machine running a Linux operating system. Limiting test execution to one platform, lowers the overall code coverage and covers platform-specific bugs. Attention should be given to make our test execution multi-platform.

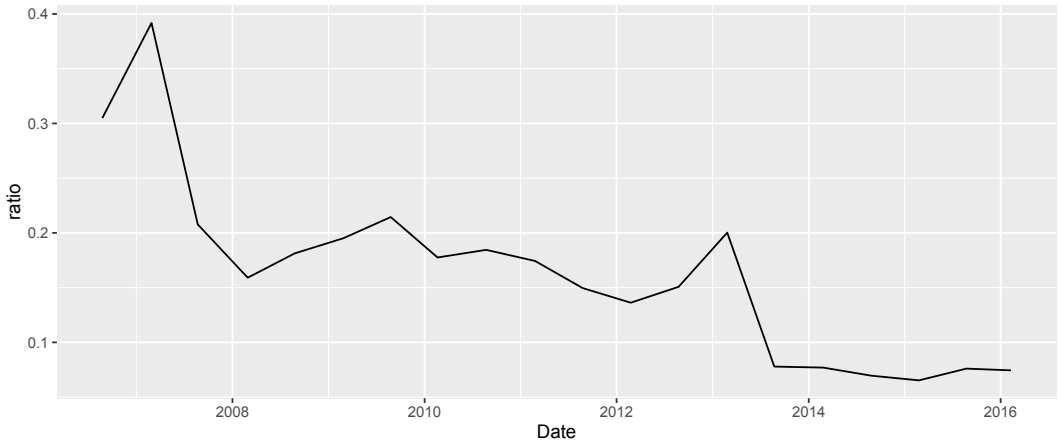


Figure 2.5: The ratio between the lines of code in the tests package and other lines of code over time.

3

Architecture and Design

Before we reach the point of proposing a new future-proof, modern architecture and design of Tribler, the evolution of architecture throughout the last decade of research in the area of decentralized networks will be elaborated. Better understanding of the architectural and design decisions that have been taken in the past, will help us to shed light on the question what contributed to the current state of the Tribler system.

According to the OpenHub tool which accumulates statistics about many open-source projects found on the internet, Tribler received code contributions of 111 unique contributors so far[9]. This list is most likely not exhaustive since some work of missing contributors might have been finished by other members of the Tribler team or has never been merged into the code base. A query for *Tribler* in the repository of Delft University of Technology[1], results in a total of 66 items, consisting of 35 results which are contributions in the form of a MSc or BSc thesis and 31 research-oriented papers in the form of a PhD dissertation or (published) work.

The remainder of this Chapter will present a historical description of the evolution of the Tribler platform, starting in 2007 and concluding with the proposal of a new, robust and scalable architecture that is ready for the next decade of research.

3.1. Tribler in 2007: A social-based peer-to-peer system

In April 2005, Tribler started out as a fork of the *Another BitTorrent Client* (ABC) application, an improved BitTorrent client. ABC is based on *BitTornado* which extended from the *BitTorrent* core system, originally written by Bram Cohen. ABC was shipped with an user interface and a variety of features to manage BitTorrent downloads. The software makes use of the BitTorrent engine, at that time completely written in Python.

In 2007, the first major research paper was published, describing Tribler as a social-based peer-to-peer system[37]. The key idea as described in the paper is that social connections between peers in a decentralized network can be exploited to increase usability and performance of the network. This is based on the idea that peers belonging to a social group are not likely to steal (free-ride) bandwidth from each other, a phenomena that is widely observed in the regular BitTorrent network. The system architecture of Tribler as described in the work of Pouwelse et al. is given in Figure 3.1. We will now highlight the most important parts of the given architecture.

3.1.1. Collaborative Downloads

The BitTorrent engine allows tools to download and seed files in a decentralized way using a BitTorrent-compatible protocol. In addition, the module allows usage of the *collaborative downloader* feature which significantly increases download speed by exploiting idle upload capacity of online friends in the network. The implemented protocol to facilitate these collaborative downloads is called *2Fast* and itt uses social groups where members who trust each other collaborate to improve their download performance.

[1] http://repository.tudelft.nl

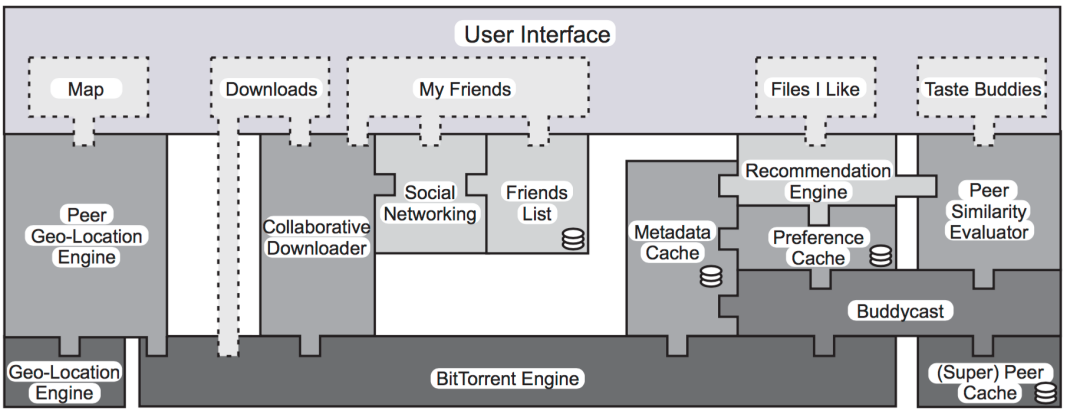


Figure 3.1: The system architecture of Tribler as described in [37].

The protocol works as follows: peers that are participating in a social group are either *collectors* or *helpers*. A collector is a peer that is interested in obtaining a complete copy of a particular file whereas a helper is a peer that is recruited by a collector to help downloading that file. Both types of peers start downloading a file using the regular BitTorrent protocol and the collaborative download extensions. However, before a helper tries to fetch a file piece in the network, it first asks the collector for approval which is granted when no other helpers have downloaded the file piece in question already. Afterwards, the helper peer sends the piece to the collector. For ADSL and ADSL-2 internet connections, the maximum achievable speed-up is 4 and 8 respectively.

3.1.2. Geo-Location Engine

In the left side of the architecture in Figure 3.1, we notice the *Geo-Location Engine*, *Peer Geo-Location Engine* and the *map*. The *Geo-Location Engine* is used to determine the location of other peers in the torrent swarm, using a freely available API[2]. The *Peer Geo-Location Engine* has been built on top of this module, providing the primitives to display the location of peers on a map in the user interface. This feature stems from the goal to ease the process of visual identification of potential collaborators.

3.1.3. Content Discovery and Recommendation

The *BuddyCast* algorithm is designed to serve recommendations to users and to enable peer and content discovery. BuddyCast is an epidemic protocol which works as follows: each peer in the network maintains a number of taste buddies with their preference lists and a number of random peers, void of any information about their preferences. Periodically, BuddyCast performs an *exploration* or *exploitation* step: When an exploration step is executed, the peer connects to one of its taste buddies. When an exploitation step is performed, the peer connects to a random peer in the network. When the connection is successful, a *BuddyCast* message is exchanged. This message contains the identities of a number of taste buddies along with their top-10 preference lists, a number of random peers, and the top-50 content preferences of the sending peer. The age of each peer is included in the message to help others know the "freshness" of peers. After the BuddyCast messages are exchanged, the received information is stored in the local database of each peer, called the *Preference Cache*. Information about discovered peers are stored in the *Peer Cache*. To limit redundant messages, each peer maintains a list of recently contacted peers.

The BuddyCast mechanism interacts with the user interface in two different ways. On the page *Files I Like*, each peer indicates its preference for certain files expressed as a number between 1 and 5. Initially, this list is filled with recent downloads of the peers. Second, the user interfaces displays similar taste buddies and facilitates a content browser where each item is annotated with an estimated interest indicator for the user.

[2] http://hostip.info

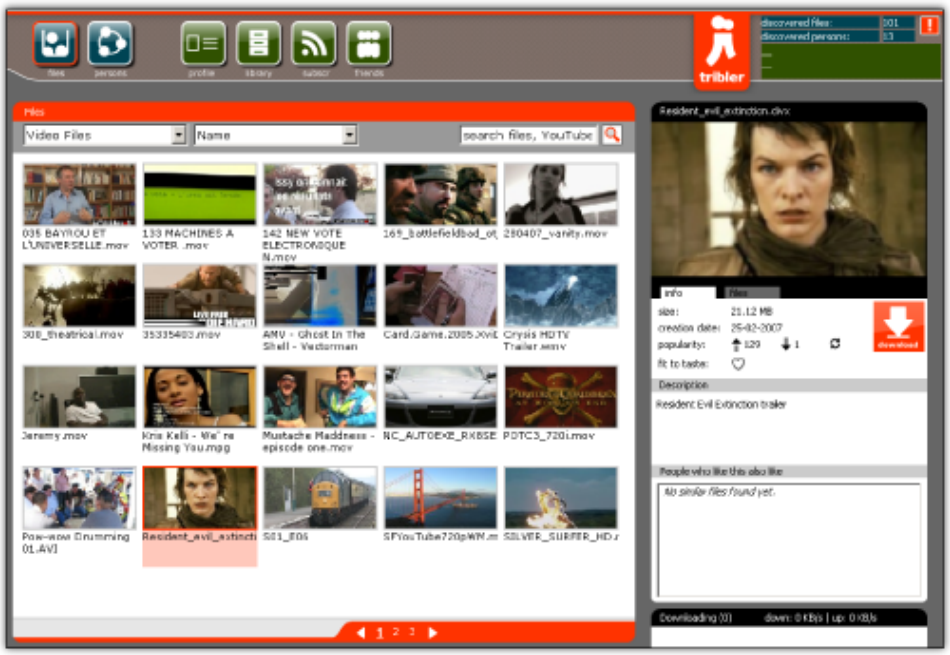


Figure 3.2: The user interface of Tribler 4.0.

3.2. Tribler between 2007 and 2012

The first version of Tribler in the 4.x series, Tribler 4.0, got released in 2007[2]. Many features from the 3.x release cycles are untouched and some new functionality have been added, most notable in the user interface. Using an embedded video player, users can play videos (while being downloaded) directly from within the user interface. This video player is powered by the popular VLC library and bindings that facilitates video playback and management in several popular user interface libraries. In addition, Tribler 4.0 allows users to remotely search for content inside the Tribler network but also queries content available on YouTube and Liveleak. These search results are presented to the user in a YouTube-like thumbnail grid. The interface of Tribler 4.0 is visible in Figure 3.2.

Development continued with the release of Tribler 5.0 in 2009[4]. The user interface has been subject to a complete redesign, introducing a more dark theme, which was replaced by a white theme a while after the release. The focus of Tribler 5.0 has been on the stability and performance of remote content search and the download mechanism. The thumbnails have been dropped in favour of a paginated list.

Tribler 5.1 contained some major improvements to the user interface, thanks to the feedback of the community. A new addition in Tribler 5.2 is the concepts of channels, similar to YouTube. One goal of the organization of content into channels was to prevent spam inside the network by favouring content present in more popular channels. Whereas custom widgets with an own look-and-feel has been used in this version, they all got replaced in Tribler 5.3 by native buttons to creating a more natural feel on each supported platform. Additionally, a tag cloud with popular keywords has been added to the home page of Tribler to help users determine which content they possibly want to look for. The paginated list was replaced by a single, scrollable list of items. In the next release, tribler 5.4, a magic search feature has been implemented where similar search results are collapsed using text similarity functions and digit extraction. The usefulness of this features is apparent when searching for content that is split into many part such as a sequel of books or a television show. This feature leads to a much cleaner and comprehensive results list when searching.

The final release in the 5.x series, Tribler 5.9, bought some major additions. The complete BuddyCast core has been rewritten, moving away from a TCP overlay to an implementation based on UDP, providing benefits to the compatibility with NAT-firewalls. Also, *libswift* has been introduced as the new download engine, providing download capabilities over UDP, thus removing the TCP layer from the BitTorrent engine.

The architecture around the time of Tribler 5.5 is visible in Figure 3.3. We notice that this architecture is significantly more complex than the architecture as presented in Figure 3.1. This model is the result of gradually adding smaller components to Tribler that have been developed during research, such as *2fast*, *BuddyCast* and the *Secure Overlay*. We notice several different threads that have to be synchronized, adding to the complexity of the code since developers need to be aware of context switches (jumping between different threads during execution of the application). Whereas the project contained around around 45.000 lines of code in 2007, this number has increased to over 90.000 in 2010.

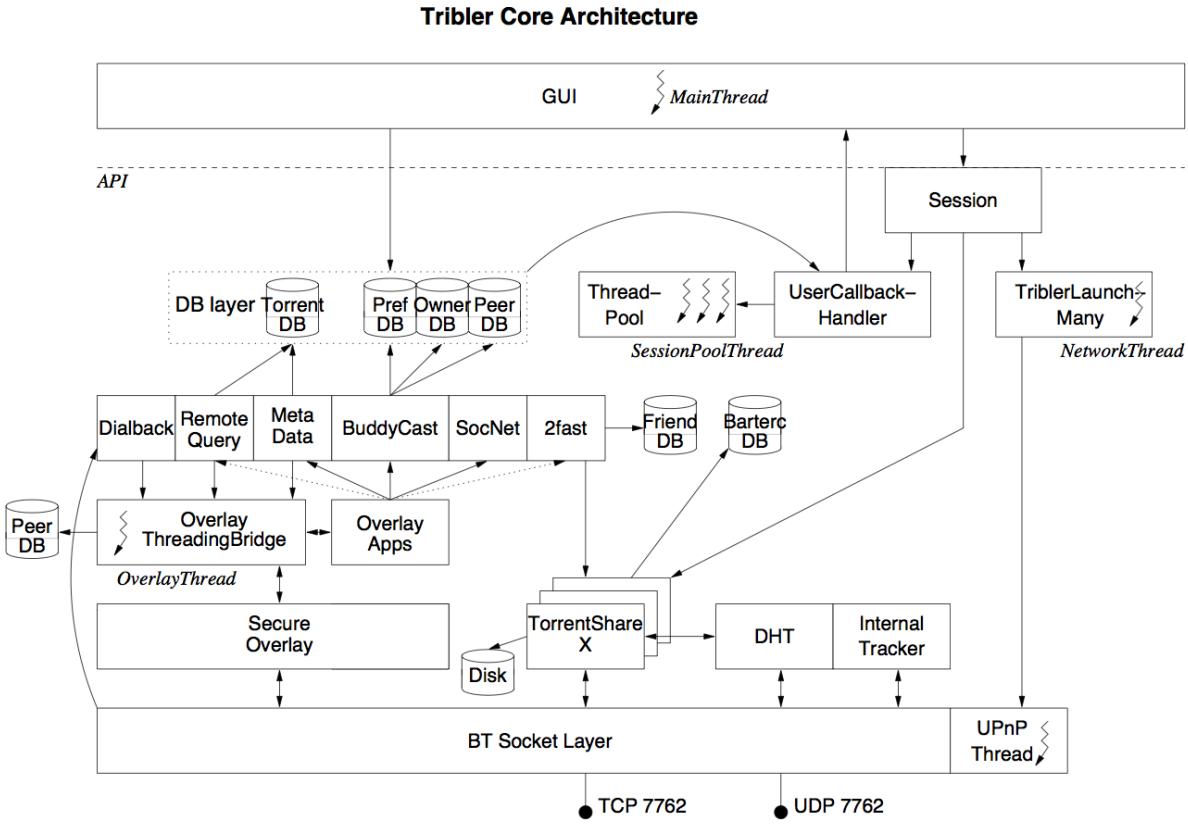


Figure 3.3: An overview of the core architecture around the time of Tribler 5.5.

3.3. Tribler between 2012 and 2016

Shortly after the release of Tribler 5.9, version 6.0 is released where a complete new user interface has been implemented and the BitTorrent engine is replaced by the *libtorrent* library, written in C++. This release also contained some minor bug fixes that increased performance and usability. After the release of 6.0, several smaller releases (6.1, 6.2 and 6.3) were released. The focus shifted toward anonymous downloads and end-to-end encryption[36][45][39]. These features were part of the Tribler 6.4 release, providing an experimental anonymous download mechanism and hidden seeding services. The *libswift* dependency got dropped since it was not stable enough. This release also introduced the Trivial File Transfer Protocol (TFTP), a simplistic version of the popular FTP protocol. TFTP in Tribler is used to exchange torrent files between peers in Tribler when searching for content. The next release, Tribler 6.4.1, contained some major security fixes after an external code review by a member on the Tor mailing list[7].

3.3.1. Dispersy

With the release of Tribler 6.1, Dispersy got introduced. Described in [47] and mainly developed by N. Zeilemaker and B. Schoon, Dispersy lies at the foundations of Tribler's messaging and synchronization system and is designed to deliver messages reliably in unpredictable networks. It provides a Network Address Translator (NAT) traversal mechanism to improve connectability of peers in the network. Dispersy provides tools to quickly create overlay networks, called communities, that peers can join and where messages be dissemi-

Community name	Purpose
AllChannel	Used to discover new channels and to perform channel search queries.
BarterCast4	While currently not enabled, this community is used to spread statistics about the performance of Tribler inside the network.
Channel	This community represents a single channel in Tribler and is responsible for managing torrents, playlists and moderations inside that specific channel.
Multichain	The Multichain community utilizes blockchain technology and can be regarded as the accountant mechanism that keeps track of shared and used bandwidth.
Search	This community contains functionalities to perform remote keyword searches for torrents and torrent collecting operations.
(Hidden)TunnelCommunity	The (hidden) tunnel community contains the implementation of the Tor-like protocol that enables anonymity when downloading content and contains the foundations of the hidden seeder services protocol, used for anonymous seeding.

Table 3.1: An overview of implemented communities in Tribler as of July 2016.

nated. The available communities in Tribler, together with a short description, is described in Table 3.1. While being a major dependency of Tribler, a throughout description of Dispersy is considered outside the scope of this thesis.

3.3.2. Twisted

In 2014, it was decided to make significant changes to the architecture by utilizing Twisted, an event-driven networking engine written in Python. Twisted allows programmers to write code in an asynchronous way. The utilization of Twisted has been motivated by the presence of callback mechanisms in Tribler as can be identified in Figure 3.3. The library provides a simple model for handling callbacks. At the heart of Twisted, we find the reactor which is the implementation of the event loop[10]. The event loop is a programming construct that waits for and dispatches events or messages in a program. The new threading model of Tribler 6 has been illustrated in Figure 5.10. In most applications utilizing Twisted, the reactor operates on the main thread of a Python application. In Tribler, the reactor runs on a separate thread since the main thread is occupied by the *wxPython* event loop, handling events raised by the user interface. Code that operates on the user interface such as refresh operations of lists, should always be executed on the Python main thread. Twisted operations however, should be scheduled on the reactor thread to function correctly. The Twisted threadpool provides a pool of additional threads to dispatch work to and can be utilized for longer-running operations that should not block the main or reactor thread. To make context switching more easy to implement, several method decorators have been introduced, visible in Figure 5.10.

Developers should always be aware of the threading context when implementing new features. Long blocking calls on the main thread should be avoided as much as possible since they lead to an unresponsive user interface. Database calls however, should be scheduled on the reactor thread. While this architecture reduced the number of threads if we compare it to Figure 3.3 and makes our threading model somewhat easier to understand, we are still stuck with a dedicated thread for the reactor and complex thread switching patterns.

3.4. The roadmap of Tribler

In the previous Section, the evolution of Tribler has been discussed, up to the current architecture. We have illustrated the increase of complexity in terms of the design and threading model. We now turn our attention to the future of Tribler and propose a new architecture where we address some of the design flaws introduced in previous versions of Tribler. This new architecture will enable Tribler for another ten year of research. The architecture to be designed should meet the following requirements:

- *simplicity*: we wish to move to an architecture that has a better learning curve for new developers. The current architecture is hard to learn, prone to errors and has a complex threading model, increasing the time for new developers to get familiar with the code. By making the architecture simpler, we increase

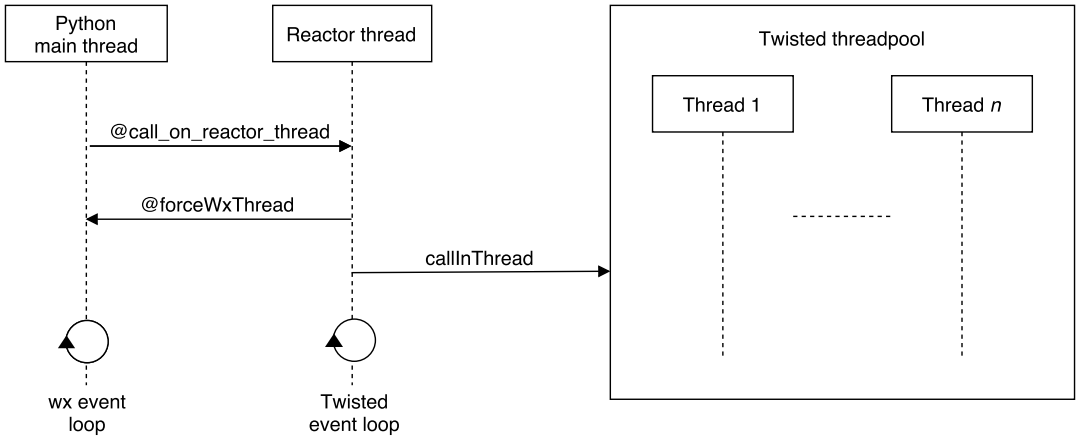


Figure 3.4: The threading model used by Tribler 6, together with the primitives to schedule operations on different threads.

the chance for contributions from external developers outside the Tribler organization.

- *flexibility*: by introducing a substantial level of flexibility in the system, developers can focus on individual components when contributing to Tribler. While we can identify many different components in Figure 3.3, there still are many interdependencies between components. We propose a component-based software engineering methodology, where we provide interfaces between components to communicate with each other. The user interface should be implemented as a separate component, in comparison to the current architecture where the core and user interface cannot be used as separate modules.

- *performance*: the new architecture should be designed to consider performance engineering that might be conducted in the future. An unclear and unstructured architecture can cause much overhead for developers when boosting performance of features as is for instance illustrated by the numerous thread switching necessaries to implement a specific feature that utilizes both the core and the user interface. By considering performance engineering as early in the process, we can build our architecture to allow for performance modifications.

We propose the architecture depicted in Figure 3.5 which desing follows a layered, component-based approach. The remainder of this Section will discuss the components in more detail and highlight decisions that have been made during the design process.

3.4.1. Trusted Overlay

The trusted overlay is the lowest layer in Tribler that provides primitives for discovering and picking new trusted peers. At the lowest level of the trusted overlay, we find the trusted walker, the central component for discovering other peers. Currently, the Dispersy library is responsible for discovering new peers within the Tribler network, using a gossiping protocol[47]. This discovery mechanism is illustrated in Figure 3.6 and executed at fixed time intervals. It works as follows: suppose node *A* wants to discover an additional peer. First, he sends an *introduction-request* to a random peer he knows, say node *B*. Node *B* now replies with an *introduction-reply* message, containing information about a node that *B* knows, in this case node *C*. Meanwhile, node *B* sends a *puncture-request* message to node *C* which in turn punctures the NAT of node *A*, making sure that node *A* can connect to him. This algorithm both provides a NAT-puncturing mechanism and allows a node to discover new peers.

The described way of discovering new peers should be replaced by a trusted walker that makes use of accumulated reputation in the *Multichain*, the accountant mechanism that keeps track of shared and used bandwidth, providing more reputation when a user provides upload capacity to help other users. The key idea is that *sybil* nodes, forged identities in the network, are ignored and not considered as a trusted peer since their reputation is low and are not likely to be selected by the trusted walker.

New peers in that network that have not built any reputation yet, start out by creating some random in-

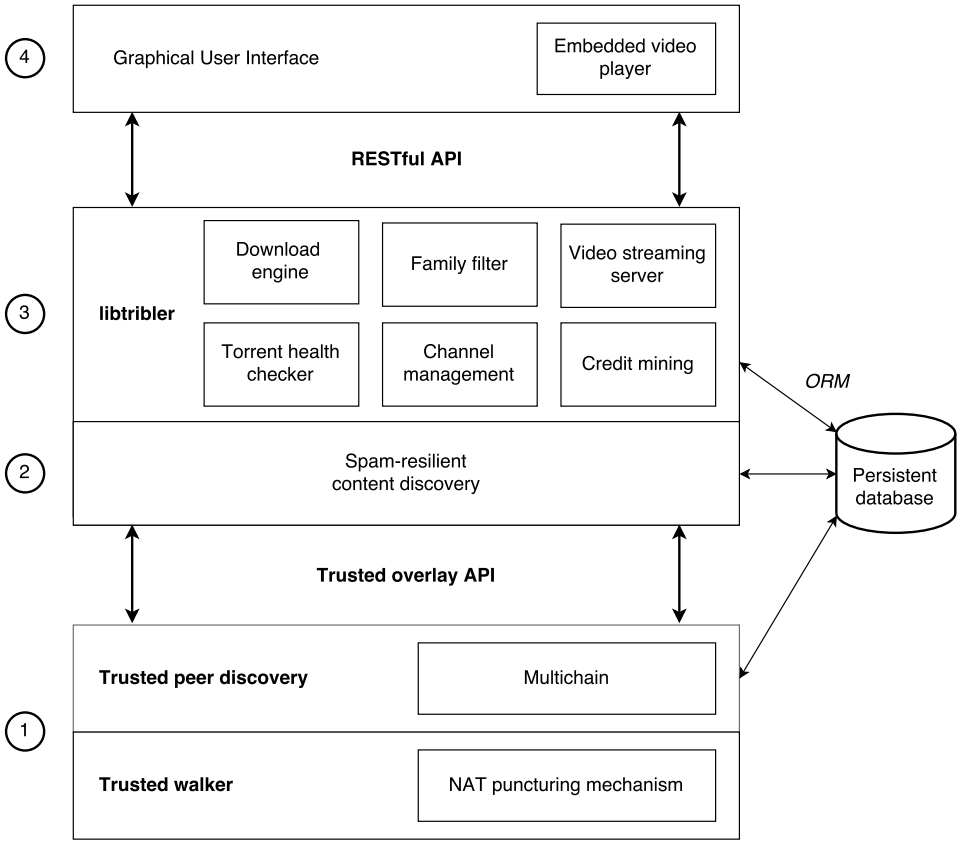


Figure 3.5: The proposed architecture of Tribler 7, consisting of a trusted overlay (1), a content-discovery mechanism (2), *libtribler* (3) and a user interface (4).

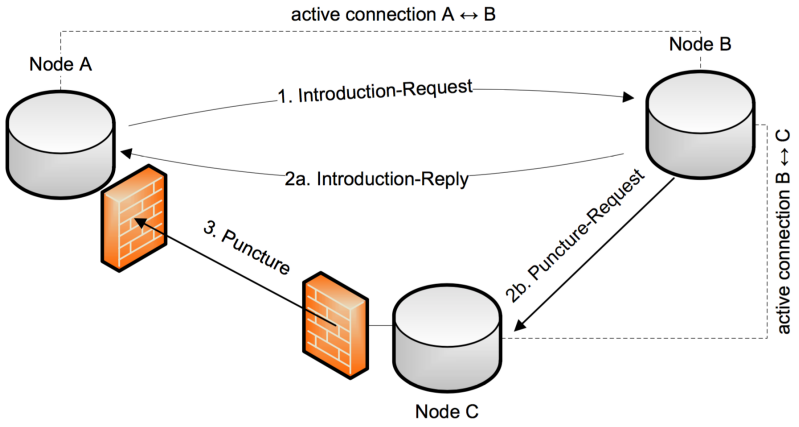


Figure 3.6: The discovery and NAT puncture mechanism as implemented in Dispersy.

teractions with other nodes while learning about the network and the amount of reputation of other users. With an interval, every node runs an algorithm to calculate the reputation of their known peers. The amount of uploaded data does not have to be the only factor of this reputation mechanism: the uptime of the user in question can also be considered, where a higher uptime might lead to a better reputation and thus a higher trustworthiness. This leads to a trust network where each node knows about other trusted peers with which they can exchange content with.

Interaction with the trust overlay can be realised by using an higher-level Application Programming Interface (API) which provides the facilities to perform operations regarding the discover of new trusted peers and

management of known ones. By providing a trusted overlay API, the component allows for easy reuse which is beneficial when the module will be published as an open-source project.

3.4.2. Spam-Resilient Content Discovery

Discovering content is a key feature of Tribler. The spam-resilient content discovery components allows users to discover and search torrents, channels and playlists in Tribler that relies on the trust overlay. The current implemented mechanism for information exchange in Tribler (exchanging messages within segregated communities) works well enough for this purpose, except for the exchange of meta data such as content thumbnails. Providing users with a visual preview of content in the form of thumbnails is a good opportunity to make the user interface more appealing, however, a robust implementation in a complete decentralized network might be challenging due to the fact that the content can be present in a huge volume, thus introducing the need to many thumbnails. We wish to keep the overhead introduced by thumbnail synchronization to a minimum and we must have a decent filtering algorithm to avoid inappropriate imagery from being shown unexpectedly in the user interface. These feature will be considered future work and not be discussed in the remainder of this thesis.

3.4.3. libtribler

Libtribler provides the primitives to developers to make use of the above described components and contains the implementation of a RESTful API that is used to communicate with *libtribler*. We will now discuss the components which together accounts for this layer.

Download Engine

The download engine is one of the most crucial parts in Tribler: before facilitated by the BitTorrent and libswift libraries, we currently use the popular *libtorrent* library to facilitate decentralized downloads. libtorrent is written in C++, however interfaces for many other programming languages such as Python, Go and Java are available. *libtorrent* uses an alert mechanism to notify the application that is using the library about events in the library, such as download state transitions, peer discovery in the torrent swarm or completion of a meta info lookup in the Distributed Hash Table (DHT). There are few reasons to replace the current download engine with a newer library that allows for decentralized and anonymous downloads. Moreover, the current way *libtorrent* is used in Tribler requires minimal changes to adhere to the proposed design, except for some optional refactoring of the current code.

We should note that the methods to fetch peers from the DHT in *libtorrent* is private and not accessible from Python. While under normal circumstances only invoked by *libtorrent*, we manually call this method when performing a DHT lookup on behalf of another peer in the hidden services protocol, described in more detail in [39]. To allow a lookup of peers in the DHT, we make use of a third-party library, named *pymdht*, an implementation of the Mainline DHT protocol, written in Python. This dependency is undesirable since it introduces extra complexity and load of the system. Effort should be made to make this DHT method public so Tribler can get rid of the dependency.

Family filter

The freedom to upload any content users that users desire, comes with a price. The legal aspect of the available content inside the network can be disputable. Tribler also contains much content that is legal, however, undesirable by most casual users, such as offensive content. A mechanism called the family filter is currently implemented in Tribler to filter out such content. This filter is enabled by default and uses a list of keywords that can be associated with pornographic content. Discovered content gets classified by this filter, according on torrent name, file names and other meta data. Unfortunately, this ad-hoc approach is not very effective since there are quite a few false positive and negative classifications. While it provides some basic filtering tools, we noticed that the keyword-based approach can be greatly improved by using more sophisticated classification approach. However, we would consider this as an enhancement rather than a defect that prevents a correct usage of Tribler.

Video Streaming Engine

The video streaming component streams the video data to a video player outside *libtribler* after or during a download. The implemented video server in the current architecture listens for and serves HTTP requests and is implemented using the *SimpleHTTPServer* library, a built-in Python module that can be used to easily

implement a HTTP web server. The video server is based on HTTP range requests, allowing the web server to serve a part of a file when the user jumps to a random location in a video.

The inner workings of the video player is illustrated in Figure 3.7 and works as follows: when the user starts playing a video in an external video player, the player performs a HTTP range request to the video server implemented in Tribler. This range request contains information in the header about the requested range of the video file. When the video server receives the request, it first checks whether the requested range has been downloaded by our download engine already. If so, the server returns the requested data to the client. If the requested range is not available, the video server notifies *libtorrent* that the bytes in the requested range should be prioritized for download, reducing the latency before the requested range is completely available. When all pieces are downloaded, libtorrent notifies the video server about this event and the video server completes the request by sending the requested data to the client.

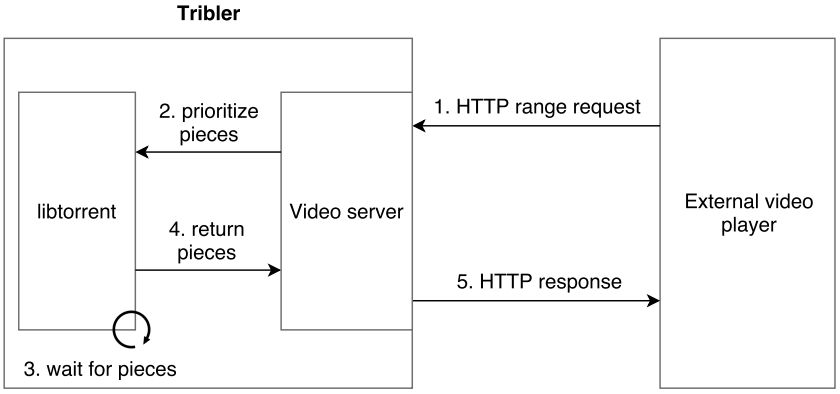


Figure 3.7: The flow when performing a HTTP range request when streaming a video using Tribler.

While the video server in the current form is functional, there is an improvement that can be considered. The video player runs on a separate thread and uses blocking calls to wait for the requested range to be downloaded. By integrating the video server inside the Twisted reactor thread, we can reduce the complexity of this component and make use all of facilities that Twisted provides, for instance, managing incoming requests. An additional consideration could be to run the video server in a dedicated process. This might increase the complexity since a communication mechanism between the Tribler and video server process is required to inform libtorrent about the prioritization of pieces.

Credit Mining

Ongoing work on credit mining in a decentralized system has been extensively described by the work of Capotą et al[15] and is defined as the activity performed by peers for the purpose of earning credit. A possible pupose of the earned credits is to access new content or receiving preferential download treatment in case of network congestion. Although the credit mining component is currently not available for end-users, a credit mining system (CMS) has been implemented in Tribler, responsible for contributing bandwidth to the community without any intervention of the user. This mechanism is displayed in Figure 3.8 and works as follows: first, the user selects a source of swarms for the CMS to take in consideration. Possible sources are channels, RSS feeds or a directory containing torrent files. Next, the CMS periodically selects a subset of the chosen swarms by the user. Finally, Tribler joins the swarms and tries to maximize earned credits by downloading as little as possible and maximizing the amount uploaded data.

The CMS can apply different policies for swarm selection. The first policy is to selects a swarm with the lowest ratio of seeders to all peers (where all peers is the combination of leechers and seeders). Intuitively, this boosts swarms that are under-supplied (having a low amount of seeders). The second policy is to select swarms based on the swarm age. The intuition behind it is that newer content is often better seeded. The final policy that can be used is a random policy that selects a swarm using an uniform distribution.

This credit mechanism is a convenient way for users to increase their reputation by supplying bandwidth

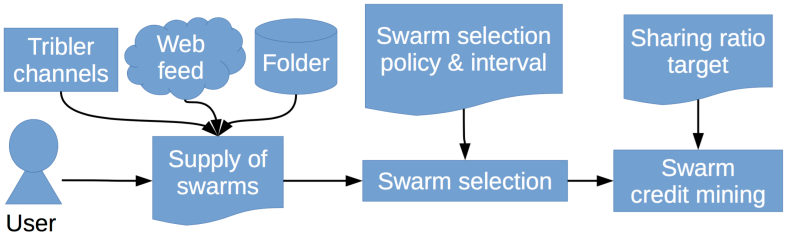


Figure 3.8: The credit mining system described in the work of Capotą et al.[15]

to the community, requiring no intervention of the user and works in conjunction with the Multichain which can be used as accounting tool to keep track of exchanged bytes.

Channel Management

Tribler allows users to create their own channel and share content within that channel. Content can be shared in the form of torrents and playlists where a playlist is composed of a bundle of potential related torrent, for instance, some episodes of a tv show. Users can add content to the channels of other users, providing that the owner of the channel has set the status of the channel to *open*.

3.4.4. Communication between the GUI and *libtribler*

The communication between the upper level of the Tribler architecture, the Graphical User Interface (GUI), and *libtribler* should be facilitated by a Representational State Transfer (REST) architecture. This architecture was introduced and defined by Roy Fielding in 2000[21] and is used frequently when building APIs that operate on the World Wide Web. A service that that conforms to the REST architecture, is called RESTful.

In a RESTful architecture, resources and collections are served to users, identified by a Uniform Resource Identifiers (URIs). HTTP verbs (*GET*, *POST*, *PUT* and *DELETE*) are used to manipulate or retrieve these resources and collections and Table 3.2 provides a summary of the most common operations that are used in a RESTful API.

Resource type	**GET**	**PUT**	**POST**	**DELETE**
Collection	Get the collection.	Replace the collection.	Create a new entry in the collection.	Delete the collection.
Item	Retrieve the item.	Replace the item, create it if it does not exist yet.	Often not used.	Delete the item.

Table 3.2: A summary of REST verbs and their usage when dealing with a resource collection or a single item.

Prior to implementation of this API, we can already define some of the web resources. In Tribler, we can identify torrents, channels, playlists and downloads as resources that should be available for retrieval or modification using the API. Other than that, we might define a *debug* object that contains various statistics that are tracked by Tribler so developers can build debug tools which is helpful during development or performance measurements.

A REST API provides a very flexible and high-level interface that allows developers to write applications around Tribler, ranging from a command-line interface (CLI) to appealing user interfaces. Moreover, the implementation of these utility applications is not bound to a specific programming language, providing a huge amount of implementation freedom for developers. It also allows to run the user interface and Tribler in separate processes, improving responsiveness, performance and testability.

3.4.5. Graphical User Interface

At the highest level of the Tribler architecture stack, we find the user interface. The interface should be able to communicate with the Tribler core using the RESTful API as described in the previous Subsection. A critical

component of the user interface is the ability to play and control a video. The current user interface uses the *wxPython* bindings to the VLC player, however, this bindings are not functional on OS X due to platform incompatibilities.

The implementation of this interface is not limited to one programming language, however, to be able to reuse prior-existing code in the Tribler code base, it is a decent choice to write the interface in Python. Since the programming language is high-level and relatively easy to learn, new developers can easily make modifications to the user interface. We might also consider to refactor the current user interface to support the API. This consideration will be analysed in more detail in Chapter 5.

3.4.6. Requirements Conformance

In Section 3.4, we defined three requirements that our architecture should meet. After the proposal and discussion of the new architecture, we will now evaluate to what extent our proposed design meets the requirements we composed.

Simplicity

Our first requirement was built around simplicity. The architecture as depicted in Figure 3.3 is complex and has a steep learning curve for new developers. The threading model as present in Tribler 6, required developers to be sufficient aware about the thread on which specific operations should be scheduled. The proposed architecture is simpler by design and more divided into separate components, increasing reusability and testability. When modifying a specific component in a layer, developers should not have to care about the layers below the layer that is being modified. In this sense, the architecture meets our requirement that it should be more comprehensible for developers.

Flexibility

The APIs that are facilitating communication between the layers in the architecture, increases the flexibility. As described in Subsection 3.4.4, the RESTful API allows a great amount of flexibility for developers. We strive towards an implementation where individual components can easily be toggled using a configuration file by developers. Some components should also be configured by users, such as the credit mining mechanism.

Performance

One addition reason to split the architecture into different components, is based on performance engineering efforts performed on the system. By having components that are communicating with each other through an API, we are able to more easily extract and refactor these parts of the system in separate processes later on, thus increasing performance since different processes can utilize more CPU cores.

4

Towards a new architecture

The discussion in Chapter 3 concluded with a proposal of a new future-proof architecture. Now, we will shift our focus on performed efforts on making this design a reality. This will mostly involve the implementation of components that can be found on the higher levels of the proposed architecture, in particular the user interface, the REST API and *libtribler*.

4.1. REST API

As described in Chapter 3, communication between the user interface and the Tribler core is facilitated by a REST API in our design. This Section explains the implementation of the API in more detail.

The REST API has been implemented using the Twisted library. While there are plenty of Python libraries available that allow developers to create a web server in their application, we made the choice to use Twisted since it is already utilized to a great extent by Tribler. With the ability to integrate the REST API into the main application flow, we avoid having to create special constructions to run the API on a separate thread, thus increasing complexity of the system, like we are doing with the video server. API endpoints in Twisted are represented as a resource tree. This is in accordance with REST where the URL of the request can be treated like a path in the resource tree. This tree-like structure is somewhat visible in the import graph of the API package as displayed in Figure 4.1. We will highlight and discuss some important files in the API package:

- *rest_manager*: the *rest_manager* file contains the *RESTManager* class which is responsible for starting and stopping the API. In addition, this file contains the *RESTRequest* class which is a subclass of *server.Request* (which in turn is instantiated by Twisted on an incoming request) and handles any exceptions that occurred during the serving of the HTTP request.
- *root_endpoint*: this file hosts the *RootEndpoint* class which represents the root node of our resource tree. This class dispatches all incoming requests to the right sub nodes in the resource tree.
- *util*: the *util* file contains various helper functions, such as conversion utilities to easily transform channel and torrent data from the database into JavaScript Object Notation (JSON) format that can be sent to the client that initiated a request.

4.1.1. Response Format

Except for some endpoints that are returning a response in binary format, most data returned by the API is structured in JSON format. The JSON format is well adopted in the field of web engineering and easy to parse. Most of the endpoints are straightforward implementations where the client performs a request and some data is returned. There are situations where the client does a request and a stream of data should be returned. For instance, this is the case when the user performs a search query. Sometimes, data should be returned to the client, even if the client did not ask for this data. When a crash in the Tribler core code occurred, the client should be notified of this crash and possibly warn the user that he or she should restart the application. For this purpose, an asynchronous events stream has been designed and created. Clients can open this event stream and interesting notifications are sent over this stream. All messages that are sent over

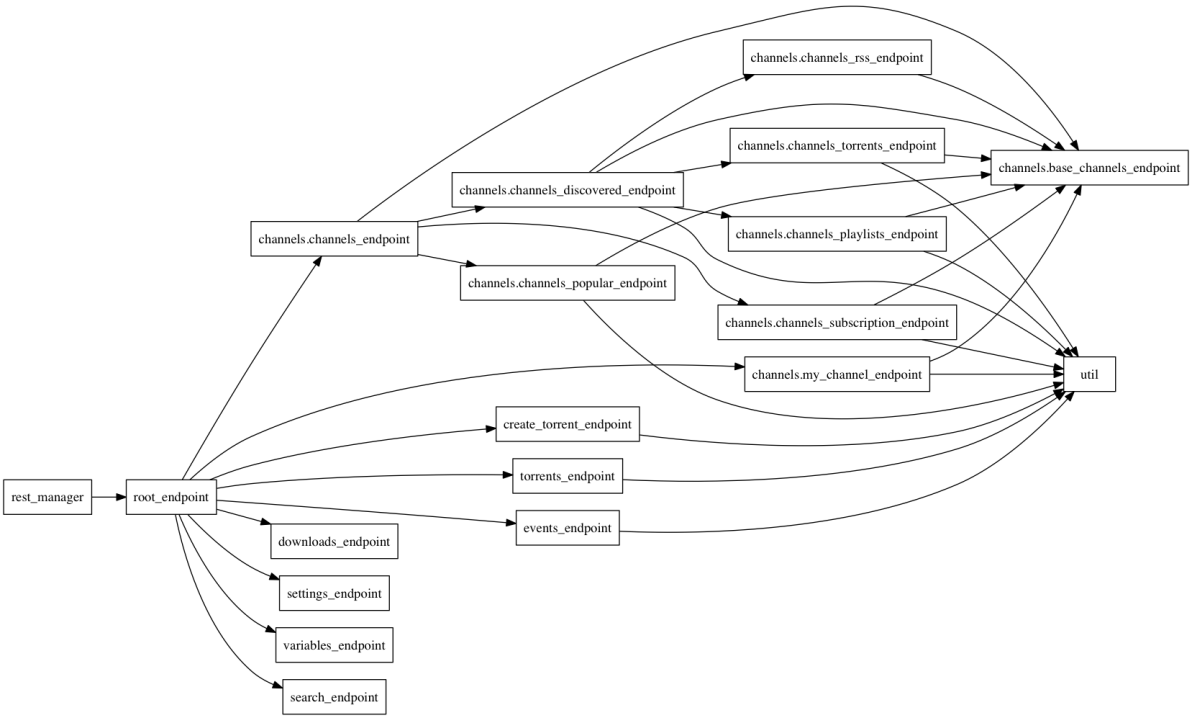


Figure 4.1: The import graph of the REST API module.

the *events* connection are shown in Table 4.1.

4.1.2. Error Handling

A proper designed API should have a mechanism to notify users about any internal errors that occurred during requests. Our API returns HTTP response code 500 (*internal server error*) when we observe a Python exception. Moreover, we return a JSON-encoded response that contains more specific information about the caught exception such as the name of the exception, whether the error has been handled by the core and optionally, the stack trace of the exception. An example of an error response is displayed in 4.1.

Listing 4.1: The response in JSON format returned when a Python exception is observed during the processing of an API request.

```
{
  "error": {
    "message": "integer division or modulo by zero",
    "code": "ZeroDivisionError",
    "handled": false,
    "trace": [
        " File \"/Library/Python/2.7/site-packages/twisted/web/server.py\",
        line 183, in process\n    self.render(resrc)\n",
        ...
    ]
  }
}
```

4.2. Graphical User Interface

The amount of accumulated technical debt in the current graphical user interface of Tribler is devastating. After going through several development cycles where some impacting changes to the user interface have been made, the code base has reached the point where it might be more beneficial to create a complete new user interface. 29,3% of the Tribler code base, excluding Dispersy, is related to the user interface. We now

Event name	Description
events_start	The events connection is opened and the server is ready to send events.
search_result_channel	Tribler received a channel search result (either remote or locally). The event contains the channel result data.
search_result_torrent	Tribler received a torrent search result (either remote or locally). The event contains the torrent result data.
upgrader_started	The Tribler upgrader started.
upgrader_tick	The status of the Tribler upgrader changed. This event contains a human-readable string with the status update.
upgrader_finished	The Tribler upgrader finished.
watch_folder_corrupt_torrent	The watch folder module has encountered a corrupt .torrent file. The name of the file is part of this emitted event.
new_version_available	A new version of Tribler is available. The version number is contained in the event.
tribler_started	Tribler has completed the startup procedure and is ready to serve HTTP requests on all endpoints.
channel_discovered	A new channel has been discovered. The events contains the discovered channel data.
torrent_discovered	A new torrent has been discovered. The events contains the discovered torrent data.

Table 4.1: An overview of all events that are passed over the asynchronous events connection, part of the REST API.

will continue the discussion that has been initiated in Section 2 regarding the architecture of the user interface module. First, the structure of the current interface will be described. We will make the consideration between refactoring efforts of the existing user interface or creating a new one. Additionally, encountered design decisions and challenges are presented and discussed.

4.2.1. Analysis of the current user interface

The user interface of the latest version of Tribler, 6.5.2, is unintuitive and cluttered with unused and unnecessary widgets. There are various spelling errors and the navigation through the interface is complex. There are no clear instructions for users that are starting the interface for the first time. For instance, when users are starting Tribler for the first time, there is no information about content that is being discovered. To provide a better user experience, we could provide an indicator about the amount of discovered content.

When focussing on the code base, we notice that it is full of undesired workarounds and bad coding practices (code smells). Much functionality that should be located in the core module of Tribler, is present in the code of the user interface package. There is no clear, documented structure to be identified throughout the code and several reasons for this issue exists. One of the underlying causes is the mindset of developers that the code base of the user interface is subordinate to the code related to core functionalities of Tribler. While it is often true that minor defects in the user interface are less critical than errors in critical core functionalities such as the download engine, developer should always strive to write maintainable and well-designed code, a responsibility which is clearly neglected by user interface developers of Tribler. The fact that the user interface has undergone dramatic changes throughout the ten years of research is an additional reason that led to this unstructured code base. Making short-term decisions were favoured over decisions that benefit the longer-term development process, leading to accumulated amounts of technical debt.

By taking a closer look at the structure of the user interface code base, several files with many class definitions can be found. We already presented the import graph of the user interface code base in Figure 2.4 where we identified many cyclic dependencies. While cyclic dependencies are not always undesired at the granularity of a class file, we are dealing here with a web of dependencies between files, each file possibly consisting of multiple class definitions. Automated testing of individual classes has become significantly more involved with these dependencies.

We now turn our attention to the layout of user interface, where we use the *wx* inspection tool to investigate

the structure of the interface at runtime. We noticed here that the naming convention of widget elements is unclear. For instance, the *ActivityListItem* class is representing a list item in the left menu of Tribler, however, this has nothing to do with an activity that the user performs.

We noticed that the developers of user have attempted to reuse widget elements, especially noticeable in list-related widgets such as headers, footers and list row items. However, we think this can be classified as a failed attempt since the amount of flexibility is too much: by making widgets look good in many different situations in the user interface, the complexity of the class definition increases due to the amount of conditional code that is only executed in a subset of all situations. However, by using the same widget throughout the user interface, we are creating a consistent look and feel.

It is hard for developers to get familiar with the code base of the user interface and to modify it. We think the most appropriate metaphor of the user interface code base is a big ball of mud:

> *A Big Ball of Mud is a haphazardly structured, sprawling, sloppy, duct-tape-and-baling-wire, spaghetti-code jungle. These systems show unmistakable signs of unregulated growth, and repeated, expedient repair. Information is shared promiscuously among distant elements of the system, often to the point where nearly all the important information becomes global or duplicated. The overall structure of the system may never have been well defined. If it was, it may have eroded beyond recognition. Programmers with a shred of architectural sensibility shun these quagmires. Only those who are unconcerned about architecture, and, perhaps, are comfortable with the inertia of the day-to-day chore of patching the holes in these failing dikes, are content to work on such systems.*
> - Brian Foote and Joseph Yoder, Big Ball of Mud[22].

We think that it is not worth the effort to refactor the current user interface and that it is better to start creating a new user interface that follows clear architecture and design principles. However, while designing a new interface, we should still fix critical issues in the old, current user interface. By guaranteeing a minimal level of maintenance of the current GUI, we are not under time pressures to ship the new interface in a specific release of Tribler. Only when the new user interface is ready, stable and tested, we will remove the old interface.

4.2.2. Choosing the right library

Before designing and implementing the new interface, we should first decide which library we would like to use. Because our proposed architecture in Figure 3.5 is communicating to *libtribler* using a RESTful API, this library does not necessary has to support the Python programming language. However, to make reuse of code easier and to maintain a consistent system which used the same programming language for all components, we will implement our new user interface in Python, There are plenty of libraries that are suitable. Below, several of such libraries are summarized, together with a small description.

- *wxPython*[38]: this is the current user interface library we are using. *wxPython* is built upon *wxWidgets* and provides the Python bindings to this latter library. The library is cross-platform and we can continue to use *wxPython*. We already have a large code base written in *wxPython* so continued usage of this library could allow us to reuse several widgets. The main disadvantages of this library are the minor inconsistencies across different platforms and the lack of a visual designer, requiring us to specify the complete layout in Python code.

- *Kivy*[42]: the cross-platform library Kivy has been used by Tribler research, particularly in the past attempts to run Tribler on Android[19][40]. The decision of using Kivy for the new user interface enables us to reuse the interface logic on Android. The layout of Kivy can either be created in *.kv* files or specified in code which is based on the separation of concerns principle. While not as old as *wxPython* or *pyQt*, the library has gained significant attention and adoption in the Python community.

- *Tkinter*[31]: the *Tkinter* library is a layer built upon the Tcl/Tk framework and is considered the defacto graphical user interface library for Python. Like the other discussed frameworks, *Tkinter* does not provide a visual designer. The library is built-in in Python which means that no additional libraries have to be installed in order to start writing code. *Tkinder* however is considered more suitable for simple applications due to the simplistic nature of the library.

- *PyQt*[44]: *PyQt* provides the Python bindings for the Qt framework and is widely used in open-source and commercial applications. With a first version released in 1995, the Qt framework has evolved into a mature state. The library is very well documentation and provides many different addons and plugins to support a wide range of applications. One of these plugins is a visual WYSIWYG designer where the layout of an interface can be specified in a drag-and-drop manner. This generates a *xml* file which can be read and parsed by *Qt*. Visual styles can be specified using the *Cascading Style Sheet* (CSS) language. The documentation of *Qt* is very comprehensive, although the documentation regarding *PyQt* is somewhat less maintained.

Since the GUI will be an important aspect of Tribler, we wish to use a library that is mature, future-proof, well-maintained, easy to use and offers a large of tools so we can reduce the amount of code that has to be maintained. We think that in the context of this thesis, choosing *PyQt* is the best choice to build a new user interface. The fact that we can specify our layout using an editor is an enormous advantage since this will mean that we have less code to maintain. In addition, this allows other developers that are not familiar with the Tribler code base to contribute to the graphical user interface. The *Qt* visual designer also offers tools for internationalization and translation of the interface in foreign languages. Tasks like these are perfect opportunities for contributions in an open source project and can potentially attract new developers. A screenshot of the used visual designer in Qt is visible in Figure 4.5.

4.2.3. Designing the new interface

Designing a user-friendly interface is a non-trivial task and creating a proper design together with mock-ups, is a thesis task itself. Since the design of the new user interface is important but should not be the main focus of this work, we decide to adopt various design principles of existing applications that contain somewhat similar use-cases of Tribler.

In 2008, two design studies have been conducted on the Tribler user interface by two groups of master students. beschrijven

Most torrent download applications have a similar interface: they present a list with downloads and a detail window with specific information about a selected downloads. The old user interface also follows this pattern when displaying the downloads and we see no reason for now to make significant changes to this page. However, Tribler provides more abilities than downloading torrents: browsing through content and managing channels are also use-cases that should be considered in the design.

We believe that YouTube is an example of application that comes close to our use-cases, namely the browsing and streaming of videos, creating and managing channels and creating playlists. The home page of the YouTube interface is visible in Figure 4.2. We take over the left menu in our design like in the current interface, however, we modify it slightly: first, we add an option to open and close the menu by clicking the hamburger menu in the upper-left corner. Next, we make more use of icons so users can identify faster what each option is doing. The adoption of more icons is a general trend in the new user interface: we think that the old interface is too textual.

To make the visual more appealing, we attach a thumbnail to each content item. There is however an issue here: the thumbnails as implemented in the current system is not working correctly. Since implementing a new thumbnail mechanism is outside the scope of this thesis, we use thumbnails that are generated based on the content. This is a technique also adopted by popular platforms such as Stack Overflow and Telegram to display a profile image when the user has not uploaded a picture yet.

Finally, we want to get rid of 'hidden' buttons that are only appearing when hovering over content like is the case in the old user interface. To make it more clear that a specific action can be performed with content, we do not conditionally hide and show buttons but instead, persistently display these widgets.

Due to time constraints, we decided to not implement all features of the old interface. Functionalities such as the debug panel, local filtering and sorting of content will not be implemented in the first iteration of the new user interface. The focus of this new interface will be centred around searching for and downloading content.

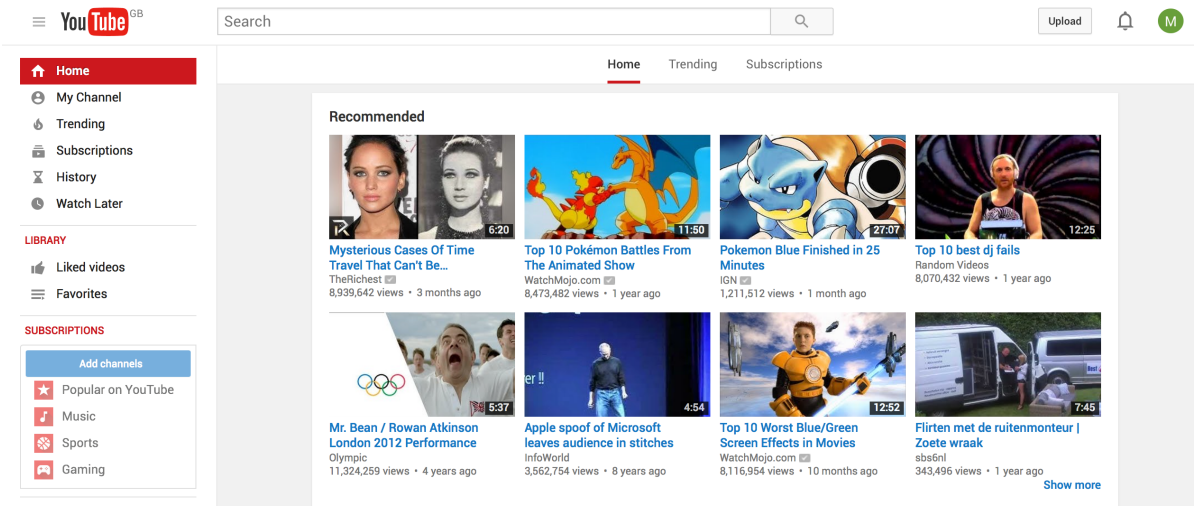


Figure 4.2: The interface of YouTube.

4.2.4. Implementing the new interface

The result after implementation of the new user interface is visible in Figure 4.3. Our vision during development of this interface is that in essence, it should only display data and do as few processing operations on this data as possible. The majority of the new user interface has been built using the visual designer, part of *Qt*. The written Python code is centred around handle requests to the Tribler core, display of the right data in lists and to manage interface-related settings.

A key feature of the *Qt* library is the signal-slot mechanism which facilitates communication between code and widgets. Widgets in *Qt* can have signals, events they want to broadcast to other widgets. Some widgets have built-in signals, for instance, a button emits a *clicked* signal if the user clicks on this widget with the mouse. Other widgets or objects in Python can subscribe to these signals and perform some specified actions when the signal is observed. Signals and slots can either be created by hand, using code, or by utilizing the visual designer. To keep the amount of code to be maintained to a minimum, we decided to specify our widgets connections in the visual designer as much as possible.

During development of the user interface, we encountered some implementation challenges that required more analysis. We will now present these issues and discuss them.

Scalability of list items

The *Qt* framework allows to display potentially many items in a simple list. The performance decreases dramatically if custom widgets are rendered in a list, like we are doing. Loading 1.000 of such list items takes over 22 seconds on a high-end iMac device, introducing an unacceptable amount of latency when displaying a list of items. For each item in the list, the associated user interface file has to be loaded, parsed and rendered, possibly many times per second. Channels hold potentially several thousand of torrents which should be displayed in a timely matter in the user interface.

This scalability bottleneck has been solved by using a simple technique: lazy loading. By taking advantage of a lazy-loading approach where more data is loaded in chunks when the user has scrolled to the end of the list, we can postpone and possibly avoid loading the whole list at once. This solution has also been implemented in the old interface. By loading only a subset of the list rows, the user experience can be significantly increased since users don't have to wait until the whole list of items is loaded, at the cost of a small delay when the end of the list is reached. The implementation of this lazy-loading solution is reusable and can be found in the *lazyloadlist.py* source file. This however, still resulted in a significant period of waiting when the next set of items is being loaded, around one second. It turned out that loading and parsing of the interface definition file is a time-consuming operation. The implemented solution to reduce this processing time is to pre-load the interface definition as soon the user interface starts. This has only a minor effect on the total start-up time (around 40 milliseconds on a high-end iMac device).

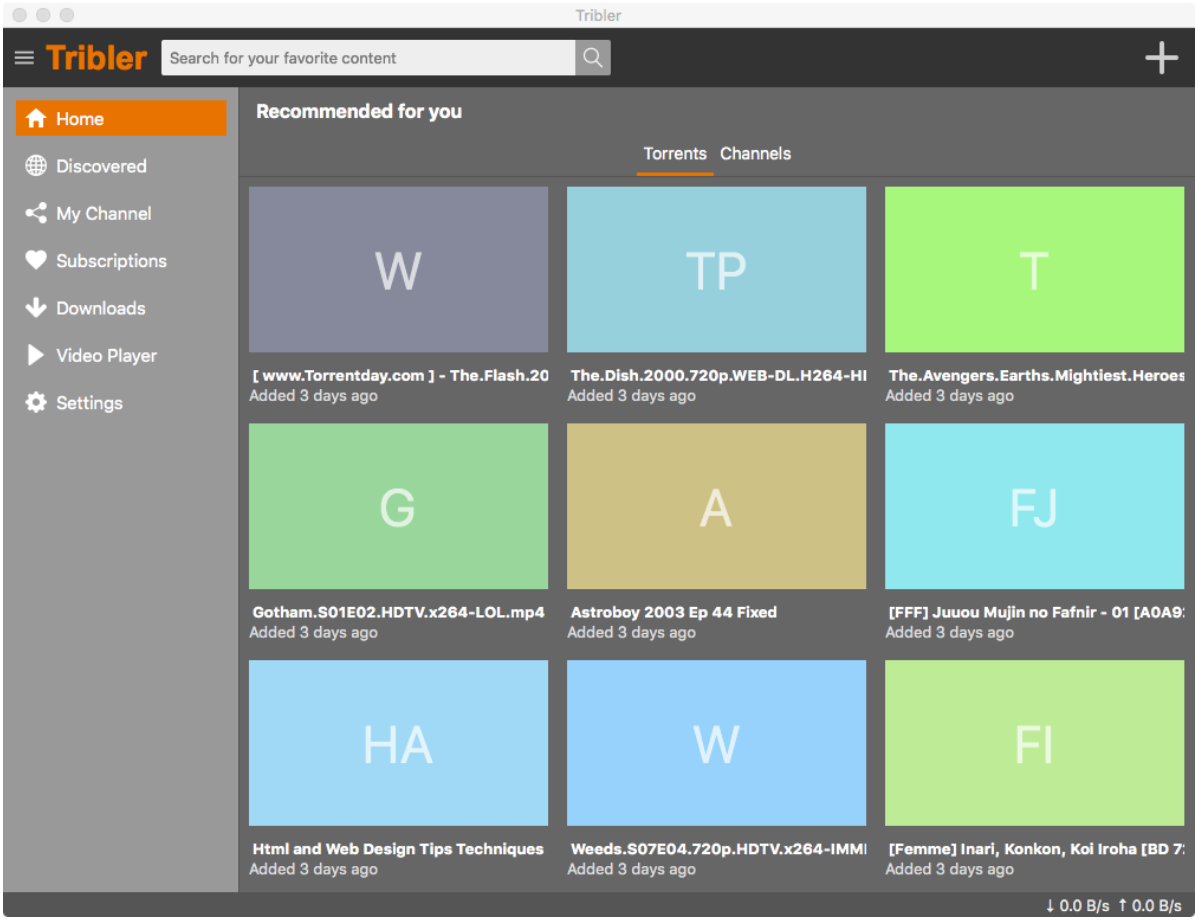


Figure 4.3: The home page of the new user interface.

A function multi-platform video player

The embedded video player in the old interface did not function correctly on MacOS due to incompatibilities with the wx library used. The video player has been implemented using the popular VLC library[11], s a free and open source cross-platform multimedia player and framework that plays most media files. We started the design of the new user interface by creating a prototype where the implementation of a cross-platform, embedded video player with support for starting and stopping a video is centrally involved. While example code was available for the PyQt4 library using VLC bindings, there were some minor quirks when implementing the video player using PyQt5, mostly involved around obtaining a reference to the frame of the video player (which should be done differently for each platform). The code for this player has been used as reference for the implementation of the video player in the new user interface of Tribler and is available as open-source project on GitHub[18].

4.3. Threading model improvements

In Section 3.3.2, we discussed that the current threading model is complex and prone to errors by developers. The implementation of a new user interface and a RESTful API as described in the last sections, has led to a better and stable threading model. Now that the user interface runs in a separate, dedicated process and because of the removal of *wxPython* from Tribler, we have the ability to run the Twisted reactor on the main thread. This allows us to get rid of confusing decorators to switch between the main and reactor thread since we only have one thread (besides the threadpool) to schedule calls on. Getting rid of the abundant thread switching should increase performance since we avoid overhead introduced by the context switch. The new, simplified threading model is visible in Figure 4.4.

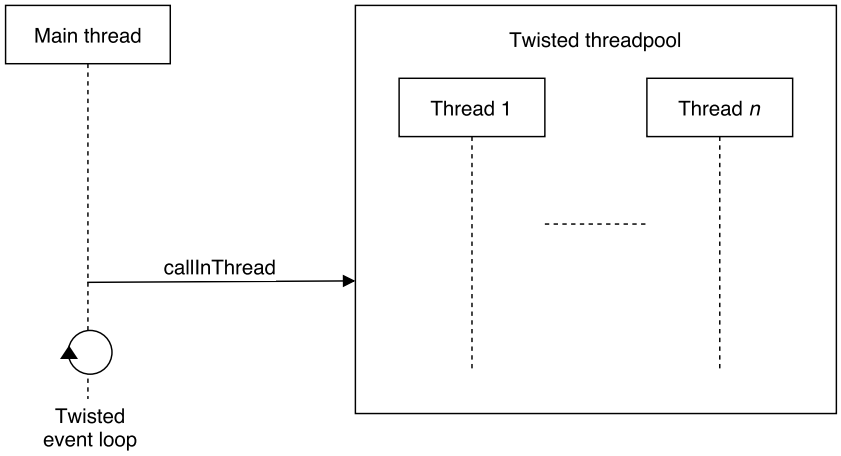


Figure 4.4: The new, simplified threading model in Tribler 7, together with the primitives to schedule operations on the threadpool.

4.4. Relevance ranking algorithm

Serving users relevant information as fast as possible is important in Tribler. When users are performing a search in the user interface, the returned search results are sorted according to a relevance ranking algorithm that considers several factors of the search results. A key problem of this algorithm is that the implementation is located inside the code base associated with the user interface. Essentially, sorting search results can be considered a task of the Tribler core. Moving the algorithm to the core module seems to be a adequate solution but this requires us to understand the old relevance ranking rules so we can reimplement the algorithm in the core module. Unfortunately, the code that is responsible for the relevance ranking lacks proper documentation and is hard to read and understand. Moreover, the code it split between several classes, making it harder to understand its behaviour.

4.4.1. Old ranking algorithm

Sorting of channels and torrents are both using a different algorithm. Channels are sorted on the number of torrents where channels that have a higher number of torrents, are displayed higher in the list. The algorithm to sort torrents on relevance is more complex and uses five different scores. These scores are determined as follows (ordered on importance):

1. The number of matching keywords in the name of the torrent. Keywords are determined by splitting the name of a torrent on non-alphabetical characters and common keywords such as *the* are filtered out.

2. The position of the lowest matching keyword in the torrent name. For instance, when searching for *One* and there is a torrent result named *Pioneer-One-S01E03.avi*, the position of the lowest matching keyword is 2, since *Pioneer* is not present in the search query.

3. The number of matching keywords in the file names that the torrent contains.

4. The number of matching keywords in the extension of the files (for instance, *avi*, *iso* etc).

5. A score that is based on several (normalised) attributes of the torrent. This score is determined after the set of local search results are constructed. To calculate this score, the following formula is used: $s = 0.8 * n_s - 0.1 * n_{vn} + 0.1 * n_{vp}$ where s is our score, n_s denotes the number of seeders (0 if this information is not available yet), n_{vn} the number of negatives votes of this torrent and n_{vp} the amount of positive votes this torrent has received. We should note that the number of positive and negative votes do not exist any more and as a consequence will always be 0, making this score only dependent on the number of seeders. The normalization process calculates the standard score for every data item, using the following formula:

$$z = \frac{x - \mu}{\sigma} \tag{4.1}$$

where z is our normalized score, x the score to be normalized, μ the mean of the data set and σ the standard deviation of the data set.

For each torrent, the set of five scores as described above is determined. The comparison between two torrents now proceeds based on these five determined scores, starting with the first score, proceeding to the next score in case when two scores are equal.

Finally, the list is prepared and a channel result is inserted between every five torrent items in the list. This is done since usually, the amount of torrents is much bigger than the amount of channels. Not only channels matching the search query are displayed: for each torrent, the most popular channel that contains this specific torrent, is determined and also considered in the list of results.

While the algorithm as described above takes many factors in consideration, we detected some problems and possible improvements:

- One of the main problem is that the amount of matches inside a torrent name/torrent file name is not taken into consideration. For instance, when searching for *Pioneer One*, a torrent named *Pioneer One Collection* probably has a higher relevance than a torrent named *Pioneer One - Episode 3, Season 4* since the matching in the first case is considered better.
- The relevance sorting of channels in the result set is only dependent on the number of torrents in that channel. The number of matching terms in the channel name and description is not even considered.
- When building the inverted index in the SQLite database for the full text search, duplicate words are removed. This means that when we search for *years*, a torrent named *best years* will be ranked equal to a torrent named *years and years* (if we only consider a ranking based on the torrent name). However, the torrent named *years and years* should be assigned a higher relevance since the keyword *years* occurs twice in the latter example. Another example is when searching for *iso*. A torrent file that contains 100 *iso* files is currently ranked equivalent to a torrent file that only has one *iso* file.
- The current relevance ranking algorithm only returns results that matches all given keywords. So when searching for *pirate audio*, only torrents are returned that are matching on both terms. It might be better to show the user also torrents matching 'pirate' and matching 'audio' (while still giving a higher relevance score to torrents that matches 'pirate audio').
- The ranking of search results are dependent on each other. This is noticeable when calculating the score based on normalized data. To normalize this data, we should have information about other search results. This prevents a "streaming-like" search operation where the relevance score of each search item is only dependent on data that search item contains and no other data.

4.4.2. Designing a new ranking algorithm

In the previous Subsection, we described the old ranking algorithm, together with some problems and improvements. In this Subsection, we will design a new, robust and simplified algorithm. The heart of the algorithm will be based on Okapi BM25, a ranking function used by search engines to rank matching documents according to their relevance to a given search query[26]. BM25 can be implemented using the following formula:

$$s = \sum_{i=1}^{n} IDF(q_i) \frac{f(q_i, D)(k_1 + 1)}{f(q_i, D) + k_1(1 - b + b * \frac{|D|}{avgdl})} \tag{4.2}$$

In the formula above, we have a document D where the length of D is denoted as $|D|$. There are n keywords present in our search query, q_i representing the keyword at index i. $f(\cdot, D)$ gives the frequency of keyword q_i in document D. The $IDF(q_i)$ denotes the *inversed document frequency* of keyword q_i which basically states how important a keyword is in a document. The IDF is usually calculated as:

$$IDF(q_i) = log \frac{N - n(q_i) + 0.5}{n(q_i) + 0.5} \tag{4.3}$$

where N is the total number of documents and $n(q_i)$ is the number of documents containing keyword q_i. The full text search engine in SQLite offers tools to easily calculate a BM25 score when performing a

query. Unfortunately, this is not implemented in the engine we are currently using, FTS3. This motivates us to upgrade to a newer engine, FTS4, which offers the necessary tools to easily calculate the BM25 score. This requires a one-time upgrade of the database engine of users which should be performed when Tribler starts.

Each search result is assigned a relevance score. The final relevance score assigned to a torrent is dependent on three other sub-scores that are calculated using the BM25 algorithm and is a weighted average of the sub-scores, determined by the name of the torrent (80%), the file names of the torrent (10%) and the file extensions of the torrent (10%). The final relevance score of a channel is the weighted average of the BM25 score of the name of the channel (80%) and the description of the channel (20%).

While this works well when searching for local search results, we should also be able to assign a relevance rank to incoming remote torrent or channel results. To do this, we keep track of the latest local searches and the gathered information that is used by Equations 4.2 and 4.3. If we receive an incoming search result, we are using that stored information to quickly determine the relevance score of the remote result. Using this approach, we avoid a lookup in the database for every incoming remote search result. If we have no information about the latest local database lookup available, we assign a relevance score of 0 to the remote result.

4.4.3. Ranking in the user interface

After each search result got a relevance score assigned, we should order the search results in the user interface. We cannot make the assumption that the data we receive from Tribler is already sorted (however, a relevance score should be available) thus we need a way to insert items dynamically in the list. The lazy-loading list we are using in the user interface makes this task more difficult since we both have to insert items dynamically in the list and make sure that we are not rendering too much row widgets. We also wish to avoid reordering operations as they are computational expensive to perform.

The implemented solution works as follows: in the user interface, we maintain two lists in memory: one list that contains the torrent search results and another list that contains channel search results. We guarantee that these lists are always sorted on relevance score. Insert operations in this list are performed using a binary search to determine the new position of the item in the sorted list, leading to a complexity of $O(log\ n)$ for each insert operation (where n is the number of items in the list). In the visible result list, we first display channels, which are usually only a few. The rationale behind this idea is that users prefer to see matching channels since these channels might contain many relevant torrents. This solution is scalable to many search results. The performance of the new relevance ranking algorithm is discussed in Chapter 6.6.

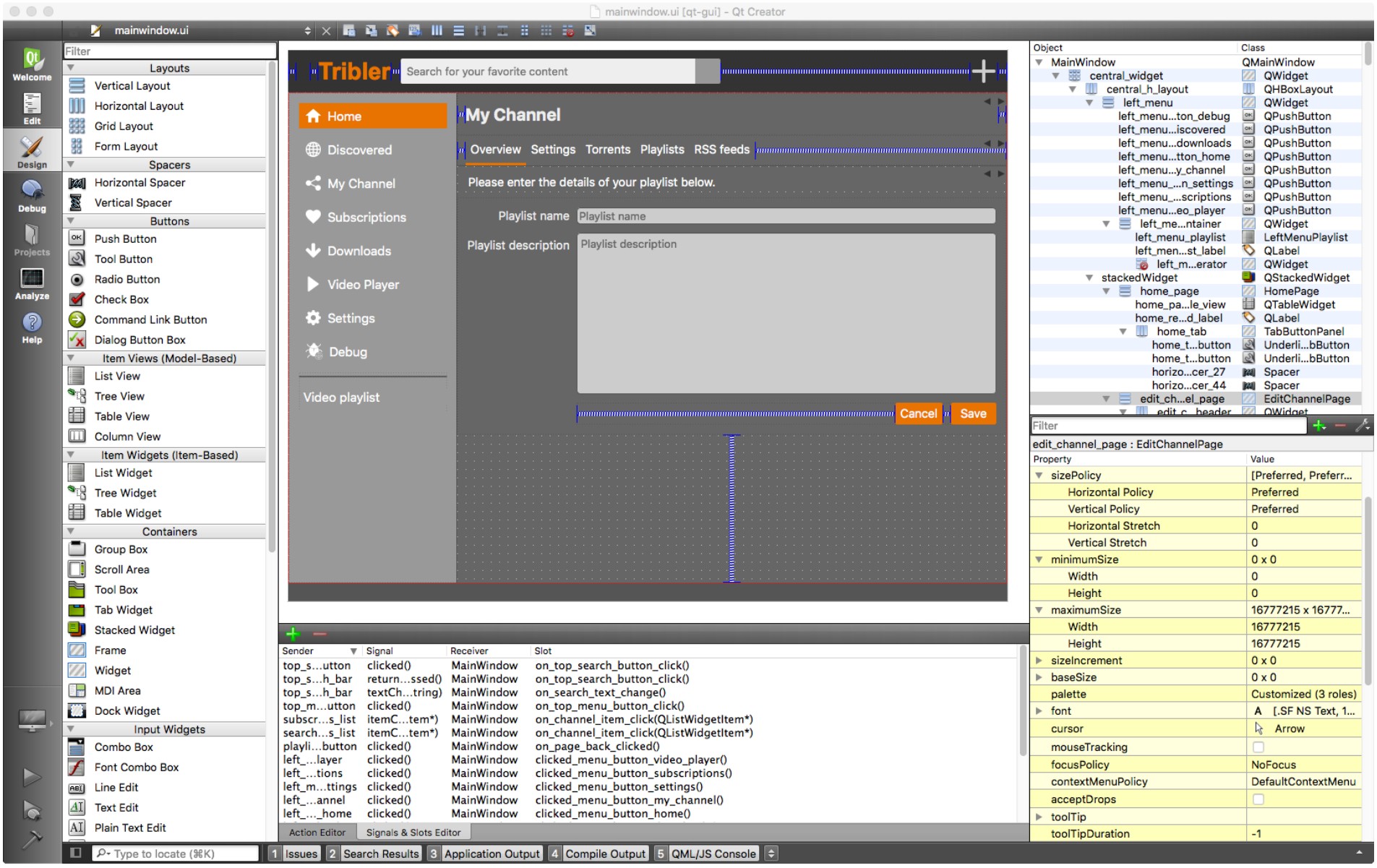


Figure 4.5: The Qt visualizer tool used to create the new user interface of Tribler.

5

Paying off the debt

In Chapter 2, the high amount of technical debt Tribler has accumulated over the past decade has been highlighted. We presented a history of architectural evolution and proposed a new robust and future-proof architecture in Chapter 3. The top-level components of of this architecture, the user interface and RESTful API, are realized and discussed in **??**, however, we did not focus yet on the *libtribler* component, which will be the core of the Tribler platform. Readying *libtribler* for the proposed architecture in Figure 3.5, requires some invasive refactoring efforts. Since this might be the most important component in our system, we will investigate *libtribler* in more detail and determine how we can pay off the accumulated technical debt. A summary of the re-engineering efforts conducted during this thesis work is displayed in Table 5.1.

Lines modified	765
Lines added	12.429
Lines deleted (without GUI)	12.581
Lines deleted (with GUI)	25.010

Table 5.1: A summary of refactoring efforts as conducted during this thesis work, excluding the work on the new user interface.

We can roughly identify five different types of technical debt[41]: *code debt*, *testing debt*, *infrastructure debt*, *architectural debt* and *documentation debt*. Tribler contains symptoms for every of the summarized types of debt. The remainder of this Section will discuss efforts to pay off each type of debt in detail.

5.1. Investigating the debt

It is hard to get accurate numbers on the amount of technical debt. When the decision is made to pay off technical debt, developers might run into unexpected situations that take longer than expected, especially if working with unfamiliar code. Several tools exist to monitor technical debt, the most prominent being CAST[1] (commercial) and SonarQube[2] [20] (open source). In this Section, we will use SonarQube to track and identify the amount of technical debt. We've installed a SonarQube server to track the amount of technical debt, bugs, vulnerabilities and code duplications in the Tribler project. The reported results are summarized in Table 5.2.

	SLOC	**Code smells**	**Bugs**	**Vulnerabilities**	**Estimated debt**
wxPython GUI	20.080	2.139	11	0	± 21 days
Tribler core (before refactor)	15.732	365	6	0	± 4 days
Tribler core (after refactor)	15.700	117	0	0	± 2 days

Table 5.2: The reported software metrics by SonarQube.

[1] http://www.castsoftware.com
[2] https://sonarqube.com

The most interesting observation is that the wx GUI contains around five times more technical debt than the Tribler core, while having 33% more SLOC and contains almost six times more code smells. To better investigate which files suffer from the most technical debt, SonarQube provides a bubble chart where we can see the relation between the amount of technical debt, the number of code smells and the amount of code. For the wx GUI, this bubble chart is presented in Figure 5.1. The files with the most symptoms of technical debt are annotated with the file name. We notice here that the files that are suffering from the highest amounts of technical debt, are also the classes with the most dependencies, see Figure 2.4.

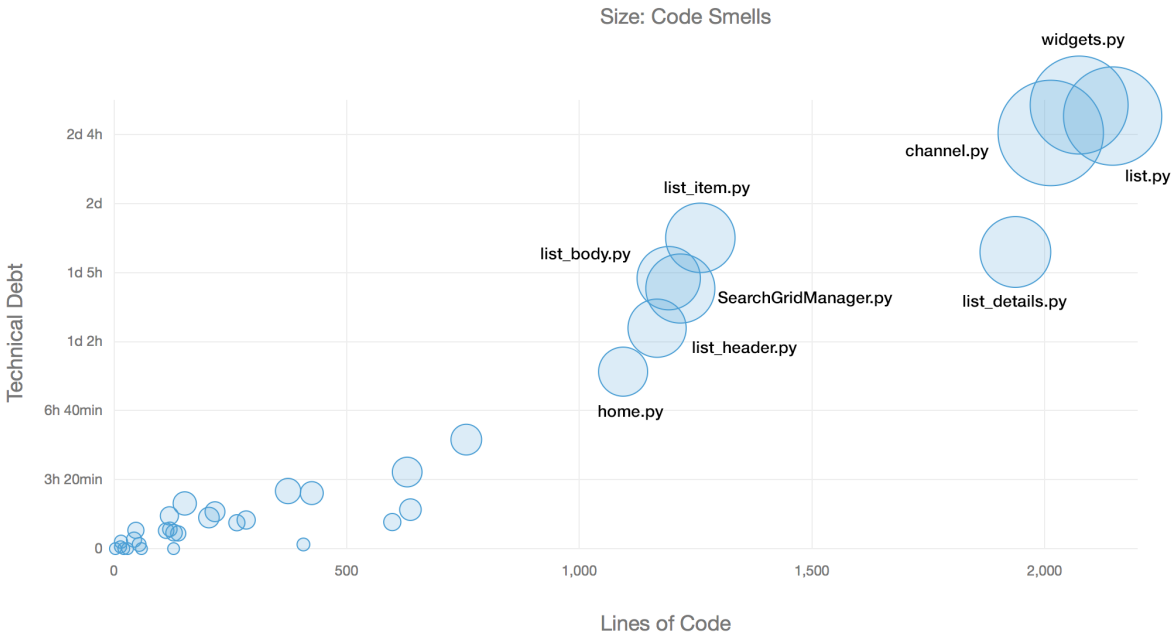


Figure 5.1: The amount of technical debt in the wx GUI reported by SonarQube.

5.2. Code debt

We now turn our attention to the Tribler core and present the bubble chart of an analysis of the core package in Figure 5.2. It is immediately evident that the *SQLiteCacheDBHandler.py* file needs some serious attention. This file contains various utility classes to perform common database operation such as fetching all channels and specific torrents. This file hosts seven classes and our first effort consists of splitting this file into separate files where each file contains only one class definition.

However, we still identify other files where technical debt is visible in the form of code smells. We will now summarize the most common identified code smells in the Tribler core package:

- The cyclomatic complexity of various methods is too high, indicating that that procedure contains too much independent linear paths through the source code. This had a negative effect on the testability of this method since more tests are required to guarantee a high coverage of the method. During this thesis, we reduced the complexity of methods by splitting them into separate parts.

- We identified various methods that could be static. A static method that is not bound to any class has a slightly better performance and it is recommended by SonarQube to switch methods that are not using instantiated class attributes to a static one.

- Naming conventions were not following during the development process and this is most notable in the inconsistency between the usage of *CamelCase* practice and the usage of underscore notation. Since we wish to conform to the PEP8 styling guidelines, we should use the latter form. Part of efforts to pay off the identified code debt in the core includes the renaming of method, function, attribute and variable names to conform to the underscore notation.

The bubble chart of the technical debt in the core after the refactoring efforts above is visible in Figure 5.2. The variance of the code debt has decreased significantly. We also notice that the database handler definition files (that were originally located in the bigger *SQLiteCacheDBHandler.py* file) still contains some technical debt. However, there are many methods in these files that should be removed if the new user interface will be deployed. Table 5.2 shows the statistics after our refactoring efforts. While we did not solve all code smells, we solve the most prominent occurrences of code debt.

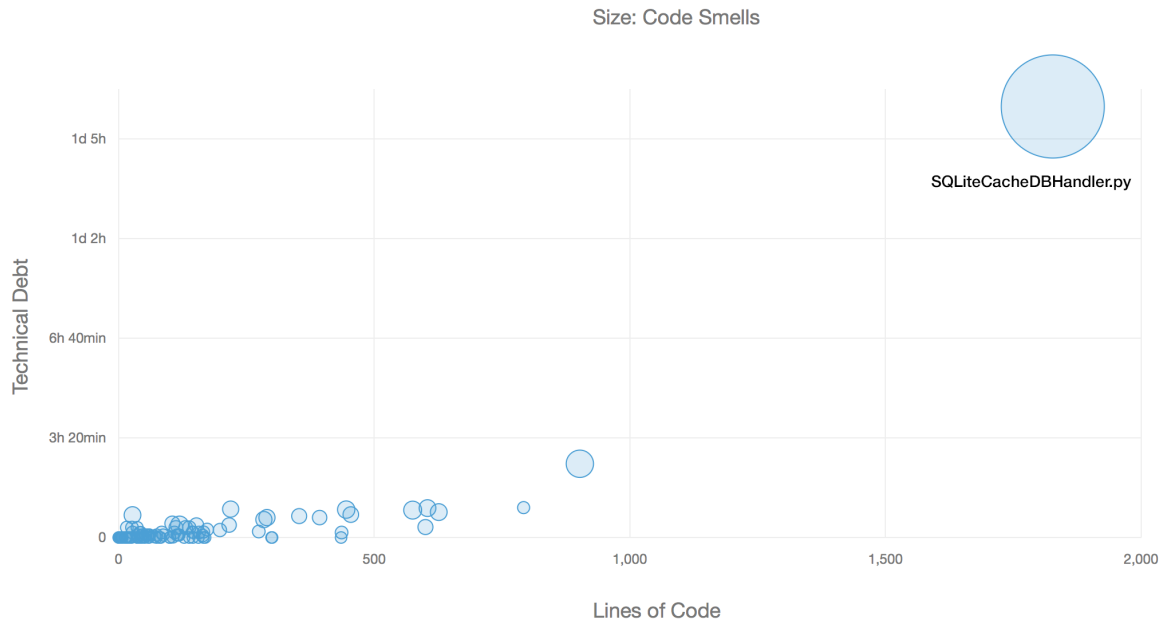


Figure 5.2: The amount of technical debt in the Tribler code reported by SonarQube before refactoring.

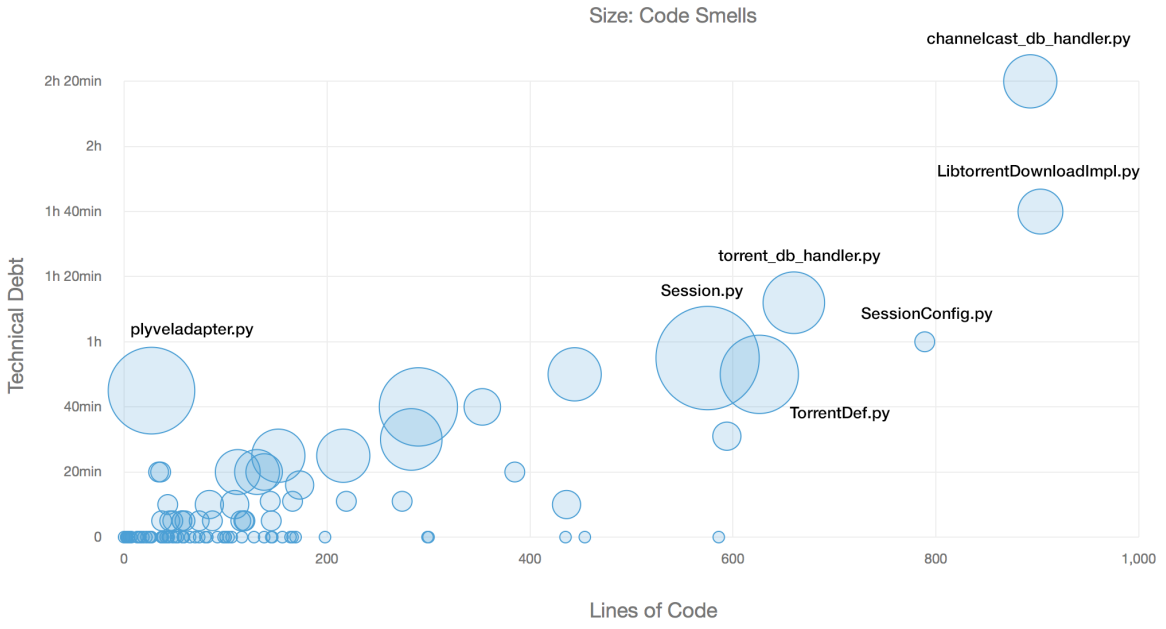


Figure 5.3: The amount of technical debt in the Tribler code reported by SonarQube after refactoring.

5.3. Testing debt

The most fundamental way to verify the correctness of software is by having an well-designed and stable automated test suite. As pointed out in Chapter 2, the current test suite is plagued with unstable and non-functional tests. We will discuss the performed work to strengthen and stabilize the test suite now. A summary of improvements made to various metrics related to the test suite during this thesis is presented in Table 5.3. We notice that the number of unit tests has dramatically increased, while decreasing the average execution time per test and the total duration of the tests.

	November '15	**July '16**
Number of unit tests	80	676
Number of assertions	117	1205
Number of failed runs after 10 runs	2	0
TLC/PLC ratio	0.06	0.14
Total Linux test duration on Jenkins (sec)	448 (7 min. 28 sec.)	350 (5 min. 50 sec.)
Average execution time per test (sec)	18.90	0.85

Table 5.3: A summary of improvements to the test suite between November '15 and July '16.

5.3.1. Identifying code smells in the tests

As described in the work of van Deursen et al[46], there is a difference between refactoring test and production code in a sense that test code often has a characteristic set of code smells, originating from the way tests are structured. Before we start to make major modifications to the test suite, we present a list of code smells identified after a manual code review in the test suite of Tribler. This list is displayed in Table 5.4 where for each code smell, we describe it and propose a solution.

Table 5.4 has been used as reference during the refactoring efforts of the test suite and in this thesis work, we fixed various of the outlined code smells. Dependencies on external resources have been reduced to a minimum as explained in Subsection 5.3.4. The efforts on increasing the stability of the tests is outlined in Subsection 5.3.5. During the refactoring process of tests, we placed clear assertions, added comments and got rid of managing Tribler sessions as much as possible.

5.3.2. Improving Code Coverage

Code coverage is defined as the percentage of source code that is covered by at least one test in the test suite. Our continuous integration environment offers tools to track the code coverage over time. After each automated test suite execution a comprehensive report with detailed information about the code coverage is generated. The reported metrics by this report are not accurate enough since some third-party libraries are included in the coverage report, such as the VLC bindings and *pymdht*, a library to fetch peers from the Distributed Hash Table (DHT). Also, the code coverage of Dispersy is included in these reports while we consider Dispersy as a separate engineering project.

The improvements in the code coverage metrics during the span of this thesis are displayed in Table 5.5. Branch coverage is a metric that specifies how well conditional statements are covered. This metric includes the fact that a conditional is either resolved to true or false, possibly influencing the program execution path. In the ideal scenario, we wish to have tests that cover all conditional statements in the case they resolve to *true* and in the case they resolve to *false* so we cover all possible execution paths in the program. This objective gets significantly harder to achieve when code with many nested conditional statements is written. The cyclomatic complexity as developed by McCabe in 1976[33] is a quantitative measure of the number of linear independent paths through a program's source code. Any conditional written has a negative effect on the cyclomatic complexity.

While at first sight it may look like the code coverage has not increased significantly, we should emphasize that the complete architecture of the tests have been overhauled in parallel. Refactoring of the test suite had consequences on the code coverage in other locations in the code base. For instance, the smaller unit tests are not starting the old user interface, leading to a lower coverage in that module.

Code smell	Description	Solution
Dependencies on external resources	Various tests are using external resources, leading to unpredictable and unstable tests.	Remove the dependency on the resource or make sure that the resource is locally available (see Chapter 5.3.4).
State leak	The state of a previous executed test is leaking to the next test, mostly notable due to delayed calls left in the Twisted reactor after shut down.	Make sure that any delayed call in the reactor is removed when shutting down Tribler.
Too much responsibility	Many tests have multiple responsibilities, testing both parts of the user interface and core components in Tribler.	Make sure that each test is only verifying one unit in the system. Also implement a separate test suite for the user interface.
Tests with a high runtime	There are some tests that are taking long to complete (sometimes over 30 seconds). This can be an indicator that the test has too much responsibilities.	Identify why the test takes long to complete and shorten the runtime i.e. by splitting the larger test in smaller tests.
Unclear assertions	Tests that have multiple assertions often do not annotate their assertion well with a clear and meaningful description	Add an annotation with the cause of the failure if an assertion fails so developers can pinpoint the problem quicker.
Dependency on a Tribler session	Some tests are starting a complete Tribler session while only a small subset of the system is tested	Use mocking techniques to inject a mocked session or refactor the component so no session is required to test the component.
Resource writing to the source code directory	Various tests are writing resources to the source code directory. They might accidentally end up in the VCS if developers are not noticing these files.	Temporary resources produced by tests should always be written to a temporary directory that is cleaned after test execution.
Claiming the same local network port	Some tests that are running in parallel are claiming the same local network port, leading to test failures.	Reserve port ranges to individual parallel test runs or try to avoid the allocation of local ports.
Timing issues	Various tests are asserting a condition after a fixed time interval. This interval is often based on intuition rather than empirical data. This is particularly dangerous when the test is dependent on external resources.	Refactor the test so the condition check is no longer necessary.
No usage of comments	There are no comments, explaining what the the tests are testing and what the expected output is.	Comments should be added that explains the purpose of the test together with the expected in- and output.
No directory structure in the test package	There is no directory structure and almost all tests are located inside the same directory.	Restructure the tests package and organise tests in different, logical named directories.

Table 5.4: Identified code smells in the test suite of Tribler as of November '15.

	November '15		July '16	
	Lines coverage	Branch coverage	Lines coverage	Branch coverage
Core	71,2%	58,1%	81,2%	67,3%
REST API	-	-	99,4%	92,7%
wx GUI	65,8%	42,7%	-	-
Qt GUI	-	-	73,4%	50,4%

Table 5.5: The difference in code coverage between November '15 and July '16.

Improving the code coverage has been done by writing small unit tests where we are using mocked objects to have better control over the system we are testing. Using mocking in Tribler is a necessary since some components have many other dependencies that are hard to keep under control without using custom, controlled objects. Libtorrent is a good example of this. During this thesis, many unit tests have been written as can be seen in Figure x where the number of unit tests over time is presented. Writing tests makes a developer more aware of the written code and can be a good way to get familiar with an unknown system. Due to this, various bugs have been solved during the process of writing additional tests.

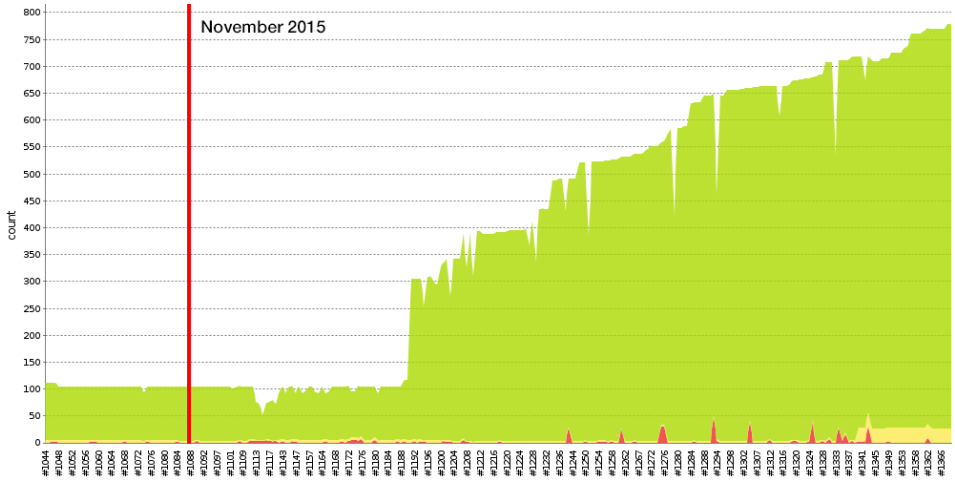


Figure 5.4: The number of tests over time until July 2016 (November 2015 is annotated).

In Chapter 2, Figure 2.5 we presented the ratio between the number of code lines in the tests package and the amount of other code lines over time. Together with the code coverage, this number can be a useful metric to developers. While one might argue that having a high code coverage in conjunction with a low TLC/PLC ratio is a desired result, it indicates that the tests are not granular enough and are actually doing many different operations. A low code coverage with a high TLC/PLC ratio indicates that there are some flaws in the tests, possibly that they are testing the wrong components of the system. In the case of Tribler, the coverage is reasonable (still a bit low) but the TLC/PLC ratio is very low, indicating that most likely, the tests are not granular enough.

After writing additional unit tests, removal of the old user interface and addition of the new one, the new ratio is *0.16* which means that there is roughly one line of test code for six lines of other source code in Tribler. Defining a good TLC/PLC ratio is dependent on the used programming language, development methodology and application structure. Discussion on the wiki of Ward Cunningham[5] proposes an optional ratio of 1:1, however, several other ratios have been proposed on the same page such as 2:1 and 5:1. In the work described in [46], an ideal ratio of 1:1 is proposed. Overall, the trend seems to be that the amount of test line code is around the same or a bit higher than the lines of production code. An important question is whether this proposed ratio also holds for Tribler. Tribler differs from a commercial software engineering project in the sense that it is used for scientific research. When performing research, it is easy to ignore testing and focus on the results that are gathered by the system. The difficulty here is that Tribler is distributed and used by over a million of users, requiring at least some form of quality assurance. We think a better optional TLC/PLC ratio for the Tribler project might be 1:2.

To make sure that the responsibility of code coverage is not neglected in future work on Tribler, an addition check for each pull request has been added that verifies that the code contributed in the respective pull request is covered by tests. While not created by the author of this thesis, this check is an effective way to keep the code coverage metric under control.

5.3.3. Testing the New User Interface

One of the issues in the old testing framework, was that there is no clear separation between tests that are testing the user interface and tests that are testing core functionalities of Tribler. This is one of the reasons that have led to big, extensive tests in the old test suite. Since testing is an important aspect of this thesis work, writing proper tests for the user interface has been a prioritized task earlier in the development process of the new user interface.

GUI testing is an interesting area in the field of software engineering and is part of the application testing methodology. GUI testing can also be more involving than unit testing since a user interface might have many different operations and verification of the correct output of an action is often a non-trivial task. A popular way of testing user interfaces is a Finite State Machine-based modelling where the user interface is modelled as a state machine that transitions when actions in the user interface are performed[16][13]. Another model to create a test script based on a genetic algorithms has been proposed by the work of Kasik et al[27].

We started out by removing the *wxPython* dependency from the test suite by making sure that no test is starting a user interface. Preferably, we want to avoid starting a headless Tribler session, however, for some situations this requires too much refactoring, for instance, when testing the tunnel community that facilitates anonymous downloading and seeding.

Testing the new Qt user interface makes use of the *QTest* framework. This framework provides various tools to perform non-blocking waits and to simulate mouse clicks and keyboard actions. A sample of a test written with the *QTest* framework is illustrated in Listing 5.1. After the interface is started, the test navigates to the home page, clicks on the *channels* tab button and waits for items to be loaded. During the test execution, two screenshots are captured, one when we are loading items and another one when the requested items are loaded and displayed.

Primitives to capture screenshots during test execution has already been implemented and used in the old test suite, using the rendering engine of *wxPython*. The *Qt* frameworks offers similar tools. Captured screenshots are exported to *jpg* files under a name specified by the developer. In the sample given in Listing 5.1, the exported screenshots are saved as *screenshot_home_page_channels_loading.jpg* and *screenshot_home_page_channels.jpg* respectively. At the end of each test run, an image gallery is generated where the generated screenshots are archived and displayed in a grid. This allows developers to manually verify whether visual elements are correctly displayed. A part of the generated image gallery is displayed in Figure 5.5.

To avoid dependencies on Tribler itself and thus re-introducing the problem we are trying to solve, we created a small piece of software that provides the same interface as the REST API implemented. This 'fake' API is much simpler in nature and has a very simplistic in-memory data model. The downside of this approach is that new endpoints have to be written twice, once in Tribler and once in this fake API, providing that the new endpoint will covered by a user interface test.

Listing 5.1: A sample of a test that tests the new Qt Tribler GUI.

```
def test_home_page_channels(self):
        QTest.mouseClick(window.left_menu_button_home, Qt.LeftButton)
        QTest.mouseClick(window.home_tab_channels_button, Qt.LeftButton)
        self.screenshot(window, name="home_page_channels_loading")
        self.wait_for_home_page_table_populated()
        self.screenshot(window, name="home_page_channels")
```

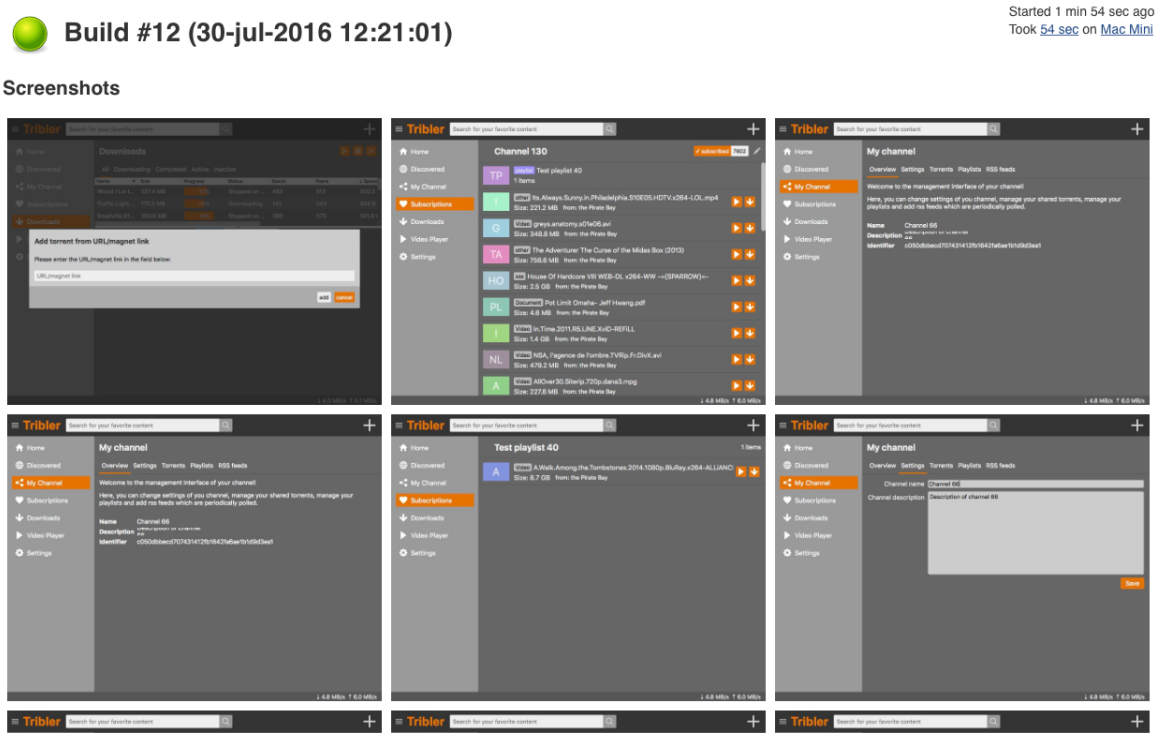


Figure 5.5: The generated image gallery after executing of the user interface tests, generated by Jenkins.

5.3.4. External Network Resources

On of the problems with the test suite was that dependencies on external network resources should either be removed or one should verify that the resources are under the control of the developer and always available. The test suite contains various tests where external torrent files are fetched from the internet, in particular, from the Ubuntu repository. While this repository can guarantee high availability, any downtime in this external resource can lead to failing tests. The implemented solution for this design flaw is to start up a local HTTP server that serves the torrent file. While this approach requires more code to manage this local server, it completely removes the dependency on the Ubuntu repository.

The same solution has been applied to solve the dependency on external seeders. A small number of tests makes assumptions on the availability of torrent pieces of the network. This certainly makes tests fail if the executing machines has a bad or even no internet connection. The process of setting up a local seeder session is straightforward. Again, this approach requires code to properly start and shut down the seeder session. The implementation is reusable to an extend that developers of tests can reuse the implemented solutions with only a few lines of code.

Unfortunately, there are some external network dependencies left which are considered harder to refactor. A handful of tests are performing a remote keyword search, requiring various communities in Dispersy to be loaded. These tests are dependent on available peers in the respective community in order to make sure there are incoming search results. The proposed solution here is to start various dedicated Dispersy sessions on the local machine. Due to time constraints, the implementation of this solution is considered future work.

5.3.5. Instability of Tests

A non-functional testing suite has a direct impact on the productivity of developers: when unit tests fails to reasons unrelated to the code that the developer contributed in a specific pull request, developers have to run the test suite again by placing a comment on the Pull Request that says *retest this please.* Every retest operation is "wasting" several minutes since developers have to wait this time before their Pull Request can be merged and before they have the necessary feedback on the stability of their pull request. This is a structural problems that Tribler developers are experiencing since the utilization of continuous integration.

To estimate the total time developers had to wait for retests, we've written a small script that that uses the GitHub API to analyse every opened pull request and count the number of retests required. Before we present the results, we should not that we might miss some occurrences since they might have been removed. In addition, some retests might be related to failures in the continuous integration environment. In total, we counted 2045 retests in 1481 pull requests, on average, 1.38 retests for each pull request. If we use an optimistic estimation of a duration of six minutes for the execution of the full test suite, we spent around 204 hours in total retesting pull requests. We argue that we can stabilize the test suite in much less time so we need no retests anymore. To demonstrate that we are dealing with a structural problem here, the number of retests over time has been displayed in Figure 5.6.

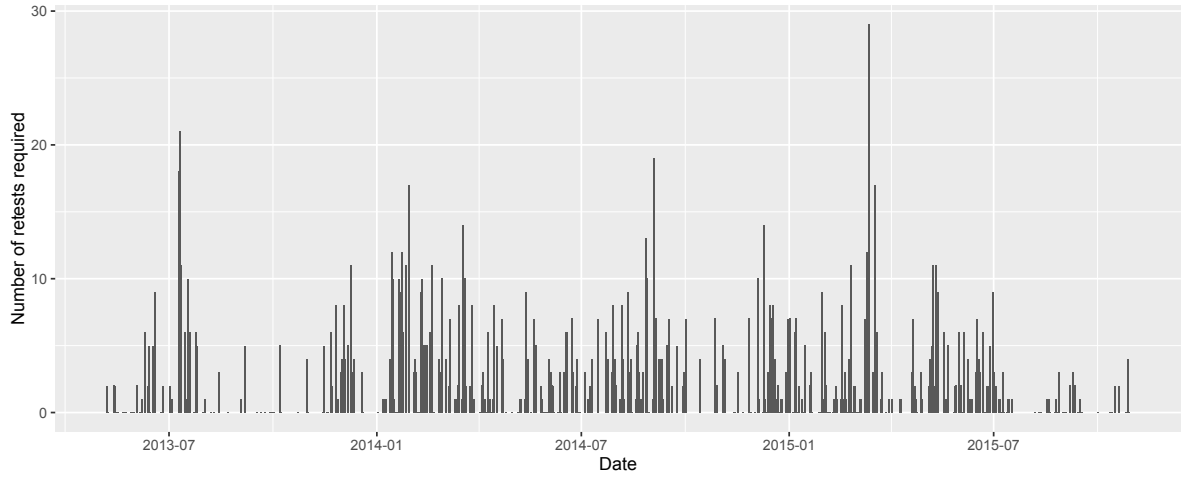


Figure 5.6: The number of retests required in Pull Requests over time.

Essentially, we are dealing here with a special kind of technical debt. Developers prudently made the decision to postpone fixing of the problem by retesting the pull request until the tests passes. The incentives to spent some time to fix errors in tests are not apparent and often, developers do not feel that they are responsible for failing tests since it might have been caused by code written by other developers. This makes it attractive to ignore test failures.

Well-designed tests should only fail if some new code is breaking existing functionality. If no changes are presents, the tests should always succeed. Reducing dependencies on external network is not sufficient to guarantee this condition in Tribler. The structural problem of the tests is that the system is infested with race conditions. Race conditions can be invisible since they often occur in a very specific runtime setting of the system, making the debugging process of these kind of errors frustrating. In fact, it is very easy to deliberately introduce a race conditions that is not noticed after the code is merged into the main branch. A complex architecture and threading model is an important asset in this process.

During this thesis, various race conditions have been detected and solved. One interesting observation is that some issues only occurred on a specific platform. We believe can be explained by differences in the implementation of underlying threading model across operating systems. The most common cause of failing tests can be addressed to delayed calls in the Twisted reactor. During the test execution, Tribler is restarted many times. If a developer leaves by accident a delayed call behind when the shut down procedure has been completed, this delayed call might be executed in the wrong Tribler session, possibly leading to an inconsistent state of the system. Making sure the reactor is completely clean is not straightforward: if one is not aware of scheduled calls in the system, the mistake is easily made.

Writing stable tests also requires the test to be limited in what they do. Each test should only be focussed on the specific part of the system that has to be tested. While often unnecessary, a significant amount of the available tests are focused on starting a complete Tribler session, testing a small subset of the system, and shutting down Tribler again. While this approach is relatively easy to code, starting a fully-fledged session

often leads to more instability and unexpected side-effects during test execution. Instead, only the classes to be tested should be instantiated and any dependencies this class have, should be mocked. Mocking ensures that developers have control over dependencies, allowing them to specify any expected return value. Moreover, the execution time of these small unit tests is significantly lower than the tests where a Tribler session is managed. The additional unit tests that have been written during this thesis, are following the described design.

5.4. Infrastructure debt

Tribler makes use of the popular continuous integration (CI) platform Jenkins. Jenkins allows developers to define jobs which can be executed manually or when pushing a commit on the code base. This continuous integration platform is responsible for running the tests, packaging Tribler and running research-oriented experiments.

When we focus on the execution of the tests, it is immediately noticed that they are only executed in a Linux environment. Beller et al[12] conducted research on CI adoption and usage and it turned out that for some languages, it might benefit to run tests in different environment. An addition argument for this is the usage of many platform-specific workarounds we are using in Tribler. To make sure that these statements are covered, we must run the tests in this environment. This will allow developers to detect defects on other platforms more earlier in the development process. By aggregating the generated coverage report on each platform, this multi-platform setup should benefit the code coverage.

The setup of the testing environments on Windows and OS X is straightforward. New slave nodes to specify the Windows and OS X test runners have been created. The tests on OS X are executed on a Mac Mini, late 2014 model with 4GB of DDR3 memory and an Intel Core I5 1.4 GHz processor. In order to run the tests on Windows, two virtual machines using Proxmox have been created, both 32-bit and 64-bit environments. In total, the tests are executed on four platforms now: Linux, Windows 32-bit, Windows 64-bit and OS X. So far, the OS X and Windows test executers have completed over 2.500 test runs. Each test runner generates a coverage reports and these reports are merged in the final analyse step in the build pipeline.

While this is certainly a step in the right direction, there are various additional steps in the execution plan that can be performed. In Figure 5.7, the ideal test execution plan is displayed, together with the various stages in this pipeline. We start by executing the tests on multiple platforms where during these runs, the code coverage is being tracked. After this phase, the coverage reports are combined and the total difference with the upstream branch is determined. When the commit decreases the total code coverage, the job fails.

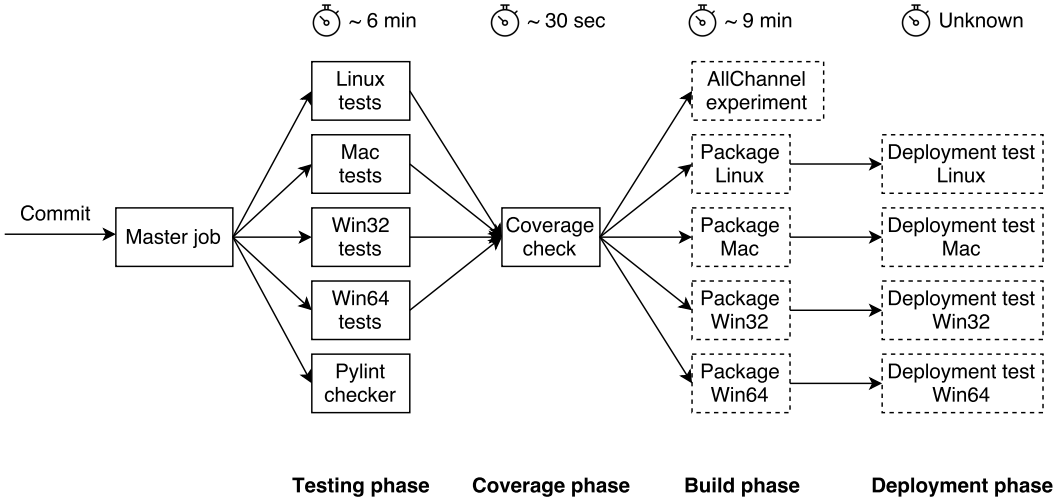


Figure 5.7: The desired test execution plan in our continuous integration environment. Dashed boxes are not implemented yet.

A static Pylint checker has been available to check for code style violations, however this only gave insight

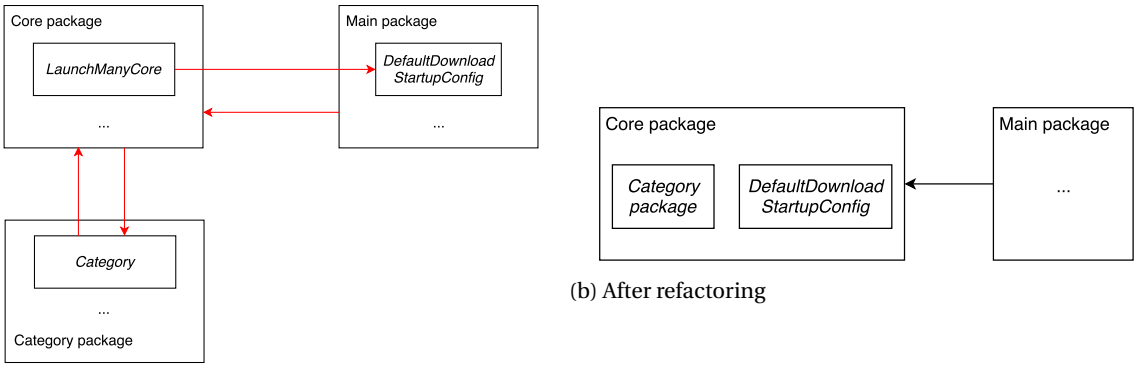
in the total amount of Pylint errors and did not stimulate to actually fix errors in the committed code. While not implemented by the author of this thesis, the Pylint checker has been extended to fail if new violations are introduced in the committed code. Additionally, a report is generated with an overview of the introduced violations. This helps developers to get more aware of the code style. This checker is ran in parallel with the tests to decrease the total time of the pipeline execution.

After the coverage phase has passed, jobs to package Tribler for distribution should be added. In parallel, the *AllChannel* experiment can be executed. This experiment is executed on the DAS5 supercomputer and starts 1.000 Tribler clients that are synchronizing torrents and channels with each other. When the experiment is completed, several graphs are generated, providing developers insights in the consequences of their modified code when Tribler runs in a more comprehensive environment. For instance, the experiment can highlight issues in the message synchronization between peers in the network.

In parallel with the *AllChannel* experiment, we can package Tribler for distribution to end-users. On Windows, an installer will be created that installs Tribler to the *Program Files*. On OS X, we create a *DMG* file that contains an app bundle. On Linux, the required files are bundled in a *deb* archive. All these jobs can be executed in parallel. Finally, we should test whether the final distributions are working. This should be achieved by executing the final Tribler executable. A small test suite that makes use of the REST API can be created.

5.5. Architectural debt

As indicated by Figure 2.4, Tribler is plagued with many dependencies that are leading to a highly coupled system where it is hard to reuse individual components. This Section will focus on identification and removal of undesired dependencies between packages.



(a) Before refactoring

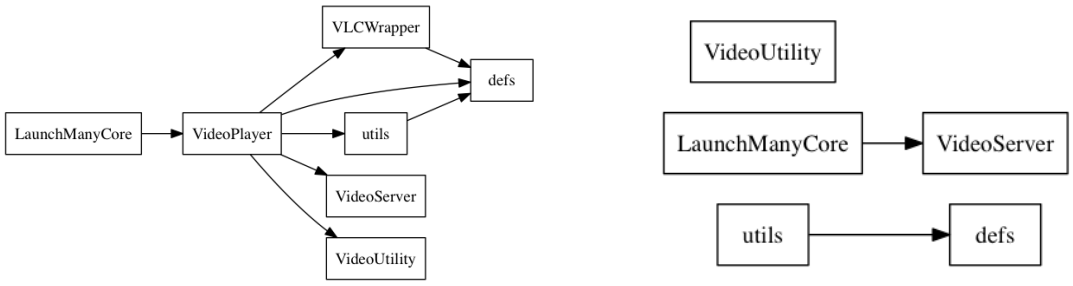
(b) After refactoring

Figure 5.8: The dependencies between Tribler modules at the highest level.

5.5.1. GUI and core packages

As described in Chapter 2, the source code for the user interface and Tribler core code is interleaved to a large extent and there is no clear separation between these components. There are various instances where we identified code present in the user interface code base that should be moved to the core and vice versa. To realise a clear separation between *libtribler* and the user interface, we should make sure that we move code to the modules where it belongs.

In the present code base, the *Core* package is dependent on the user interface which is a situation we wish to avoid since it influences the reusability and testability. The exact dependency is visible in Figure **??** and is caused by the *DefaultDownloadStartupConfig* class which is located in the *globals.py* file, part of the user interface module. This class is responsible for getting default configuration options when a download is being started, in case the user did not override the default options, such as destination of the downloaded file and the amount of anonymous hops used. Since the superclass of *DefaultDownloadStartupConfig*, *DownloadStartupConfig*, is already located in the Tribler core, the easiest solution is to move the *DefaultDownloadStartupConfig* class to the *DownloadConfig.py* file, which already contains the *DownloadStartupConfig* class.



(a) Before refactoring

(b) After refactoring

Figure 5.9: The import graph of the *Video* package in the Tribler core before and after refactoring.

After we moved this class to the core and modified the references to point to the new location of the class, the core is completely independent of the user interface.

The final result of the refactoring effort described above is displayed in Figure 5.8b. We readied the Main package for removal when the new user interface is ready for deployment.

5.5.2. Category package

Referring to Figure 5.8, we note a cyclic dependency between the *Core* and *Category* package. The *Category* package hosts the source code to facilitate the family filter. Obviously, the family filter is used by the Tribler core, however, the family filter also has dependencies on classes inside the Tribler core, causing a cyclic dependency.

In the architecture proposed in Figure 3.5, we specified the family filter as component of libtribler. We think that the best solution to solve this dependency, is to refactor the *Category* package inside the Core package so it's part of libtribler. This change is reflected in Figure 5.8b.

5.5.3. Video Player

We will now focus on the core package which contains some code that should not be present. The most obvious piece of user interface-related code is attributed to the (embedded) video player in Tribler which is handled by the *VideoPlayer* class in the *Video* package. This class makes use of the VLC bindings for Python, however, in our design, the core does not need to have any dependency on VLC since managing the video player is a operation that should be performed on the level of the user interface. Figure 5.9a shows the import graph of the *Video* package before refactoring. The *LaunchManyCore* class contains code to initialize all components available in Tribler, including the *VideoPlayer*. When initializing, this *VideoPlayer* creates a *VideoServer* that is responsible for the streaming capabilities of Tribler. The *VLCWrapper* class contains various utility methods to work with raw VLC data such as the time position within a video.

We performed some refactoring work on this package and removed the *VideoServer* and *VLCWrapper* classes. The composition of the *Video* package after this operation is displayed in Figure 5.9b. We modified the code such that *LaunchManyCore* the starts a video server instead of a video player. We note that there are some classes that appears to be unused, such as *VideoUtility* and *utils*: these classes contains some helper methods to retrieve thumbnail images from a video file. Due to time constraints, we are unable to implement these features in the new user interface so we keep these files as reference for future development.

5.6. Documentation debt

During the last ten years of development on Tribler, the main focus of the project has been to deliver working code. The project has a severe lack of maintained software artifacts, including documentation, comments and architectural diagrams, leading to a huge amount of *documentation debt*. Most of the conducted research was documented on the Tribler wiki[3], however, this wiki is very outdated and not maintained anymore. After the migration of the project to GitHub, this platform was favoured over continued usage of the Tribler wiki

[3]https://www.tribler.org/TitleIndex/

archive.

At the moment, there are several distinct locations where we store the few software artifacts we have. Documentation is either stored in the GitHub wiki or in the 'docs' directory in the Tribler source code. The ideal situation is to have one single, useful location for all generated documents during the process. Many Python projects are using *readthedocs*, a platform to host documentation for free. The hosted documentation should be located in the Tribler repository, in *reStructuredText* (RST) format. By using the Python module Sphinx, a HTML website can be generated from all the available documentation. Sphinx also provides tool for localization of documentation.

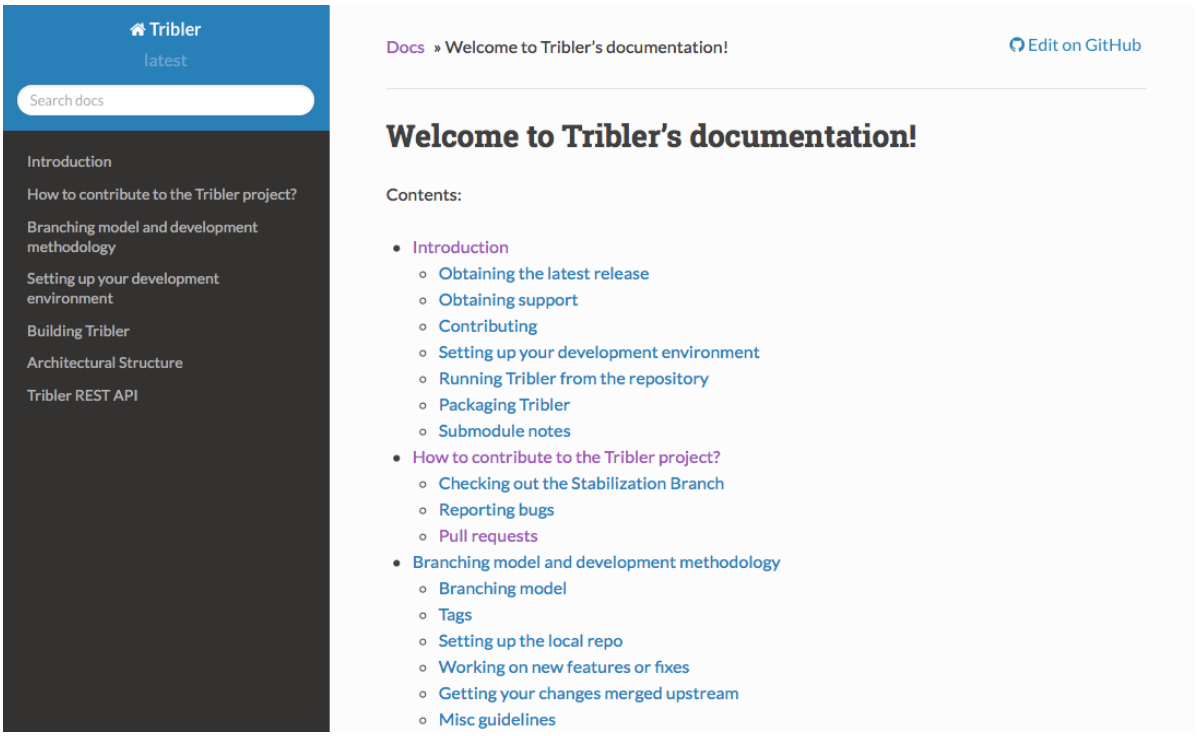


Figure 5.10: The documentation of Tribler, as displayed on the *readthedocs* website.

During this thesis, all available documentation of Tribler has been rewritten to make use of RST in conjunction with *Sphinx*. Moreover, the available documentation has been improved with several guides, in particular, guides that help users to create a developer environment on their machine. Prior, these guides were not available and development on other platforms than Linux was not supported. By the addition of these guides, new developers can start as soon as possible with development on Tribler.

The REST API in particular has been very well documented. Since external developers can use the REST API to control Tribler, we wish to provide a clear and comprehensive documentation base for this API. To simplify the process of writing documentation, the documentation can be written as doc strings above each method. The *autosummary* tool that is executed each time the documentation is built, navigates through the API code base, extracts all doc strings and generates page sections for each documented method. The doc string can also be attributed with *RST* syntax. This feature decreases chances that developers accidentally forget to write documentation since the code and documentation is present in the same file instead of being spread across different files.

5.7. Preventing Technical Debt

Prevention is the best medicine and we should think about the prevention of technical debt in future development stages. Tribler needs a culture change regarding technical debt: developers have never been aware of the long-term consequences of the Tribler architecture and their work. To stop the deterioration of the

system, we need to raise awareness of technical debt and the term needs to play a bigger role when making longer-term decisions. In addition, we present the following list of preventions:

- Code reviews is an effective way of ensuring that problems in the code are detected as early as possible[6] but additionally, it helps developers to learn from their mistakes. The new policy introduced during this thesis requires each pull request of developers to be at least reviewed by two other Tribler developers. This policy also helps developers to get aware of ongoing projects that other developers are working on.
- Continuous integration and automated testing is an excellent opportunity to maintain a high level of code quality and to catch bugs during the development process before customers report them. The work as described in this Chapter, has matured the CI and testing environment so it can be used reliably by the next generation of Tribler developers.
- Our CI environment already used static analysis tools to report violations in the source code which is an effective way to make developers aware of their introduced violations[34]. However, this tool has been implemented as separate job and is not executed on every pull request. This has been changed so developers receive fast feedback when they push a new commit to GitHub. The implemented checks for every pull request are visible in Figure 5.11. Besides the reports of the test execution on multiple platforms and the code violation reporter, the code coverage report fails if developers added or modified lines that are not covered by a test. This tool will definitely contributes towards an increase of the code coverage metric.

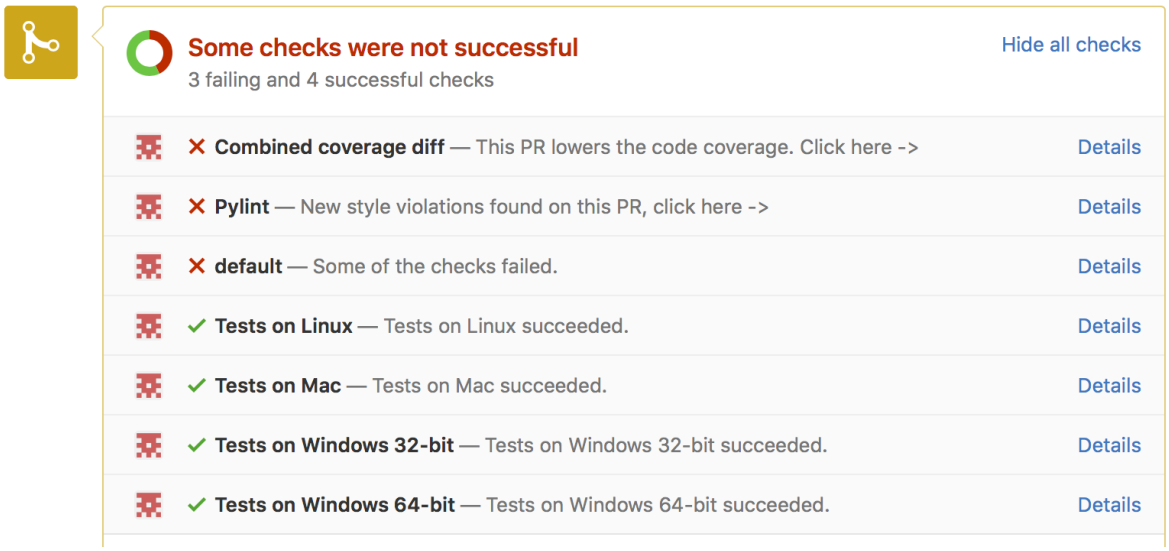


Figure 5.11: The implemented checks in Jenkins, executed on every new commit in a pull request.

6

Benchmarking and Performance Evaluation

The goal of this Chapter is to quantify the performance of various common operations performed by users in Tribler. We will perform a number of experiments and for each experiment, we will present and discuss the observed results. The underlying reason for this experiment is twofold: on the one hand, we would like to show that the performance of the system did not degrade with to unacceptable extent. On the other hand, we use the performance measurements to identify possible issues that is classified as future work.

6.1. Environment specifications

The experiments performed in this Chapter using the Tribler core are executed on a virtual private server. An important condition is to stay as close as possible to the specifications of a machine that an actual user could be using. The virtual server has 8GB of memory and 1 processor with 4 cores (where each core has a clock speed of 2.5GHz). The used operation system is Ubuntu 15.10. The experiments are not executed in an isolated, artificial environment but instead in the wild, using the deployed Dispersy network. While the obtained results may be different between users, this setup can be used to get insight in the performance of Tribler from a user's perspective.

If not stated otherwise, the default values of the Tribler configuration file are used. These default values can be found in the 'defaults.py' file in the source code directory of Tribler[1]. In this configuration file, all communities, except for *BarterCast*, are joined.

Some of the experiments are specified by the usage of a scenario file. In such a scenario file each line specifies a specific command of a peer at a specific point in time into the experiment. Our framework to run the experiments, Gumby, contains code to read scenario files, interprets the commands to be executed and to schedule them on the reactor thread. Several utility methods have been implemented to gather and write statistics to files in a processable and readable format that can be parsed by visualization tools such as *R*. The usage of scenario files is already adopted in various Dispersy experiments, mainly in our *AllChannel* experiment that runs on the DAS5 supercomputer. We extended the usability of this approach to run a Tribler client and we improved the framework by adding various commands to support operations as conducted in the performed experiments in this Section. An overview of the implemented commands can be found in Appendix A. The flexibility of these scenario files gives the next generation of Tribler developers a robust framework to use when conducting performance analysis, scientific research and benchmarking.

6.2. Profiling Tribler on low-end devices

The addition of a REST API allows developers an option to run and control Tribler remotely using the HTTP API. For instance, one can run Tribler on a low-end, cheap devices such as a Raspberry Pi. Android is another example of a device that can run Tribler and during the last years, various research have been conducted to

[1] https://github.com/Tribler/tribler/blob/devel/Tribler/Core/defaults.py

explore the possibilities of Tribler on Android devices[40][19]. Executing and profiling Tribler on a low-end device with limited resources can yield much information about bottlenecks that might not be directly visible when running Tribler on a desktop or supercomputer.

The experiments described in this Section are all executed on a Raspberry Pi, third generation with 1GB LPDDR2 ram, 4× ARM Cortex-A53, 1.2GHz CPU and 16GB storage on a microSD card. The used operating system is Raspbian, a system specifically designed for the Raspberry Pi and derived from the desktop Debian operating system.

Regular usage of Tribler on the Raspberry Pi using the REST API has us suspected that the Raspberry Pi is under heavy load when running Tribler. Monitoring the process for a while using the *top* tool, reveals that the CPU usage is often around 100%, completely filling up one CPU core. To get a detailed breakdown of execution time per method in the code base, the Yappi profiler has been used to gather statistics about the runtime of methods. This profiler has been integrated in the *twistd* plugin and can be started together with Tribler by passing a flag. The output generated by the profiler is a *callgrind* file that should be loaded and analysed by third party software. The breakdown of a 20-minute run is visible in Figure 6.1. This breakdown is generated using *QCacheGrind*, a *callgrind* file visualizer. In this experiment, we start with a clean state directory which is equivalent to the first boot of Tribler.

Incl.	Self	Called	Function	Location
131.47	1.22	340 246	wrapper /home/pi/Documents/tribler/Tribler/dispersy/util.p…	util.py
98.28	0.00	(0)	EPollReactor.run /usr/local/lib/python2.7/dist-packages/tw…	base.py
98.14	0.01	1	EPollReactor.mainLoop /usr/local/lib/python2.7/dist-pack…	base.py
98.06	0.05	5 132	EPollReactor.runUntilCurrent /usr/local/lib/python2.7/dist-…	base.py
90.33	0.21	9 635	AllChannelCommunity._on_batch_cache /home/pi/Docu…	community.py
79.84	0.22	13 050	AllChannelCommunity.on_incoming_packets /home/pi/Do…	community.py
66.00	0.06	9 596	StandaloneEndpoint.dispersythread_data_came_in /hom…	endpoint.py
65.49	0.11	9 665	Dispersy.on_incoming_packets /home/pi/Documents/tribl…	dispersy.py
57.93	0.74	59 406	DiscoveryConversion.decode_message /home/pi/Docum…	conversion.py
51.27	0.31	9 508	AllChannelCommunity.on_messages /home/pi/Document…	community.py
47.22	0.04	34 523	Implementation.has_valid_signature_for /home/pi/Docum…	authentication.py
47.18	0.11	34 523	Member.verify /home/pi/Documents/tribler/Tribler/dispers…	member.py
47.02	0.10	34 523	ECCrypto.is_valid_signature /home/pi/Documents/tribler/…	crypto.py
46.23	0.20	33 908	M2CryptoSK.verify /home/pi/Documents/tribler/Tribler/dis…	crypto.py
45.89	0.05	33 908	EC.verify_dsa /usr/lib/python2.7/dist-packages/M2Crypto/…	EC.py
45.81	45.81	33 908	ecdsa_verify M2Crypto.__m2crypto:0	M2Crypto.__m2crypto
26.76	3.52	5 987	AllChannelCommunity._resume_delayed /home/pi/Docu…	community.py

Figure 6.1: The breakdown of a 20-minute run of Tribler on the Raspberry Pi.

The file created by the Yappi profiler provides a detailed overview of the execution time of methods and can be used as a tool to detect performance bottlenecks in the system. Referring to Figure 6.1, the column *Incl.* denotes the inclusive cost of the function, in other words, the execution time of function itself and all the functions it calls. The column *self* denotes only the execution time of the function itself, without considering callees. The other columns are self-explanatory and can be used as reference to the location of the respective function in the source code.

If we analyse the breakdown, it is clear that Dispersy has a big impact on the performance of Tribler when running on the Raspberry Pi. The *ecdsa_verify* method (second method from the bottom) is dominating the runtime of Tribler: 45.81% of the time Tribler is running, is spent inside this method. This specific method verifies the signature of an incoming Dispersy message and is invoked every time a signed message is received. Disabling cryptographic verification of incoming messages should improve the situation, however, this is a trade-off between security and performance: by not verifying incoming messages, fake messages by an adversary can be forged and are accepted in such as system.

To verify whether the responsiveness of Tribler improves when we disable cryptographic verification of incoming messages, we measure the CPU usage of two runs. Both runs start with a non-existing Tribler state directory and have a duration of ten minutes. In the first run, we are using the default configuration of Tribler, like in most of the other experiments described in this Chapter. In the second run, we disable verification of incoming messages. The CPU utilization over time of the two runs are displayed in Figure 6.2.

In Figure 6.2, some occurrences are visible where the CPU usage appears to be slightly over 100%. This is

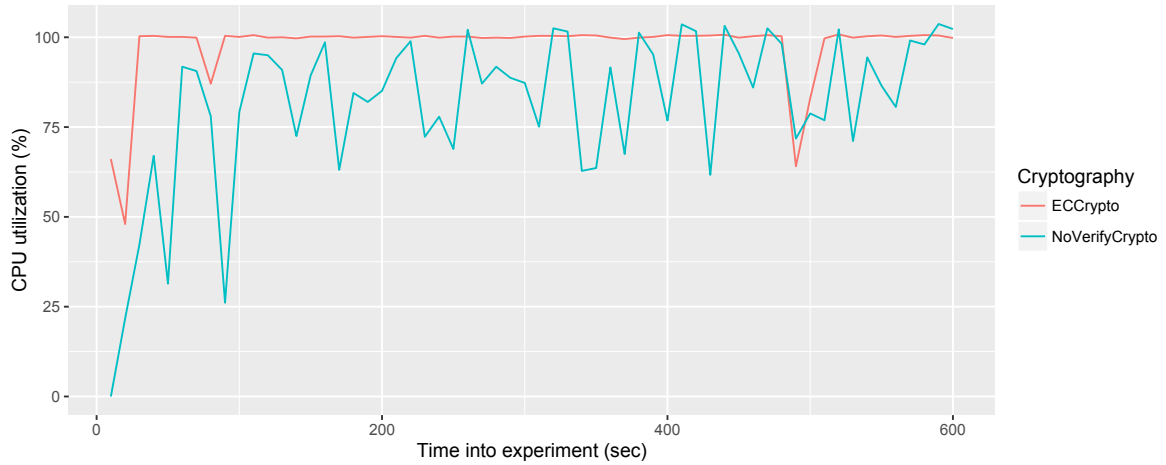


Figure 6.2: The CPU utilization of one core on a Raspberry Pi device when running Tribler with different cryptographic policies.

explained by the fact that some of the underlying code is designed to run on multiple processors. While the threading model of Tribler is limited to a single core, the Python interpreter might execute code on additional cores to improve performance. In the run where we enable all components of the system, the CPU usage is often 100%. When verification of Dispersy messages is disabled, we observe a somewhat lower CPU usage but overall, this utilization is still high. Unfortunately, disabling incoming message verification is clearly not enough to guarantee a more usable and responsive system.

To detect other performance bottlenecks, we sort the report generated by the Yappi profiler on the *Self* column to get insight in methods that are taking a long time to complete. This is visible in Figure 6.3. An interesting observation here is that the Python built-in *all* method takes up a significant amount of time (6.13% of the runtime). The *all* method takes an iterable object and returns *true* if all objects of this collections are true. Both the *all* method and *zip* method (also visible in Figure 6.3) is used in the *_resume_delayed* method, indicating that this method might causing performance issues. Since further analysis of this method requires more knowledge of Dispersy, optimization of this bottleneck is considered future work and described in GitHub issue 505[2].

Incl.	Self	Called	Function	Location
45.81	45.81	33 908	ecdsa_verify M2Crypto.__m2crypto:0	M2Crypto.__m2crypto
26.76	3.52	5 987	AllChannelCommunity._resume_delayed /home/pi/Documents/trib…	community.py
6.13	2.86	3 013 394	all __builtin__:0	__builtin__
0.00	2.61	454	isinstance __builtin__:0	__builtin__
1.73	1.73	6 773 230	<genexpr> /home/pi/Documents/tribler/Tribler/dispersy/community…	community.py
1.51	1.50	1 607	ecdsa_sign M2Crypto.__m2crypto:0	M2Crypto.__m2crypto
131.47	1.22	340 246	wrapper /home/pi/Documents/tribler/Tribler/dispersy/util.py:145	util.py
1.20	1.05	340 246	<method 'format' of 'unicode' objects> __builtin__:0	__builtin__
0.96	0.96	2 380 444	zip __builtin__:0	__builtin__
10.56	0.89	67 526	Implementation.__init__ /home/pi/Documents/tribler/Tribler/disper…	message.py

Figure 6.3: The breakdown of a 20-minute run of Tribler on the Raspberry Pi, sorted on the *Self* column.

In this Section, we demonstrated how adequate usage the Yappi profiler can lead to the detection of bottlenecks in the system. Integration in the twistd plugin makes it convenient for developers to run and analyse Tribler sessions under different circumstances.

6.3. Performance of the REST API

The responsiveness of the REST API is directly influencing the user experience. If the response times of API calls is high, users of Tribler have to wait longer before their data is available and visible. For this reason, we wish to make the API serve requests as fast as possible. The experiments to assess the performance of the

[2]https://github.com/Tribler/dispersy/issues/505

Requests/sec	Avg. (ms)	Std. dev (ms)	Median (ms)	Min. (ms)	Max. (ms)	KB/S
1	241	476.34	76	56	4246	585.58
2	170	327.86	68	58	3394	1127.04
5	123	210.23	60	52	2082	2538.36
10	115	238.72	60	50	2450	4120.70
15	182	497.61	68	52	4937	3296.45

Table 6.1: A summary of the experimental results when measuring the performance of the REST API.

API will particularly focus on latency of requests, however, some other statistics will be considered such as average request time, standard deviation of the response times and observed bandwidth. These statistics will help us to get more insights in the performance of the REST API.

We make use of Apache JMeter[25] that is used to perform HTTP requests to Tribler and to gather and process performance statistics. The application allows to simulate a realistic user load, however, in this experiment we will limit the load to one user that performs a request to Tribler with a fixed interval. This request will be targeted to a specific endpoint in the API: */channels/discovered*. This exact call happens when users are pressing the *discover* menu button in the new Qt GUI and the response of the request contains a JSON-encoded dictionary of all discovered channels that Tribler has discovered. As a consequence, the returned response can be rather large, especially if Tribler has been running for a long time and has discovered many channels (in our experiments, the average response size is around 613KB). When Tribler is processing the request, a database lookup is performed to fetch all channels that are stored.

We perform various experiments with different intervals between requests made and a fixed total amount of 500 requests. First, we perform the experiment with one request every second and we expect that the system should easily be able to hand this load and serve these requests in a timely matter. Next, the frequency of requests is increased to respectively 2, 5, 10 and 15 requests per second. These numbers are determined emperically and are based on the average request time, which appears to be several hundred milliseconds. Each experiment is started around five seconds after Tribler has started where we are using a pre-filled database with around 100.000 discovered torrents and 1.200 channels. A summary of the results of these experiments are visible in Table 6.1.

The most interesting observation in this Table is that it appears that requests are completed faster if we are performing requests at a faster rate, indicating that Tribler is able to handle the incoming requests well. This is surprising since one would expect the results to be the other way around: when the frequency of requests is increased, the average request time increases since Tribler might receive incoming requests while the previous incoming request is still being processed. The observed result is most likely due to caching of data which might be performed by the underlying database engine.

The standard deviation of the request times in Table 6.1 is rather large compared to the average request time. We suspect that this can be explained by the fact that Tribler is performing many different operations that are influencing the request times. In particular, we think that the reactor thread is busy with processing other calls that are scheduled earlier, causing the API calls to be processed later. To verify this, we ran the experiment again where we enable Dispersy, the component responsible for many calls in the reactor (as described in Section 6.2). We perform five requests per second and 500 requests in total for this experiment. The observed results of are illustrated in Figure 6.4 (the left plot corresponds to the 5 requests/sec row in Table 6.1). In the left plot, the response times of the performed requests with a regular Tribler session is displayed whereas in the right plot, we display the response times of the run where we disable Dispersy. Note the different scale on the vertical axis, indicating that the requests performed when Dispersy is disabled, are substantially faster. Indeed, the average request time of the right plot is 48 ms, significantly lower than the average of the response times when Dispersy is enabled, namely 123 ms. While both graphs are producing a spiky pattern, the standard deviation of the right plot is 5.73 ms and the standard deviation in the left plot is 210.23 ms. We conclude that the variation in response times is much lower in the right plot and that most likely DIspersy is producing a big amount of work for the reactor thread, introducing considerable amounts of latency when performing API requests.

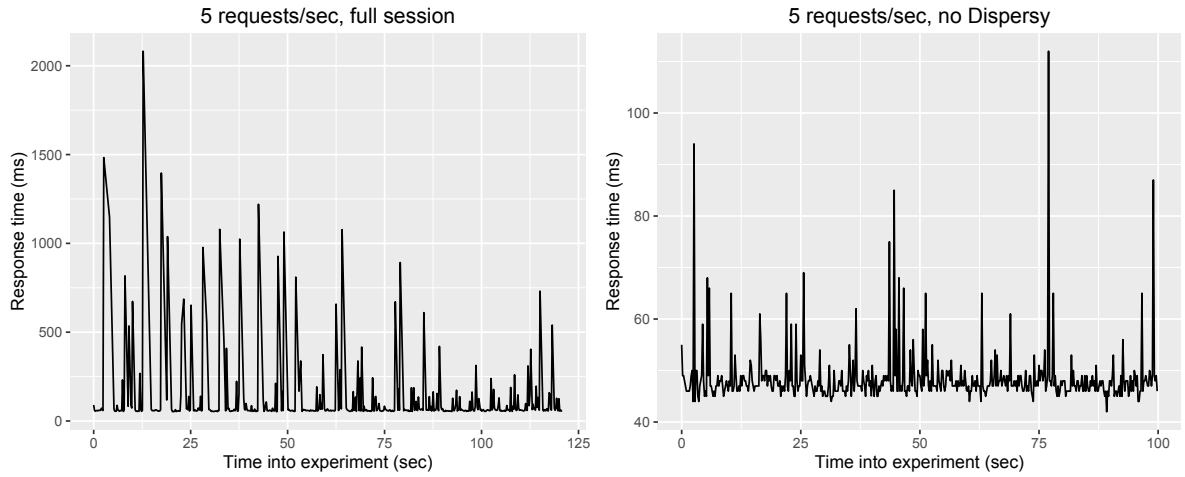


Figure 6.4: The response times of API requests, both within a full session and in a session where Dispersy has been disabled.

We identified a key issue here: the latency of methods to be processed in the Twisted reactor is high, causing the processing of incoming requests to be delayed. This does not only hold for the REST API: we can conclude the same for Dispersy and the tunnel community where possibly many incoming connections have to be served. The most important part of the solution is to make sure that there are no big blocking calls scheduled on the reactor thread that are taking a long time to complete. When a method call with a high runtime is executed on the reactor thread, Tribler is unable to process other events during that period, leading to an unresponsive system. Ongoing work is focussed on making the disk operations on the reactor thread non-blocking and as a consequence, reducing the latency of event processing and improving the responsiveness of the system in general.

Table 6.1 gives us another interesting observation, namely that we it appears that the bandwidth is reducing as the number of requests per second increases. This is in particular clear if we plot the theoretical maximum bandwidth against the observed bandwidth during the experiments, see Figure 6.5. In this Figure, we presented both the obtained bandwidth for a run using the regular Tribler session and a session where Dispersy has been disabled. We assume that each request contains 613KB of data in the response. The theoretical bandwidth is calculated as $b = 613 * n$ where n is the number of requests per second and b is the theoretical maximum bandwidth in KB/s. In practice, we will never reach this theoretical bandwidth since some time is required to create the connection and to process the response data in Tribler which we do not consider in our simple bandwidth model. We still notice that the obtained bandwidth is somewhat becoming constant, indicating that the bandwidth we can obtain is limited. This picture clearly shows the impact of a running Dispersy on the bandwidth. Whereas we almost obtain the theoretical output when we disable Dispersy, the gap between the theoretical and observed bandwidth becomes bigger in the run where we use a full session. When performing fifteen requests per second, the bandwidth even decreases, possibly due to the high system load the concurrent requests are causing.

6.4. Start-up experience

The first interaction that users have with Tribler, is the process of booting the software. During this boot process, various operations are performed:

- The Tribler state directory is created and initialized with necessary files such as the Dispersy key pair and configuration files.
- A connection to the SQLite database is opened and initialized. If this database does not exist, it will be created first.
- Dispersy is started and the enabled communities in the configuration file are loaded.

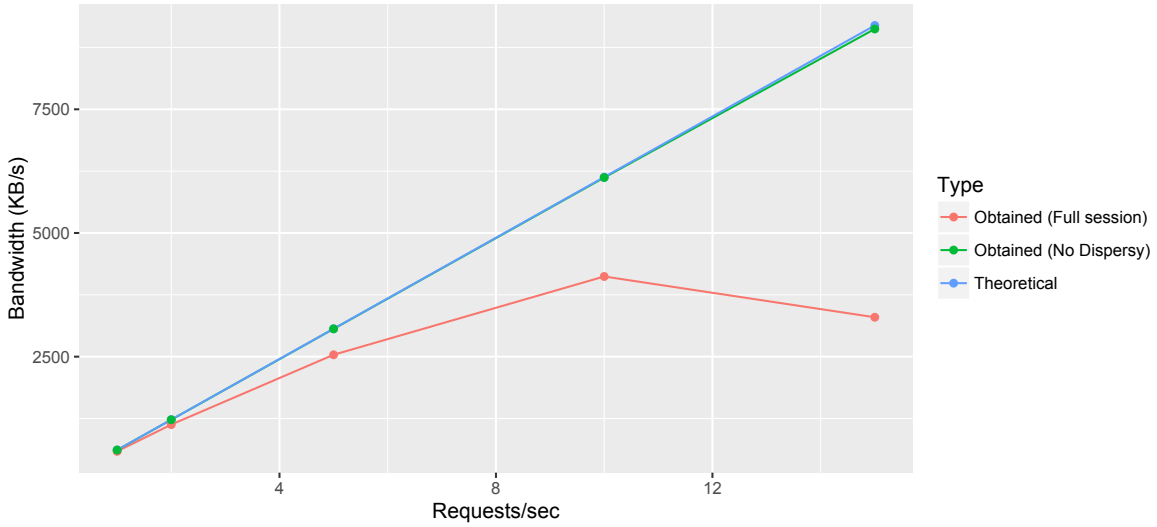


Figure 6.5: The maximum theoretical bandwidth compared to the obtained bandwidth (using a full Tribler session and disabled Dispersy) in the experiments.

- Various Tribler components are created, including the video streaming server, the REST API, the remote torrent handler and the *leveldb* store.

The start-up process of the Tribler core proceeds sequentially and no parallel operations are implemented to speed up the process. Depending on the number of enabled components, the start-up time might vary.

To analyse the start-up time, Tribler is started 50 times. The experiments are performed several times where in one experiment the software is started for the first time, with no prior existing state directory. In these runs, a state directory is created and the required files are initialized. In another experiment, a database containing just over 100.000 torrents is used. This database is the result of running Tribler idle for several hours, after subscribing to some popular channels to fetch as much torrents as possible. The filled Tribler database comes in conjunction with a filled Dispersy database. In both scenarios, there are no active downloads. The experiment starts when the *start* method of the *Session* object is called and ends when the notification that Tribler has started, is observed. During the span of this thesis, there have been various changes to the start-up procedure of Tribler where some code has been modified. Since we wish to make sure that our modifications do not significantly decrease the start-up speed, we make a comparison between the code in November '15 and July '16. The results are displayed in Figure 6.6, where for each commit we compare, we present an ECDF with the boot time on the horizontal axis and within each plot, the distribution of boot times from a clean and pre-filled state.

In both plots, It is clear that magnitudes of the Tribler and Dispersy databases have impact on the time for Tribler to completely start. However, this impact is relatively minor since Tribler still starts well within a second. We think that this statistic justifies removal of the splash screen that is shown in the old user interface. The relatively short time the splash screen would be visible in the new interface is so short that users would not even be able to read and interpret the content of the splash screen. In contrast to the old user interface, the new interface starts Tribler and shows a loading screen after the interface has started. However, users are able to already browse through other tabs such as their downloads and discovered channels.

Whereas the boot times of the runs performed with the November '15 code are very constant, we notice a variation in the runs with the code base from July '16, indicating that there is some component that has a high variation in initialization time. Further analysis learns us that this variation can be addressed to Dispersy, possibly caused the boot procedure of one of the communities. However, further analysis of the boot time of Dispersy is outside the scope of this thesis work.

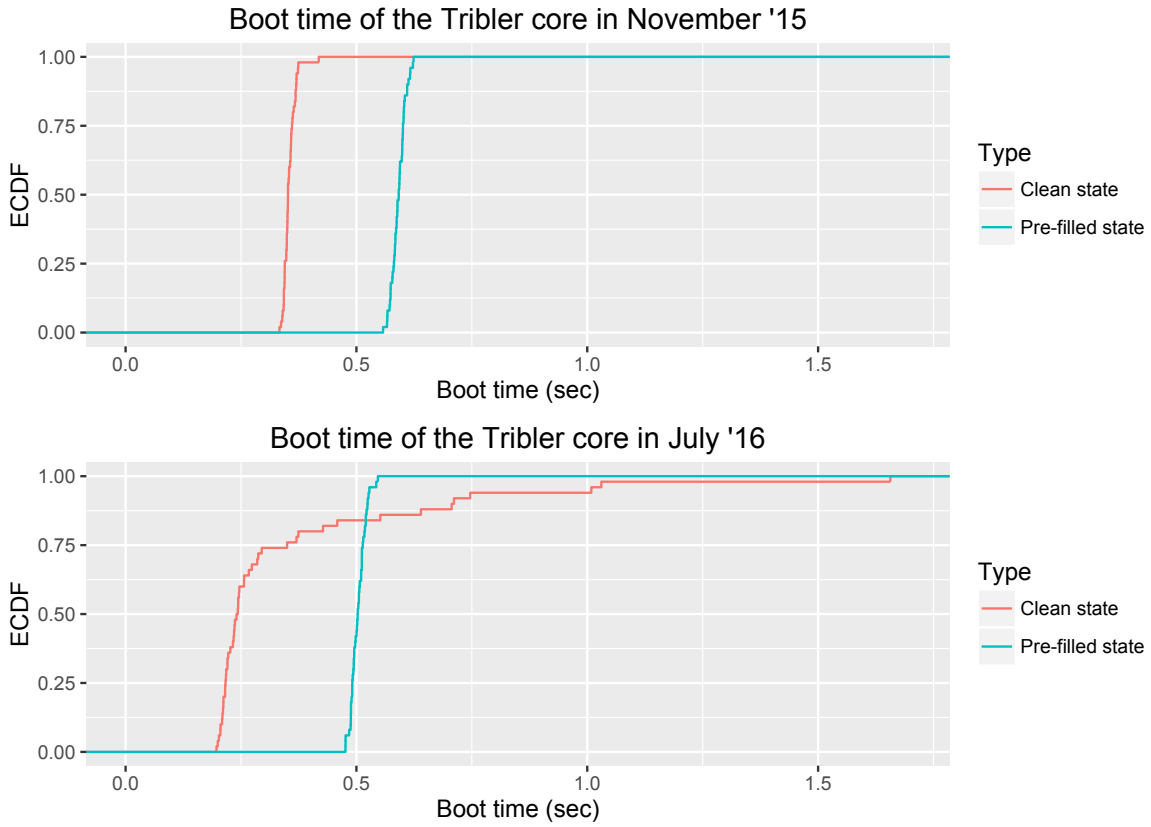


Figure 6.6: The boot time of Tribler from a clean and pre-filled state using the code base in November '15 and July '16.

6.5. Remote Content Search

We wish to serve relevant information to users as fast as possible. To help users search for content they like, a remote keyword search has been implemented, where users can search for torrents and channels. Channel results are fetched by a query in the *AllChannel* community whereas torrent results are retrieved by a query in the *search* community.

To verify the speed of the remote torrent search, various experiments are conducted. We are using a list of 100 terms that are guaranteed to have matches in the network. Each search query is executed when there are at least 20 connected peers in the *SearchCommunity*. The time-out period of the remote search is 60 seconds, indicating that search results that are coming in after this period are not regarded. This experiment has a particular focus on two statistics: the time until the first remote torrent search results comes in and the turnaround time of the search request, indicating the time until the last request comes in. We should note that users performing a remote search might see results earlier since a search query in the local database is performed in parallel. The results are visible in Figure 6.7.

Overall, the remote torrent search as implemented in Tribler is very fast and performs well. For every search query performed, we had at least one incoming result and on average, 61 search results are returned for each query where the first incoming torrent result takes 0.26 seconds to arrive. As we see in Figure 6.7, over 90% of the first remote search results are available to the user within a second. During our experiment, we always have the first incoming torrent result within 3.5 seconds. The other graph shows the turnaround time of the request, indicating the time until the last response within our time-out period. On average, it takes 2.1 seconds for all torrent search results to arrive. In the plot, we see that in over 90% of the search queries, we have all results within 10 seconds.

The same experiment has been performed in 2009 by Nitin et al. where 332 remote search queries have been performed, see Figure 6.8 where the time until the first response from any remote peer in the network

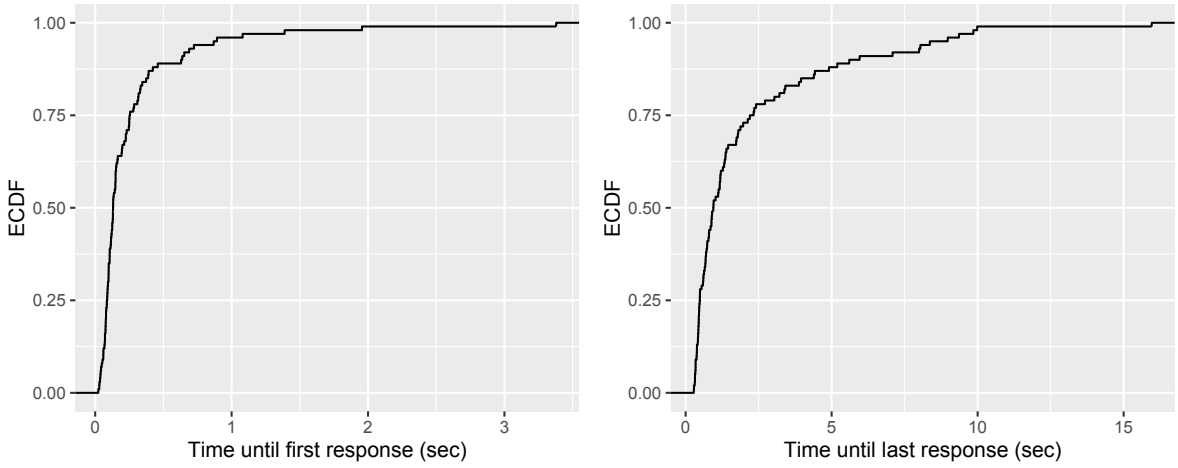


Figure 6.7: The performance of remote content search, expressed in the time until the first response and time until last response.

is measured. The graph makes a comparison before and after a significant improvement to the I/O mechanism, causing messages to be exchanged faster. The observed average time until first response in 2009 is 0.81 seconds whereas our observed average time is 0.26 seconds.

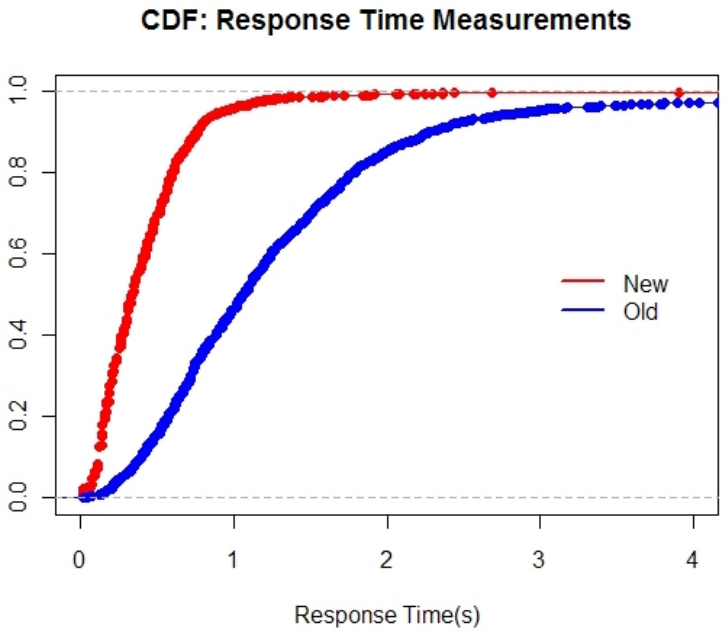


Figure 6.8: The performance of remote content search, performed by Nitin et al. in 2009. The new remote search had an improved I/O mechanism, causing messages to be exchanged faster.

6.6. Local Content Search

In the previous Section, we demonstrated and elaborated the performance of the remote content search mechanism. Now, we will shift the focus to performance measurements of a local content search, which is considered more trivial than the remote search counterpart where network communication is required. In particular, our goal is to quantify the performance gain or loss when switching to the new relevance ranking algorithm, as described in Chapter 4.4.

The setup of the experiment is as follows: a database with just over 100.000 torrents is used. Around ten seconds after starting Tribler, we perform a local *torrent* search every second and we do this for 1.000 ran-

dom keywords that are guaranteed to match at least one torrent in our database. We will measure both the time spent by the database lookup and the time it takes for the data to be post-processed after being fetched from the database. In the old relevance ranking algorithm, this post-processing step involves determining the associated channels for each torrent result. This experiment is performed for the old ranking algorithm that uses the Full Text Search 3 (FTS3) engine and the new ranking algorithm that uses the more recent FTS4 engine. According to the SQLite documentation, FTS3 and FTS4 are nearly identical, however, FTS4 contains an optimization where results are returned faster when performing searches with keywords that are common in the database. The results are visible in Figure 6.9, presented in two ECDF plots.

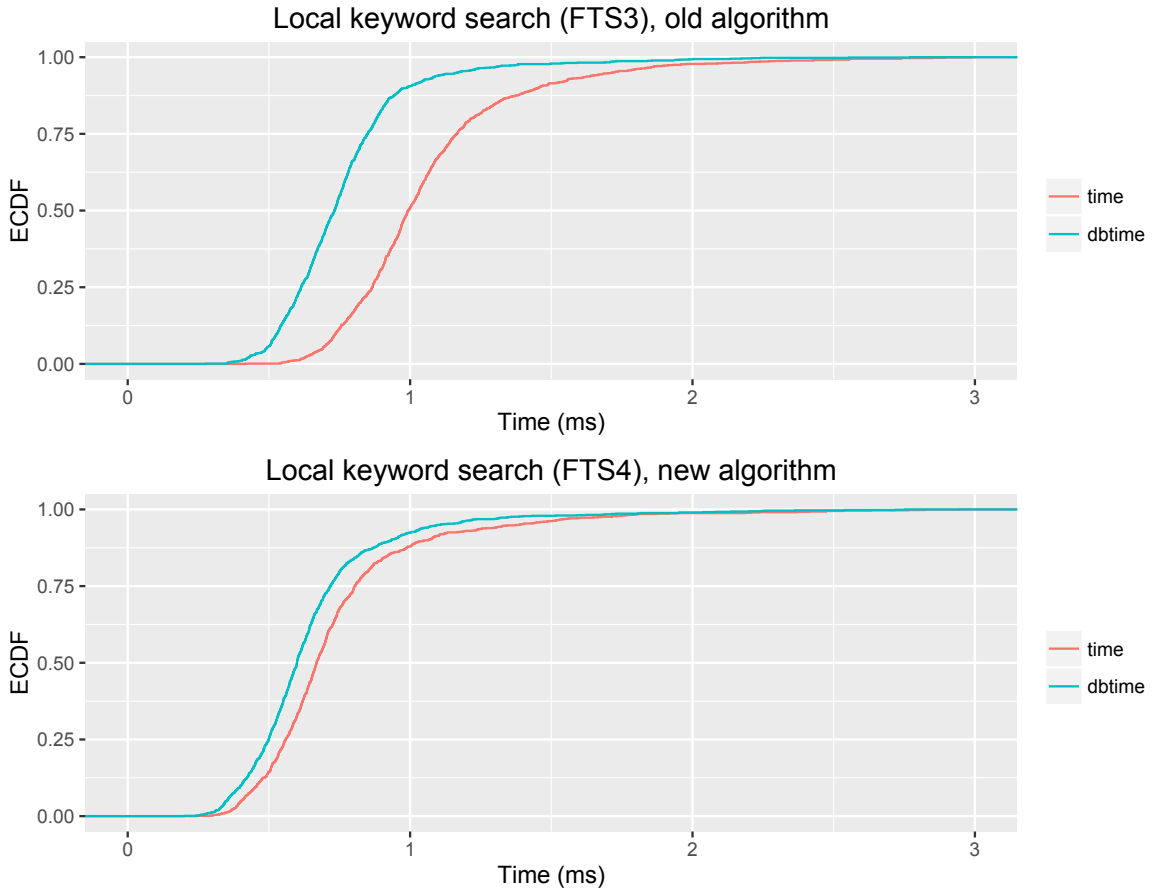


Figure 6.9: A comparison of the performance of local keyword searches between the old ranking algorithm with the FTS3 engine and the new ranking algorithm utilizing the FTS4 engine.

Local content search is very fast, delivering results in several milliseconds and low priority should be given to performance engineering on the local content search engine. We see that the two lines in the FTS3 and FTS4 graphs have moved closer to each other which means that the speed of post-processing of torrent results has increased. This is in line with our expectations since the new relevance ranking algorithm should be less computationally expensive than the old one. In addition, the new algorithm takes less factors in considering, for instance, the swarm health of the torrent. The increase in performance from FTS3 to FTS4 is visible but not significant.

In 2009, Nitin et al. performed the same experiment where they used a database filled with 50.000 torrents. Their generated ECDF is displayed in Figure 6.10. We notice that the current performance of local search in our experiment is dramatically better than the performance obtained during the 2009 experiment. This can be explained by the fact that Tribler used a custom inverted index implementation when the experiment in 2009 was conducted. An inverted index is an index data structure where a mapping is stored from words to their location in the database and is used on a large scale by search engines, including the FTS engine of SQLite. By utilizing this mapping when performing a full text search, we can get results in constant time.

However, there is a slight overhead for maintaining and building the inverted index when new entries are added to the database, also impacting the size of the database disk file. The built-in FTS engine of SQLite is optimized to a large extent and clearly offers a higher performance than a custom implementation.

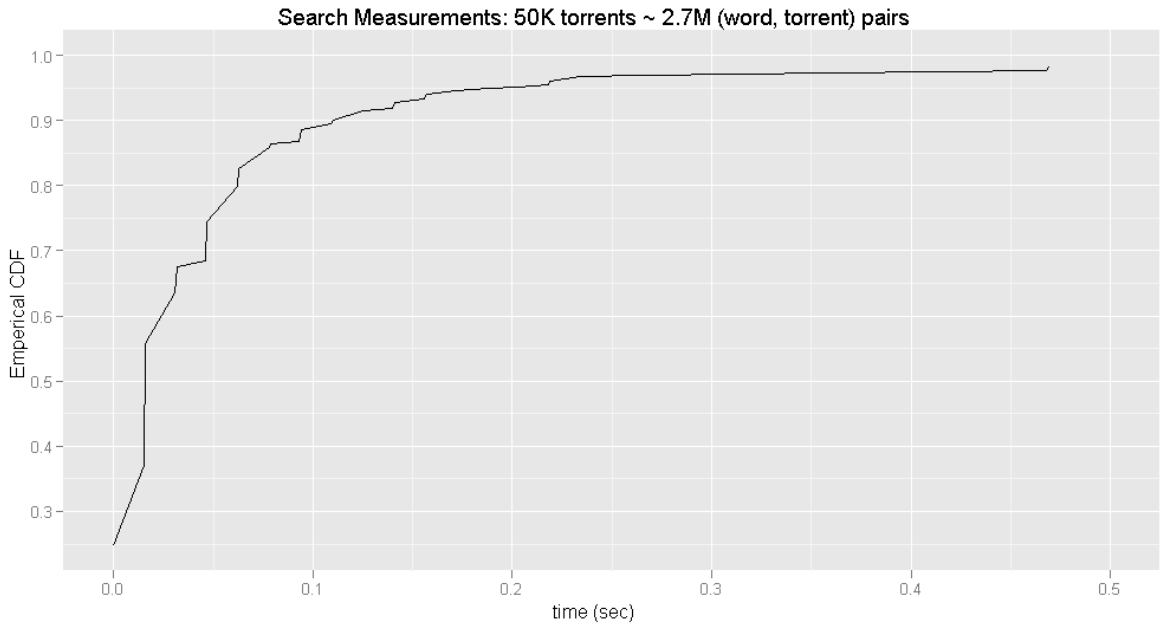


Figure 6.10: The performance of a local database query as verified by Nitin et al. in 2009.

6.7. Video streaming

The embedded video player in Tribler allows users to watch a video that is being downloaded and is explained in more detail in Chapter 3.4.3. Video playback has been available since Tribler 4.0. It is based on VLC and offers support for seeking so the user can jump to a specified offset in the video. Video downloads have a special Video On Demand (VOD) mode which means that the *libtorrent* library piece picking mechanism uses a linear policy mode. In this mode, pieces are downloaded in a timely matter. When the user seeks to a position in the video, the prioritization of the pieces are modified, giving priority to pieces just after the specified seek position. Users also have the possibility to use an external video player that support playback of HTTP video streams.

The bytes are streamed to a VLC client using a HTTP stream. When Tribler starts, a HTTP video server is started. This server supports HTTP range requests which means that a specific part of a video file can be queried by using the HTTP *range* header. This is useful when the user performs a seeking operation since only a specific part of the file has to be returned in the HTTP response. If some pieces are not available, the video server will wait until these bytes are downloaded before returning these bytes in the response.

To improve user experience, we wish to minimize the delay that users experience when performing a seek operation in the video player. The experiment performed in this Section, will quantify this buffering delay. For this purpose, the well-seeded *Big Buck Bunny*[3] movie will be downloaded. The movie file itself is 885.6 MB in size and has a duration of 9:56 minutes. We will perform various HTTP range requests using the *curl* command line tool, immediately after starting the download in Tribler. For every run, we will request 10 megabyte of data and we will measure the total time it takes for each HTTP request to complete. The results are visible Table 6.2.

Theoretically, we would expect around the same request time for each range request, assuming that the availability of each piece is high. When performing a seek operation in the video, the piece picking mecha-

[3]https://peach.blender.org

First byte	Request time (sec)
0	11.6
$1 * 10^9$	64.4
$2 * 10^9$	64.6
$3 * 10^9$	65.9
$4 * 10^9$	100.6
$5 * 10^9$	115.6
$6 * 10^9$	115.8
$7 * 10^9$	12.2
$8 * 10^9$	66.6
$9 * 10^9$	52.4

Table 6.2: Performance of the video server when requesting bytes at different offsets of the video being downloaded.

nism adjusts priorities and these prioritized pieces should start to download immediately. The experiments shows some serious flaws in this mechanism where it might take up to two minutes for data to be available. Further investigation of this issue learns us that the video player always tries to download the first 10% of the video file, except in the 7th run of the experiment, where the prioritizing policy seems to be correctly applied. Solving this bug is considered further work and documented in GitHub issue 2508[8].

6.8. Content discovery

Content discovery is a key feature of Tribler. By running Tribler idle for a while, content is synchronized with other peers using the Dispersy library. When a user starts Tribler for the first time, there is no available content yet. We will verify the discovery speed of content after a first start. The experiment is structured as follows: we measure the interval from the completion of start procedure to the moment in time where the first content is discovered. We perform these experiments for both torrents and channels and repeat this 15 times. The results are visible in Figure 6.11.

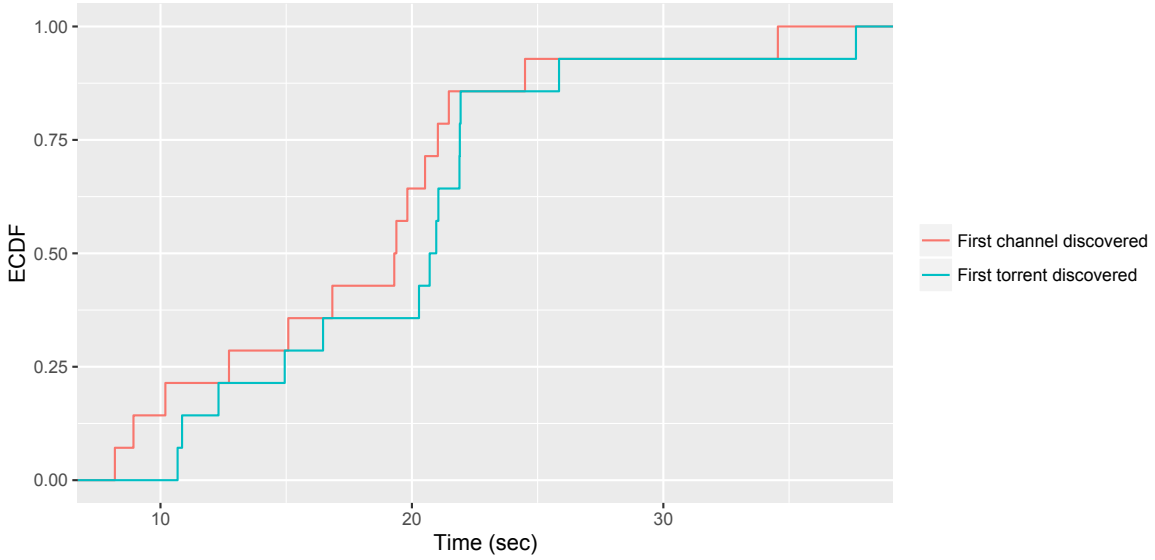


Figure 6.11: The discovery speed of the first channel and torrent after starting Tribler for the first time.

The delay of discovering the first channel is reasonably: on average, this happens 18 seconds after start-up. In all runs, we have our first channel discovered within 35 seconds. Discovery times of the first torrent is slightly slower and in all runs, the first torrent in a channel is discovered within 40 seconds. Figure 6.11 suggests that a torrent discovery always happens after there is at least one discovered channel. This is true: after the channel is discovered, the *PreviewChannel* community is joined where torrents are exchanged and

discovered.

In the old user interface, users were presented with a blank screen with no feedback about new discovered content. In the new interface, the user is presented with a screen that informs the user that Tribler is discovering the first content. This screen is only shown the first time Tribler is started and goes away when there are five discovered channels, after which the page with discovered channels is displayed to the user.

6.9. Channel subscription

When Tribler runs idle, not all available content in the network is discovered. The majority of content is discovered when users subscribe to channel (in the old user interface, this is referenced to as marking a channel as favourite). When Tribler discovers a new channel, users are presented with a preview of this channel. Internally, Tribler connects to the *PreviewChannelCommunity* associated with that channel, a community derived from the *ChannelCommunity*. In this preview community, the amount of torrents that are collected is limited. The *ChannelCommunity* in turn is joined the moment the user subscribes to a channel, after which the full range of content is synchronized. Removing the preview mechanism might significantly increases the resource usage of the Tribler session since the amount of incoming messages to be decoded and verified will increment.

The experiment as described in this Section, will focus on the discovery speed of additional content after the user subscribes to a specific channel and on the resource allocation when we are running Tribler without enabling a preview mechanism of channels. For the first experiment where we determine the discovery speed of additional content inside a channel, the twenty most popular channels (with the most subscribers) are determined. For this purpose, we are using a Tribler state directory with many discovered channels but void of any channel subscriptions. Exactly ten seconds after Tribler started, we subscribe to one of these popular channels and we measure the interval between subscription to the channel and discovery of the first additional torrent. Tribler is restarted between every run and the state directory is cleaned so we guarantee a clean state of the system. The observed results are visible in Figure 6.12.

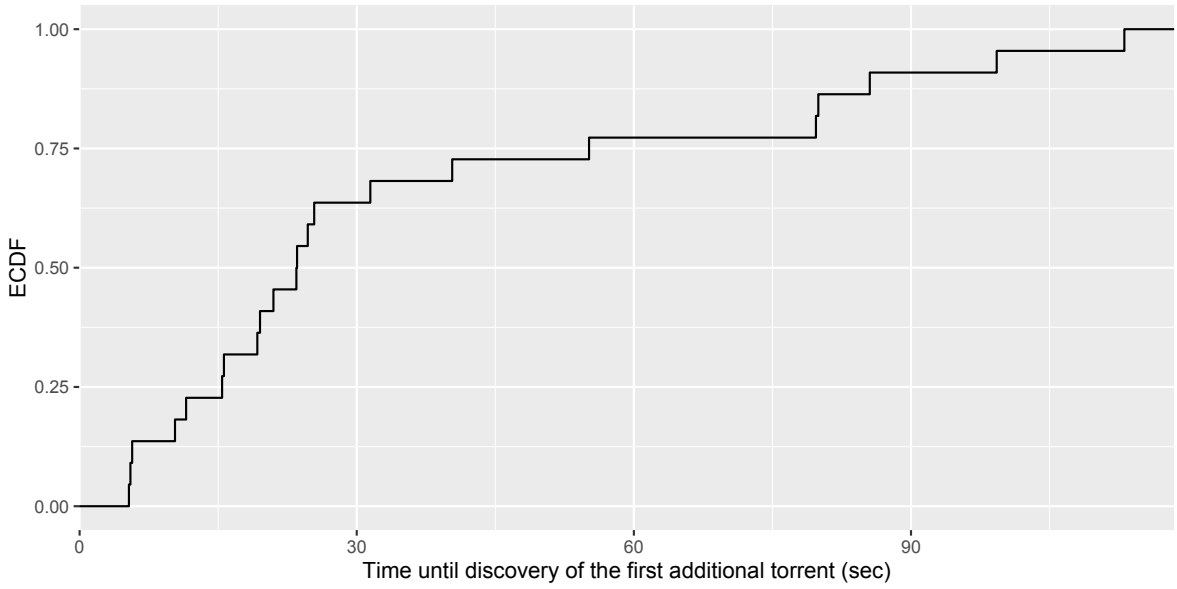


Figure 6.12: The distribution of discovery times of the first additional torrent after subscribing to a popular channel.

The average discovery time of additional torrents after subscription to a channel is 36.8 seconds which is quite long, compared to the discovery speed of the first channel and torrent as described in Section 6.8. The discovery times have a high variation as can be seen in Figure 6.12. This can be explained by the fact that immediately after subscribing to a channel, Tribler will connect to the *ChannelCommunity* that is joined after subscription and peers have to be found.

To verify the impact of automatically subscribing to each channel when it is discovered, we perform a CPU usage measurement. In two idle runs of a Tribler session, both lasting for ten minutes, we measure the CPU usage every ten seconds using output provided by the *top* tool. In the first run, a regular Tribler session is used where previews of discovered channels are enabled. In the second run, we bypass the preview of a discovered channel and immediately join the channel, synchronizing all available content. Both types of runs start with an empty state directory. The results of this experiment are visible in Figure 6.13.

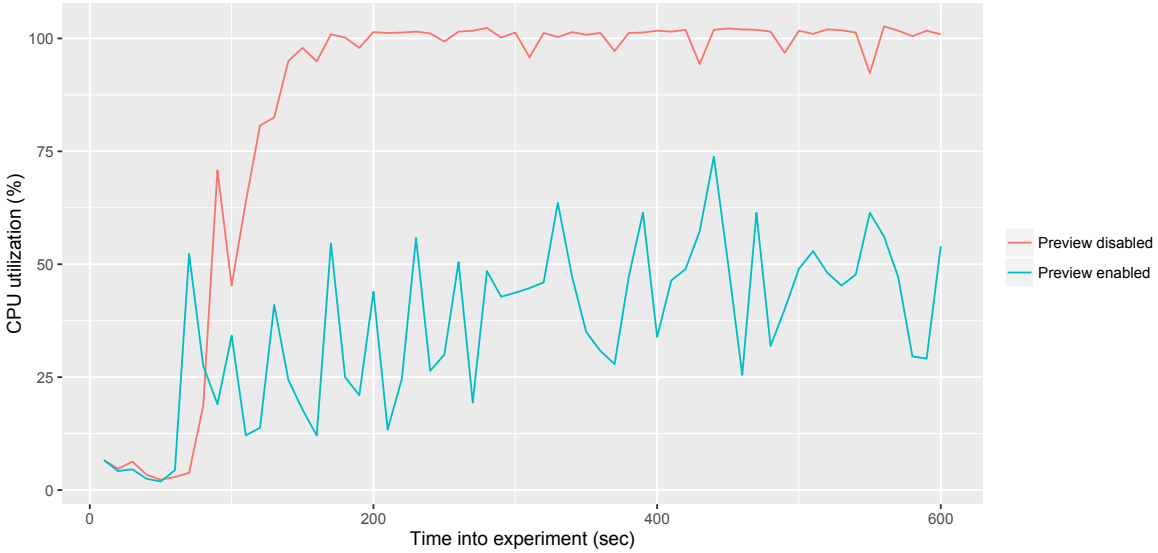


Figure 6.13: The CPU utilization of one core during a period of ten minutes with channel preview enabled and disabled.

Whereas the CPU usage of the normal run is around 45% on average, the CPU is busy and quickly rises to 100% utilization when we enable the auto-join mechanism of channels. This shows that it is infeasible to enable this auto-join feature if we still wish to guarantee a responsive system. One might limit the rate at which discovered torrents are fetched, however, this requires a feedback mechanism where we should notify other peers in the community to limit the amount of messages sent to the peer that is discovering content. Implementing of such as feature is outside the scope of this thesis work and is considered future work.

6.10. Torrent Availability and Lookup Performance

While specific information about torrents such as the name and file names are distributed within the Dispersy communities, this does not hold for the meta info about the torrent itself, which includes additional data such as trackers and piece information. This meta info can be important for users since trackers provides information about the health of a torrent swarm. The experiments as explained in this Section, will investigate the torrent availability and lookup performance of meta info of torrents, either by using downloading them from remote peers in the Tribler network or from the Distributed Hash Table (DHT).

6.10.1. TFTP Handler

When users are performing a remote torrent search, the first three incoming results are pre-fetched which means that the meta info of these torrents are fetched automatically. An incoming search result can possibly contain information about remote peers (candidates) that have the meta info of this torrent available. If candidates for a specific remote torrent result are present, an attempt to fetch the torrent meta info from this candidate is scheduled. This request is performed using the Trivial File Transfer Protocol (TFTP)[43] which is a simplified version of the more sophisticated File Transfer Protocol (FTP), commonly used to transfer files over the internet. TFTP is also used to transfer meta data about torrent files such as thumbnails between peers, however, meta data of torrents is currently disabled in Tribler. The implementation of TFTP can be found in the core package in the code base.

There has been no published studies yet about the performance of our TFTP implementation so we have no available reference material. The experiment performed in this Subsection will focus on the performance

of TFTP when fetching meta info from remote peers. We start from a clean state directory and exactly one minute after starting Tribler, we perform a remote torrent search. For each incoming remote search result, we perform a TFTP request for each candidate attached to this result. We perform ten remote torrent search operations, with interval of 60 seconds between them. After eleven minutes, we stop Tribler and gather the statistics of the TFTP sessions.

Total requests scheduled	1008
Requests in queue	761 (75.5%)
Requests failed	106 (10.5%)
Requests succeeded	141 (14.0%)

Table 6.3: A breakdown of the performed requests during the TFTP performance measurement.

We notice that the queue keeps growing: when our experiment is finished, 75.5% of the initiated requests is still in the queue. The second observation is the high failure rate, when compared to the amount of succeeded requests (42.9% if we do not consider the requests in the queue). We identified two underlying reasons for the failed requests. Some of the requests timed out, possibly due to the fact that some remote peers are not connectible. A solution for this kind of failure would be a more robust NAT puncturing method. The other reason is that the remote peer does not have the requested file in the local persistent storage. While this situation might seem unusual, it can happen if the remote peer has the requested torrent in the SQLite database but not in the meta info store. We can solve this by not returning this peer as candidate if the torrent is not available in the meta info store. This solution will also reduce the total bandwidth used by the TFTP component.

Next, we will focus on the turnaround time of the successful TFTP requests, these are displayed in figure 6.14 in an ECDF. Here, we notice the weird distribution of the turnaround times. We would expect that the total request times to fetch torrents is somewhat constant, however, we see outgoing requests that take over 400 seconds to complete. This trend will probably continue if we did not stop the experiment after ten minutes. The most logical explanation for this is that requests are added to the request queue at a faster rate than the processing speed of these requests. This also explains the values denoted in Table 6.3 where 75.5% of the request are still in the queue after the experiment ends. Better support for parallel requests should help, however, this is considered further work and outside the scope of this thesis work.

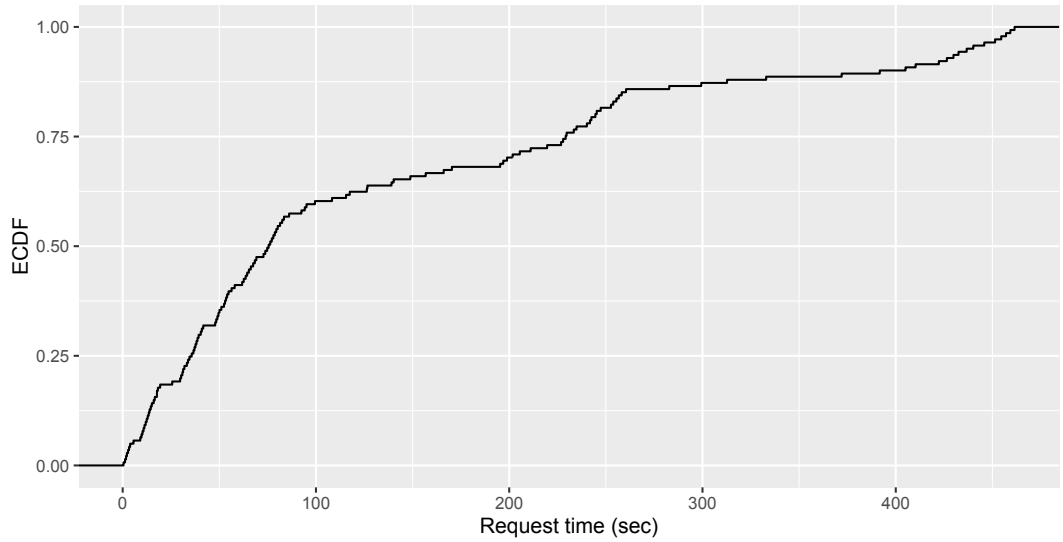


Figure 6.14: An ECDF of the performance of the torrent meta info download mechanism using TFTP in Tribler.

6.10.2. Distributed Hash Table

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A possible source of torrents is the Distributed Hash Table (DHT). The DHT provides primitives to query tor-

rent files and peers, based on a specific infohash of a torrent. Querying the DHT for torrent files can be done by invoking the *download_torrentfile* in the *Session* object. One should specify the callback to be invoked after the meta info is successfully downloaded. In this Section, experiments will be conducted to get insights in the availability of torrent files and the performance of lookup operations in the DHT. This experiment is has a relevance to user experience since users that want to determine whether specific content is interesting or not, they first might want to view meta info of the torrent file, such as names and sizes of the files. This meta info should be available as soon as possible.

In the current user interface, the torrent file is fetched when the user single clicks on a torrent in the list of torrents, either when browsing through contents of a channel or after performing a remote keyword search. In addition, when executing a remote search, the first three top-results are pre-fetched since the user might be interested in them. For this experiment, a popular channel with over 5.000 torrents is considered and a subset of torrent infohashes in this channel is taken. Every 40 seconds, a DHT query is performed with one of the 1.000 random infohashes. The time-out period used in Tribler is 30 seconds, after which a failure callback is invoked and an error is displayed in the user interface to notify the user about the failed request. The results of this experiments are visible in Figure 6.15. Torrents that cannot be successfully resolved from the DHT, are assigned a value of 30 seconds in the graph.

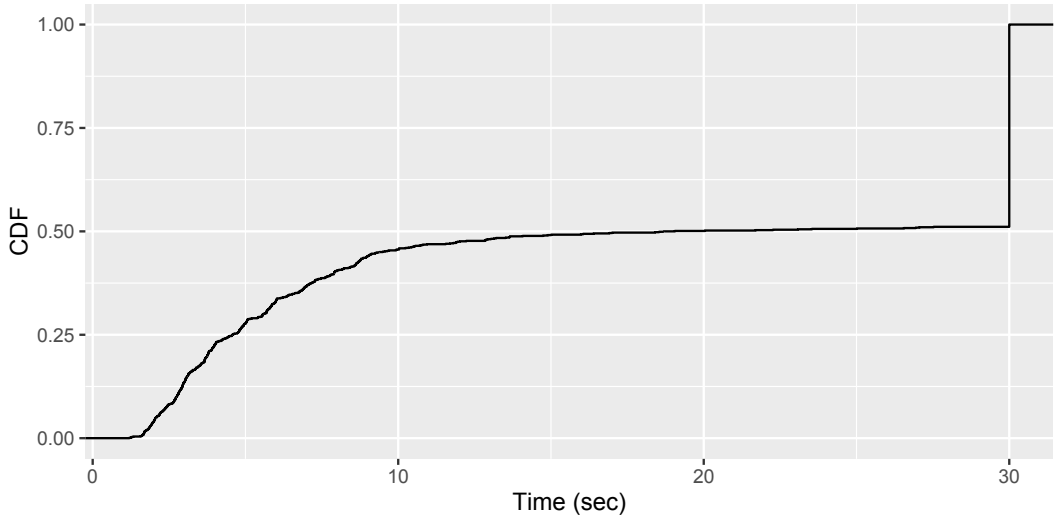

Figure 6.15: Test.

We immediately notice that the failure rate of DHT lookups is quite high: a little under 50% of the lookup operations are timing out. This issue might be addressed to dead torrents (when no peers in the DHT have this torrent information available) or private torrents (torrents which information is not available in the DHT). The amount of failures might be even higher in a less popular channel since the content in these channels are probably less seeded. As explained in the previous Subsection, the DHT is not the only source for torrents in Tribler and we might also fetch torrents from other peers using TFTP. Unfortunately, the approach of fetching meta info about torrents from other peers is only usable when searching for torrents. Caching and exchanging torrent candidates is not successful since the availability of candidates cannot be guaranteed.

The average lookup time of torrents that are successfully fetched from the DHT is 5.81 seconds which is reasonably fast. Additionally, Figure 6.15 shows that a little over 90% of the successfully fetched torrents are retrieved within 10 seconds.

To improve performance of metainfo lookup, dead torrents should be handled correctly. One possible solution might be an implementation of a periodical check for each incoming torrent. By limiting the number of outstanding DHT requests, this approach does not create require much additional resources. To further improve performance, the result of DHT lookups might be disseminated to remote peers in the network. Torrents that are not successfully fetched from the DHT, could be hidden automatically in the user interface. The

downside of this approach is that it might not give a realistic view of the availability of a torrent since their might be candidates which have a copy of this torrent available.

7

Testing Tribler at a large scale (concept)

In the previous Chapter, we performed many small performance measurements and quantified the usability and performance of various common performed operations in Tribler. While these experiments gave us insights in the performance of Tribler, we didn't chain together multiple operations to investigate a pipeline.

One of the main selling points of Tribler is the built-in anonymous overlay which provides anonymous downloading and seeding capabilities. In this Chapter, we will test a full pipeline of Tribler on a large scale, where we start Tribler, perform a remote keyword search, select a download and start this download anonymously. We will first discuss the setup of the experiment in more detail, after which we turn our focus to the results we observed during the experiment.

7.1. Setup of the experiment

The order of operations as performed in this experiment is visible in Figure 7.1. The experiment itself is executed on the DAS5 supercomputer where in every run, we allocate ten nodes and run one Tribler instance on every node.

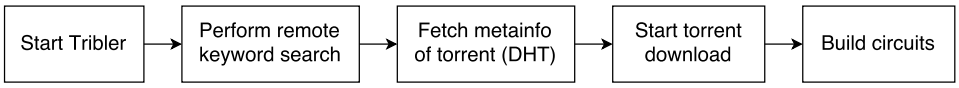

Figure 7.1: The setup of the experiment as described in this Chapter.

The experiment starts when Tribler is booted and we start with no pre-filled state directory. After Tribler has been started, we wait until we are connected to a sufficient amount of peers (30) in the *SearchCommunity* before we perform the remote search. In the experiment described in Section 6.5, we waited until we are connected to at least 20 peers. We increased this number since we are running ten other Tribler nodes inside the same network that might connect with each other. When these Tribler nodes connect to each other, they provide no remote search results to each other since there is likely to be no discovered content in the database yet. The check to see whether we are connected to a sufficient amount of peers is performed every second.

Once we have enough connections, we perform a remote torrent keyword search. For this purpose, we created a list of 1.000 popular keywords that have been constructed as follows: we analysed the database with just over 100.000 torrents, determined all keywords in the database, together with the frequency of each keyword and calculated a list of the keywords with the highest frequency in the database. In every run, we uniformly pick a random keyword from this list and perform a remote keyword search with the selected query.

We wait 30 seconds for incoming search results and we store the time of the first and the last incoming remote search results. If we have no search results within 30 seconds, we abort the experiment. We save all incoming torrent results and after 30 seconds, we pick five random, non-explicit torrent results and query a metainfo lookup in the DHT. We are using a timeout period of 60 seconds for the DHT lookup operation: if we did not

receive any response from one of the scheduled DHT lookup, we abort the experiment.

As soon as the first incoming metainfo is received, we start the download of this torrent, where we enable anonymous downloading with one hop and hidden seeding. After three minutes, we abort the experiment and clean the downloaded data. We keep track of the time until the circuits are build and we receive the first incoming bytes. Additionally, we keep track of the total number of downloaded bytes after these three minutes.

There are various failures that could lead to an interruption of the experiment, which we will summarize below:

- If we are not connected to at least 30 peers in the *SearchCommunity* after Tribler has started, we abort the experiment.
- If we do not receive any remote torrent result within 30 seconds, we abort the experiment.
- If we do not receive a response from any scheduled DHT lookup, we abort the experiment.

We also have various failures that influences our result but are not failing our experiment. An example of these failures is when we fail to build circuits within three minutes after starting the download. In this situation, we are still able to finish the experiment, however, our final results are influenced since we were not able to download any byte.

7.2. Observed results

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Todo

8

Conclusions

The work in this thesis investigates the technical debt that has been accumulated by over 40 unique contributors over the last ten years of scientific research in the area of decentralized networks. After a comprehensive discussion of the architectural evolution Tribler has made, A future-proof and robust architecture of Tribler is proposed, discussed and some parts of the new design have been implemented. The main components as created in this thesis are a new user interface, built using the Qt framework, and a REST API, allowing Tribler to run on remote devices while giving developers high amounts of flexibility and ease when developing with Tribler. The testing environment has been improved with the addition of proper and stable unit tests and the tests are now executed on multiple platforms, allowing us to find defects due to platform incompatibilities earlier in the development process. Summarizing, this work transformed Tribler from an unattractive, unmaintained and untested system into a platform that is ready for development during the next decade of scientific research.

While this is a step in the right direction, there still is a lot of work to do by the next generation of Tribler developers. We should learn from the mistakes made in the past years. Being critical towards the implementation of quick workarounds is one example of that. Mandatory code reviews by other team members helps to improve one's code and to get a more critical attitude towards favouring short-term decisions over long-term agreements. We also propose that it is the responsibility of every developer to write code that is covered by the right amount of tests. By forcing a strict increasing code coverage policy, the code coverage metric can be controlled and gradually improved over time.

Additional future work proposed is the implementation of the trust walker, which will become the foundations of the Tribler platform. This way, the Dispersy framework could be removed, allowing the deletion of much legacy code. Although not the main subject of this thesis, the amount of accumulated debt in Dispersy is also rather high. From a performance perspective, research should be conducted to see how the performance on low-end embedded devices could be improved. Since our main performance bottleneck is the limited amount of CPU power in a specific core, one of the proposed solutions is to increase utilization of multi-core architectures. This can be achieved by splitting the architecture of Tribler in separate components that can independently run on several cores, however, this requires one to think very carefully about the final design and communication structure.

A

Gumby scenario file commands

As described in Chapter 6, a standalone Tribler runner that uses a scenario file has been created. The scenario file allows developers to specify commands at specific points in time after Tribler has booted. This Appendix describes the implemented commands and usage.

Command	**Argument(s)**	**Description**
start_session	-	Start a Tribler session.
stop_session	-	Stop a running Tribler session.
stop	-	Stop the experiment and write the gathered statistics.
clean_state_dir	-	Clean the default state directory of Tribler.
search_torrent	The search query and optionally the minimum number of peers required in before the search is performed.	Perform a remote torrent search.
local_search_torrent	The search query.	Perform a local torrent search in the database.
get_metainfo	The infohash of the torrent to be fetched.	Fetch meta info of a specified torrent from the DHT.
start_download	The URI of the download.	Start a download from a torrent specified by a given URI.
subscribe	The Dispersy channel identifier of the channel (can also be *random*).	Subscribe to a random or specified channel.

Table A.1: An overview of commands for the Gumby scenario file when performing experiments with Tribler.

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