In bilateral accounting of resource consumption both the consumer and provider independently measure the amount of resources consumed by the consumer. The problem here is that potential disparities between the provider’s and consumer’s accountings, might lead to conflicts between the two parties that need to be resolved. We argue that with the proper mechanisms available, most of these conflicts can be solved online, as opposite to in court resolution; the design of such mechanisms is still a research topic; to help cover the gap, in this paper we propose a peer–to–peer protocol for online dispute resolution over storage consumption. The protocol is peer–to–peer and takes into consideration the possible causes (e.g., transmission delays, unsynchronized metric collectors, etc.) of the disparity between the provider’s and consumer’s accountings to make, if possible, the two results converge.

1 Introduction

The general scenario of our research interest is the consumption of computing resources (storage, bandwidth, computation, etc.) offered by providers to remote users (consumers) over the Internet. The consumer regards the resources as a service reachable through a user’s interface and pays for it on a pay–per–use basis. Central to this scenario is resource consumption accounting. Currently, most providers use unilateral provider–side accounting based on metrics collected by devices deployed within the providers’ premises. An alternative and innovative approach is bilateral accounting where both the consumer and provider independently measure resource consumption and verify the parity of the accounting results [5]. A potential problem here is the emergence of potential conflicts derived from divergences between the independently produced accounting results. The practicality of bilateral accounting depends on whether most conflicts can be solved online, as opposite to off-line resolution; this issue is still an open research question. To help cover the gap, in this paper we present an online peer–to–peer protocol for dispute resolution over resource consumption. To meet space and time constraints and focus the discussion on an specific and practical example, we deal only with storage consumption and in particular we concentrate on a rather simple scenario where the consumer can only upload data to an incremental storage service.

An abstract view of our scenario of study is shown in Figure[1] where Provider represents an storage service and Consumer represents the consumer of the service which can be a single individual or a large enterprise with scores of employees or a university with thousands of students. As shown in the figure, consumer and provider deploy their own resource accountings services (RAS_c and RAS_p, respectively) within theirs respective infrastructures. A RAS is composed of three components: a metering service (MS) responsible for collecting raw metering data about storage consumption; an accounting service (AS) that retrieves the metering data and applies an accounting model to produce accounting data; and a billing service (BS) that on the basis of the accounting data provided by the AS and pricing policies (e.g., discounts to golden customers, fines to late payments, etc.) produces the actual bill, say monthly,
for the consumer. As shown in the figure, the consumer can access the service only through a storage interface—the service interface offered to consumers.

The CCRP (Comparison and Conflict Resolution Protocol) is the central topic of this paper and represents the protocol that the consumer and provider execute when conflicts over storage consumption emerge, with the intention of solving them online. As shown in the figure, the protocol is executed by the accounting services when the difference between their independently produced accounting results is greater than an agreed upon value. We anticipate several sources of conflicts. For example, a primary source of conflicts is the accounting model used by consumer and provider to compute accounting data. As shown in the figure, to avoid this problem, in this paper we require that both consumer and provider use the same accounting model which is published by the provider. Such a model is basically an algorithm that aggregates raw metering data (e.g., 300000 upload this week) and converts it into accounting records over agreed upon consumption intervals (10 Mbytes/Mon, 12Mbytes/Tue, etc.). Another source of potential conflicts is the techniques used by consumer and provider to collect metering data with their MSs. For example, the consumer might rely on interceptors whereas the provider—with unrestricted access to its infrastructure—might measure storage consumption directly from its file servers. At this stage of our research, and as shown in the figure, we assume that both consumer and provider use interceptors to collect metering data. There are others sources of potential conflicts, yet we will concentrate on the transmission time of requests and the accuracy of accounting intervals as these two parameters are the most relevant to the scenario of our interest. We will discuss the CCRP (as well as the interceptors) at large in the following sections.

2 The Protocol

The CCRP is an peer–to–peer conflict resolution protocol in the sense that it is executed between the two conflicting parties without the intervention of a third one, such as a referee or arbitrator. It is an online protocol in that it is executed immediately upon the detection of a conflict and as the service is delivered to the consumer. More importantly, it is an evidence–based protocol in the sense that, on the basis of evidence provided by the conflicting parties, it tries to identify the source of the divergency between
the two accounting results. It is worth mentioning that this approach departs from conflict resolution protocols based on Utility Theory which are interest–based in that, they take into consideration the conflicting parties’ preferences and tradeoffs [10].

3 Assumptions

We admit that the CCRP is still under development. In this paper we explore its feasibility in a very simple incremental storage consumption scenario described by the assumption discussed below. As explained in Section 8 we are planning to relax these assumptions in the future to generalise our scenario. We believe that the fundamental ideas (e.g. the architecture shown in Figure 5) discussed in the current scenario will still hold in a more general one.

The scenario of study can be described by the following assumptions:

1. The provider offers an incremental storage service where upload file is the only operation available to the consumer to alter its storage space and each execution results in the creation of a new file. This service is far from being a general scenario, yet it is still of some practical interest (e.g. in archival storage [9]) and more importantly, it is good enough to explain our ideas.

2. All the consumer’s upload operations are requested from within its premises (see Figure 1); consumers with laptops that roam outside the premises are not considered.

3. The service is delivery continuously over an agreed period of time, for example, over a year.

4. In the interest of accountability, the total period is divided into Consumption Intervals (CI) with SP and EP (Start Point and End Point, respectively) determined by the provider.

5. Zero or more requests can issued by the consumer during the duration of each consumption interval.

6. There are no gaps in the accounting line. Except for the last interval, the end of a given interval correspond to the start of the next one.

7. The consumer and provider independently produce their accounting record about the storage consumed over each consumption interval. The two independently produced records do not necessarily match.

8. The CCRP is executed for each consumption interval to compare the two independently produced accounting records and to try to solve potential conflicts.

9. The provider’s and consumer’s clocks are synchronized.

10. The interceptors used by the consumer and provider are deployed as shown in Figure 1 to intercept each consumer’s request.

11. The $MS_c$ and $MS_p$ collect the following data about each request: Request id, Request Time Stamp (RTS) and Bytes Transferred per Request (BT). In addition, $MS_p$ also collects Request Received Time (RRT).

4 Accounting Model

The accounting model is used by both the consumer and provider to calculate the storage consumed by each request issued by the consumer. Under the assumption that the provider relies on conventional file
systems to implement his service, our accounting model considers the number of bytes uploaded by the request and the configuration parameters of the provider’s file system.

The number of bytes transferred by each request ($BT_{req_i}$) is determined by the interceptors after intercepting and examining the request.

The configuration parameters are inherent to the file system. In our accounting model we consider the amount of metadata ($MD$) associated to each file and the size of the disk chunk ($ChSize$)—also called, size of disk cluster. Typical values of $MD$ and $ChSize$ are, respectively, 2KB and 4KB. In this order, the number of chunks consumed by a request can be calculated by equation 1.

$$NofCh_i = \frac{BT_{req_i} + MD}{ChSize}$$  

It follows that the storage consumed by a given request can be calculated by equation 2:

$$SCUF = RoundUp(NofCh) * ChSize$$

$RoundUp$ represents a round up operation to the nearest integer and counts for the fact that disk chunks are allocated only in whole units.

The amount of storage consumed within each consumption interval can be calculated as the sum of the storage consumed by each request issued within the interval; we represent it by equation 3 and show it graphically in Figure 2.

$$SC = \sum_{i=1}^{n} SCUF_i$$

![Figure 2: Storage consumed within each consumption interval.](image)

### 5 Two Potential Causes of Disparities over Storage Consumption

In this section we will explain how mismatches between the consumer’s and provider’s accounting intervals can results in disparities between the consumer’s an provider’s accounting results. Likewise, we will discuss how transmission time impacts the accounting results produced by the two parties.
5.1 Consumption Interval

The impact of potential mismatches between the consumer’s and provider’s consumption intervals is shown in Figure 3. In the figure, $CI$ and $R$ stand, respectively, for Consumption Interval and Requests. Similarly, $SP$ and $EP$ stand, respectively, for Start Point and End Point of a given interval. We refer with superscripts $c$ and $p$, to consumer and provider, respectively. Subscripts represent the sequence number of the interval; for example, $SP^c_1$ represents the start point of the consumer’s interval number one. Notice that for simplicity, the figure assumes that the transmission time of the requests is zero.

![Diagram](image)

Figure 3: Mismatch between consumer’s and provider’s consumption intervals.

As suggested by the figure, it is quite possible that for a given interval the consumer’s Start Point ($SP$) and End Point ($EP$) do not match the provider’s. Such a mismatch is very likely to result in divergencies between the consumer’s and provider’s accounting records for the interval under question. In the figure, $EP^p_1 > EP^c_1$, consequently, $CI^p_1$ includes $N$ requests more than the consumer’s $CI^c_1$. Naturally, the length of the divergency between the two results depends on the amount of bytes transferred in each requests and more importantly, on the value of $N \geq 0$. As shown in the figure, length of the divergency for $CI_2$ depends on the value of $N$ and $M \geq 0$.

In practice, this situation can arise when the provider does not offer precise information to the consumer about when to start and end a given consumption interval. For instance, most storage providers, like Amazon [2] and Nirvanix [7] do not offer (e.g. in their Service Level Agreements) sound accounting models to their customers. For example, in Amazon S3 service, the storage consumed by a given customer is calculated as follows: Amazon checks at least twice a day the consumer’s storage space, it measures the amount of storage occupied by a consumer’s buckets and multiplies the result by the amount of time elapsed since the last check. However, Amazon S3 does not state exactly when (in time units) they undertake their measurement.
As discussed in Section 4, the consumer and provider calculate storage consumption within a given consumption interval by equation 3. The requirement to make the two independently produced results converge is that both parties use exactly the same SP and EP for the interval under question. We anticipate two possible solutions to this problem. An alternative is to keep the consumer’s and provider’s metering services strictly synchronised; for example, the provider can notify the consumer when each consumption interval starts and ends. As shown in the pseudocode presented in Section 6.3, in this paper we explore a second alternative where the parties exchange their SP and EP upon detection of conflicts between their accounting results.

5.2 Transmission Time

We define transmission time (TT) as the time it takes a consumer’s request to travel from the consumer to the provider. In practical applications, TT is normally greater than zero, say of the order of 100 milliseconds. In Figure 4, TT represents the average transmission time. As shown graphically, this parameter can cause divergencies between the consumer’s and provider’s accounting results for a given consumption interval. For the sake of simplicity, let us assume that the consumer’s and provider’s SP and EP of a given interval are synchronised. Under this assumption, convergency between the consumer’s and provider’s accounting records can be achieved by compensating the provider’s results by the amount of memory consumed by the requests in the wire, that is, requests issued in a given interval but received and counted in the following due to TT.

![Figure 4: Impact of transmission time on storage accounting.](image)

Let us take an arbitrary interval \( CI_i \). The consumer can calculate its storage consumption by equa-
However, to compensate for $TT$, the provider would need to use equation 4:

$$SC = \sum_{i=1}^{n} S\text{CU}F_i + |N - M|$$

where $N$ is the amount of storage consumed by requests issued and counted by the consumer in interval $CI_{i-1}$ but received and counted by the provider in interval $CI_i$ due to the effect of $TT$; in the figure this time gap is shown as $TT_1$. Similarly, $M$ is the amount of storage consumed by requests issued and counted by the consumer in interval $CI_i$ but to be received and counted by the provider in interval $CI_{i+1}$, due to $TT$; in the figure, this time gap is shown as $TT_2$. Both $N$ and $M$ can be calculated by equation 3. Notice that for the first interval $N$ is to be taken as $N = 0$.

An equivalent alternative to compensate the provider’s accounting results is for the provider (or the consumer) to shift its consumption interval to count for $TT$. This is the strategy taken in the pseudocode presented in Section 6.3.

It is worth keeping in mind that accounting records can be impacted simultaneously by both asynchrony of consumption interval and transmission time. The protocol presented in Section 6.3 handles the two potential sources of conflicts separately. First it tries to match the results by considering the asynchrony of the interval; if it fails, it takes $TT$ into account. Failure to produce matching results leads to offline dispute resolution.

6 The Model

A crucial problem in accounting of storage consumption is the generation of non-repudiable evidence about the consumption. We address this issue with the help of the piece of middleware for Non-Repubidiable (NR) information sharing presented in [4, 3]. The fundamental idea is that the middleware provides multi-party, non–repudiable agreement to updates to shared information which can be maintained in a distributed manner with each party holding a copy. Essentially, one party proposes a new value for the state of some information and the other parties sharing the information subject the proposed value to application–specific validation. If all parties agree to the value, then the shared view of the information is updated accordingly. Otherwise, the shared view of the information remains in the state prior to proposal of the new value.

The architecture of our solution is shown in Figure 5. NR Midleware represents the non–repudiable middleware. Similarly, $RAS_c$ and $RAS_p$ represent, respectively, the consumer’s and provider’s resource accounting systems. Non-Agreed NRData and Agreed NRData are files to store, respectively, non-agreed and agreed accounting records, as determined by the P2P online Dispute Resolution protocol. Records from the Non-Agreed log can be used in case of offline dispute resolution.

The signed two-phase commit protocols works as follows:

1. The provider $RAS_p$ calculates the accounting record $SR_p^i$ for a given consumption interval $CI_i$ and sends it to its NR Midleware which produces non–repudiation of its origin $NRO(SR_p^i)$ and sends $NRO(SR_p^i)$ and $SR_p^i$ to the consumer.

2. The consumer’s NR middleware validates $SR_p^i$ and $NRO(SR_p^i)$ and sends $SR_p^i$ to its $RAS_c$.

3. $RAS_c$ produces an accounting record $SR_c^i$ for $CI_i$, compares it with the $SR_p^i$ and produces a decision, $decni$. $decni$ is essentially a binary Yes or No value. If $decni = Yes$, $RAS_c$ sends $decni$ to the
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Figure 5: Architecture to support the online dispute resolution protocol.

consumer NR middleware, otherwise, it triggers the online P2P dispute resolution. When this protocol is completed decni is sent to the consumer’s NR middleware.

4. The consumer’s NR middleware sends the decision decni, non-repudiation of receipt of SR\textsubscript{p}, NRR(SR\textsubscript{p}) and non–repudiation of origin of the decision NRO(decni).

5. The provider NR middleware validates decni, NRO(decni) and NRR(SR\textsubscript{p}). The protocol terminates with the provider sending non–repudiation of receipt of the validation decision to the consumer NRR(decni).

6.1 The Provider’s Resource Accounting Service

We will elaborate on how the provider’s resource accounting service work, with the help of Figure 6 which is an expansion of Figure 5. RAS\textsubscript{p} is a service with a negotiator used by the provider to collect data, compute and negotiate resource consumption. RAS\textsubscript{p} consists of a Manager With Negotiator (MW\textsubscript{p}), Metering Service (MS\textsubscript{p}) and Accounting Service (AS\textsubscript{p}). The MS\textsubscript{p} collects data about resource consumption caused by all uploaded requests and stored them in a permanent file. It records the following data user Id, request Id, request time stamp, request arrived time and number of bytes transferred per request.

AS\textsubscript{p} determines the (SP, EP) for each CI\textsubscript{i}, obtains the metered data from MS\textsubscript{p}, calculates the average TT and produces a standard accounting record SR\textsubscript{p} for each CI\textsubscript{i}. The AS\textsubscript{p} uses equation 5 to compute TT of a request:

\[
TT = RequestArrivalTime - RequestTimeStamp
\]  

(5)

The average TT is calculated by equation 6

\[
TTave = \left( \sum_{i=1}^{n} TT_i \right) \ast \frac{1}{n}
\]  

(6)

The MW\textsubscript{p} obtains SR\textsubscript{p} from its AS\textsubscript{p} and sends it to the provider NR middleware. Another responsibility of MW\textsubscript{p} is to negotiate with the consumer RAS\textsubscript{c}. In the negotiation steps, the MW\textsubscript{p} receives negotiation requests with the consumer’s accounting parameters and the negotiator counter from
the \( RAS_c \). \( MWN_p \) obtains the negotiator requests and sends it to \( AS_p \) who compares them with its accounting parameters. The \( AS_p \) obtains the parameter or parameters which cause the conflict, updates the negotiator counter and sends the negotiation response to the \( MWN_p \) who sends it to the \( RAS_c \) and waits for new negotiation requests.

### 6.2 Consumer Resource Accounting Service

Similarly to the provider’s resource accounting system, the \( RAS_c \) is a service with a negotiator that is used by the consumer to collect data, compute, negotiate and produce decisions about storage consumption for each CI. \( RAS_c \) consists of a Manager With Negotiator (\( MWN_c \)), Metering Service (\( MS_c \)), Accounting Service (\( AS_c \)) and a Comparator (see Figure 6). The \( MS_c \) collects data about resource consumption caused by all uploaded requests and stores them in a permanent file. It records the following data: request \( Id \), request time stamp, number of bytes transferred per request. \( RAS_c \) works as follows:

1. \( MWN_c \) receives the provider’s standard accounting record \( SR^p_i \) from the consumer NR middleware.
2. The \( MWN_c \) sends the available accounting parameters \( R^c_i \) to \( AS_c \).
3. \( AS_c \) configures its accounting model using the \( R^c_i \) details. \( R^c_i \) consists of \( CI \) and \( TT_i \).
4. \( AS_c \) obtains metered data from \( MS_c \) based on the \( CI \), computes \( SR^c_i \) using its accounting model and sends it the \( MWN_c \).
5. \( MWN_c \) sends \( SR^c_i \), \( SR^p_i \) to the Comparator, who compares them and returns the decision \( decn_i \) to the \( MWN_c \).

If \( decn = No \) the \( MWN_c \) starts negotiation with \( RAS_p \) aiming at solving the dispute. When \( MWN_c \) receives a negotiation response it resets the value of \( R^c_i \) according to the evidence received from the negotiation response and executes steps 2 to 5. When the negotiation is completed or \( MWN_c \) obtains \( decn = Yes \) from the Comparator, the \( MWN_c \) sends the \( decn_i \) to NR middleware and waits for a new accounting record from the consumer NR middleware.
6.3 P2P Protocol for Online Dispute Resolution

The base of our dispute resolution protocol is the exchange of SP, EP of the interval under question and the average TT. The main idea of this protocol that the provider computes the resource consumption for each consumption interval \( C_i \) and sends it through its NR middleware to the consumer. The consumer sends the record to its \( RAS_c \) which compares it with its own record and in case of dispute it starts a negotiation with the \( RAS_p \). The \( RAS_c \) sends a negotiation request to \( RAS_p \). The negotiation request should contain the accounting parameters of the \( RAS_c \). The \( RAS_p \) compares the consumer parameters with its parameters, finds the parameter or parameters that cause the conflict and sends them to the \( RAS_c \) with a negotiation response. The \( RAS_c \) uses the provider’s parameters to compute storage consumption. It then compares the two records: if they match it sends a \textit{deci} to the consumer NR middleware and waits for a new accounting record. Otherwise, it sends a new negotiation request until the end of the protocol. The negotiation protocol is completed either when the \( RAS_c \) has received a stop negotiation message from the \( RAS_p \) or the \( RAS_c \) obtains an agreed decision.

We now show the pseudocode of the protocol for dispute resolution. We use the following notation:

- \# \textit{nc}_c = \text{consumer negotiator}
- \# \textit{deci}_c = \text{decision}
- \# \textit{SR}_p = \text{provider’s storage consumption record containing storage consumption (SC)}
- \# \textit{SR}_c = \text{consumer's storage consumption record containing storage consumption (SC)}
- \# \textit{TT} = \text{transmission time}
- \# \textit{SP} = \text{start point, EP = end point}
- \# \textit{R}_c = \text{consumer’s accounting parameters } SP_c, EP_c, TT_c
- \# \textit{R}_p = \text{provider’s accounting parameters } SP_p, EP_p, TT_p
- \# \textit{NReq} = \text{negotiation request } R^i, nc^i
- \# \textit{NRes} = \text{negotiation response } R^p, nc^p

- \text{MWN, (SR): } \{ \text{ # nc} = \text{true} \}
  \text{ # deci=false}
  \text{ if selected the start and end point of } C_i
  \text{ set the value of } SP^i = X, SP^i = Y, TT^i = 0
  \text{ if set the accounting parameters } \text{ R}^i = \{ (SP^i, EP^i, TT^i) \}
  \text{ get the storage consumption from AS}_r
  \text{ SR}_c = \text{call AS}_r ( \text{ R}^i )
  \text{ while (deci })
    \text{ if (SR} = \text{SR}( \text{ R}^i ) \text{ (deci=true and NC=false)) flag deci else}
      \text{ if (!nc) } \text{ // Start negotiation}
        \text{ // set negotiation request}
        \text{ NReq} = \text{ ( R}^i, \text{ nc) }$
        \text{ if send the consumer accounting parameters evidences to } \text{ RAS}_c$
        \text{ NRes} = \text{ Call RAS}_c ( \text{ NReq) }$
        \text{ it obtains the provider accounting parameters from NResi and update the consumer}
        \text{ accounting parameters } \text{ R}^c = \text{ R}^i \text{ // update acc. parameters}
        \text{ nc} = \text{nc} \text{ // update the nc.}
        \text{ re-compute storage consumption according to the provider parameters}
        \text{ SR}^c = \text{call AS}_r ( \text{ R}^c )$
      \text{ if end if}
      \text{ else ( break ) } \text{ // deci, not agree and stop}
    \text{ // end while loop}
    \text{ Send deci, to MWN, and stop } \text{ // send decision and stop}
  \text{ // end MWN,}
7 Related Work

The idea of bilateral measurement of resource consumption with online dispute resolution of potential conflicts was firstly suggested in [5], however, no protocol to solve the problem was discussed; in this respect, our work can be regarded as a step forward in this research direction. Online Dispute Resolution (ODR) systems based on Utility Theory have been studied by some authors (see for example [10]). A particularity of these ODR systems is that they attempt to reach interest-based voluntary settlement agreements based on parties’ preferences and tradeoff. In contrast, in our work disputes are solved—if possible—on the basis of evidences presented by the two parties involved in the conflict. Another particularity of these ODR is that they normally rely on a third party (e.g. arbitration) to help solve the dispute; we depart from this idea and suggest a peer-to-peer conflict resolution protocol.

The use of middleware interceptors to monitor Service Level Agreements–regulated interactions between two parties is discussed in [6].

The problem of deciding the physical location of the components of metering services to measure resource consumption is related to the concept of monitorability discussed in [8]. In accordance with these authors, a given service level parameter (for example, response time, storage consumption, etc.) is unmonitorable, monitorable by a trusted third party, monitorable by one party, monitorable by both parties. In [5] the authors explain that the monitorability of a given parameter depends on several factors; among the most important ones are the accuracy of the metering, the physical location of the application (one or many) that affects the parameter, the physical location of the metering service and the trust assumptions about the metering service and its location.

In [1] the authors discuss a protocol to provide non-repudiable evidence of services consumption in mobile internet services. Non-repudiable evidence is used by the provider to prove the correctness of his bill and allows the consumer to verify the service consumption. The protocol suffers from several limitations. For example, it involves an online trusted third party to insure fairness of the protocol. Likewise, it works for time–base accounting only. Furthermore, the non–repudiable service increases the number of messages exchanged through the network. Consequently, the additional messages reduce the effective bandwidth for users’ data traffic. Moreover, if disputes over a service interval appear, the service is simply terminated; when this happens, the provider looses money because the consumer would have already consumed part of the service interval. Our work constrasts with this approach in that we try to solve conflict when they apper rather than terminating the service.

8 Conclusion and Future Work

In bilateral accounting of resource consumption the consumer and the provider independently measure resource consumption, compare their outcomes and try to agree on a a single outcome. In this paper we have discussed when, why and where conflicts might happen in bilateral accounting for storage consumption. We propose a peer-to-peer online protocol to be executed between the consumer and provider to solve conflicts over the consumer’s consumption. In future, we are planning to study other parameters (different techniques to collect data about resource consumption) that might cause disputes over storage consumption.
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