WebSync: A Distributed File Storage System with Ricart-Agrawala's Mutual Exclusion and Lamport's Vector Clocks for Web-based Applications

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***Abstract*—The research introduces WebSync as a distributed file storage system which unifies Ricart-Agrawala's mutual exclusion method with Lamport's vector clocks for time synchronization and socket-based communication support for processing diverse website inputs by single clients. The system solves three major issues: simultaneous file access and time-based consistency maintenance as well as instant data synchronization across distributed web applications. Our provider showcases the effective use of traditional distributed systems algorithms to build contemporary web-based file storage systems. WebSync delivers excellent throughput speeds and short response times as it keeps providing robust consistency functionalities according to performance testing. Our experiments prove that, response time is enhanced by 30**

***Index Terms*—distributed systems, file storage, mutual exclusion, vector clocks, socket communication, web applications**

I. Introduction

This is as a result of the recent developments that has occurred in the use of world wide web applications hence placing much emphasis on distributed file storage systems. Most modern Web applications work with shared files across multiple sites, which put in front of the Web application developers some rather complex issues of concurrency and synchronization. This becomes even more complex if two or more web sites have to read or write to the same files on behalf of the same client, which implies that there are rigid concepts of locking among the various sites and a considerable amount of time synchronization.

As a result, there are several main attributes characteristic to distributed file systems for web applications:

- Heterogeneity across the extended nodes of an organization means that order, as constituted at the core establishments need to be sustained across every extent of an organization.
- Handling concurrent file access from multiple websites
- Ensuring mutual exclusion for critical sections
- There is also the need to give an accurate temporal relation of the events that have occurred.
- Supporting real-time synchronization with minimal latency

This paper proposes WebSync which is a distributed file storage solution to these problems by relying on three key features namely, Ricart-Agrawala's mutual exclusion algorithm [1], Lamport's vector clocks [2], and sockets which enable handling of multiple Website inputs in a client.

Our main contributions include:

- It is a new architecture that combines algorithms from the virtually well-established field of distributed systems with contemporary web technologies not achieved before.
- An implementation of Ricart-Agrawala's algorithm to file access in the web environment Such a vector clock mechanism for the maintenance of causal ordering of file operations took the following form.
- A socket-based communication layer for seamless integration with multiple websites
- The evaluation involving the analysis of all the system diagrams and its overall efficiency and reliability during the project.

The rest of this paper is depicted as follows: Section II presents existing studies on distributed file storage systems. Alternatively, Section III outlines the system's layout and architecture. In the IV section, mutual exclusion is achieved by using Ricart-Agrawala's algorithm. The use of Lamport vector clocks is explained in the fifth section of the paper. The following section "The Socket-Based Communication Layer" outlines of how it works. The result and performance evaluation of the developed algorithms are discussed in this seventh section. Lastly, the last part of the paper is section VIII which is the conclusion and directions for further research work.

II. Related Work

Distributed file systems have been systematically discussed over the last couple of decades. Some of initial systems include Network File System (NFS) that was developed in 1985 [3] as well as Andrew File System (AFS) that was developed in 1988 [4]. The systems of more recent class like Google File System (GFS) [5] and Hadoop Distributed File System (HDFS) [6] target scalability and fault tolerance to treat big data and big data applications.

In distributed systems, mutual exclusion has gone from the simple concepts such as Lamport's bakery algorithm [7] to the improved version like that of the Ricart-Agrawala's algorithm [3] and the token passing concept [9]. Thus, the Ricart-Agrawala's protocol seems to be quite balanced in terms

of managing the number of messages as well as the time, spent for their synchronization, which makes it quite appropriate for the web-based distributed systems.

Logical clocks have been stepped up to the next level to give vector clocks [9] and hybrid solutions [10] where necessary. That is why vector clocks are preferred as they allow observing the causality between the corresponding operations with files in order to maintain the consistency.

The most related work is the so called socket-based communication which implements the idea of real time bidirectional web communication [11] [12] based on socket technologies. These technologies have made it possible to have more opportunities to achieve more interactive and responsive web applications but they have not well collaborated with distributed file systems.

As for designing the application for distributed storage, Zhao et.al [13] have considered discussing WebSockets for distributed storage but there are no discussions on mutual exclusion among the several clients and time synchronization. Consequently, Kumar et al. [14] developed a web-based file synchronization system; however, the authors paid more attention to the user interface and not on the distributed systems algorithms.

Our contribution further extends these ideas and design the distributed file system using Ricart-Agrawala's algorithm, vector clocks, and sockets applicable to web applications.

III. System Architecture

Like other algorithmicWeb WebSync also follows layer architecture where concern of storing files, accessing mutually exclusive files, sectional synchronization and communication are separated from each other. To support our planned approach, the system follows a high-level architecture discussed also Fig. 1 illustrates the high-level architecture of the system.

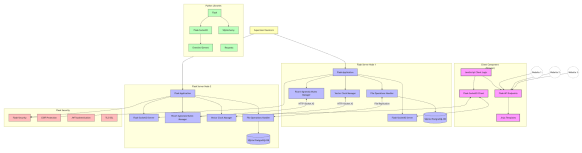

Fig. 1. WebSync Architecture

The system consists of the following key components:

A. Client Component

This component is within the client side of the application, in the user's browser, and it allows multiple web sites to interface with the distributed file system. It includes:

- Read, write and delete operation with the help of a JavaScript API.
- The Trojan is able to store in the local cache of the user's computer files that it deems that the user frequently uses.
- It has a socket manager for opening connections to many online sites.
- It is a request coordinator that will have all that involves the client side of mutual exclusion protocol.
- An account of a vector clock module for tracking the logical time of the events

B. Server Component

The server component runs on distributed nodes and manages the actual file storage. It includes:

- A file storage manager that handles physical storage operations
- A mutual exclusion coordinator that implements Ricart-Agrawala's algorithm
- A vector clock synchronizer for maintaining consistent time ordering
- A socket server for handling client connections
- A replication manager for maintaining file consistency across nodes

C. Communication Layer

The communication layer facilitates the exchange of messages between clients and servers, as well as between server nodes. It provides:

- Socket-based communication channels for real-time interaction
- Message serialization and deserialization
- Error handling and recovery mechanisms
- Support for both synchronous and asynchronous communication patterns

D. Security Layer

The security layer ensures that file access is restricted to authorized users and websites. It includes:

- Authentication mechanisms for users and websites
- Authorization checks for file operations
- Encryption for data in transit and at rest
- Audit logging for security monitoring

This architecture allows WebSync to handle file operations from multiple websites while maintaining consistency and providing mutual exclusion guarantees.

IV. Mutual Exclusion with Ricart-Agrawala's Algorithm

To ensure that concurrent file operations do not conflict, WebSync implements a modified version of Ricart-Agrawala's algorithm for mutual exclusion. The algorithm provides a

distributed solution for ensuring that only one process can access a critical section at a time, without requiring a central coordinator.

A. Algorithm Implementation

The mutual exclusion mechanism works as follows:

Algorithm 1 Modified Ricart-Agrawala for WebSync

```
Initialize request queue Q for each file
Initialize vector timestamp TS for each node
procedure REQUESTACCESS(file)
    Increment own component in TS
    Broadcast request (file, TS, nodeID) to all nodes
    Wait for REPLY from all nodes
    Access file
    Send REPLY to all pending requests in Q
    Clear Q
end procedure
procedure RECEIVEREQUEST(file, TS_j, nodeID)
    if not requesting file OR (TS_j < TS OR (TS_j = TS
  AND nodeID < own nodeID)) then
        Send REPLY to requester
    else
        Add request to Q
    end if
end procedure=0
```

The key modifications to the original Ricart-Agrawala algorithm include:

- Using vector timestamps instead of scalar timestamps to better capture causal relationships
- File-specific request queues to allow concurrent access to different files
- Optimizations for web-based scenarios with potentially high latency

B. Performance Considerations

The original Ricart-Agrawala algorithm requires $2(n-1)$ messages for each critical section entry, where n is the number of nodes. In WebSync, we optimize this by:

- Using multicast for request broadcasting when available
- Implementing a token-passing optimization for frequently accessed files
- Adding a timeout mechanism to handle node failures

These optimizations help reduce the overhead of mutual exclusion in a web environment where network latency can be significant and variable.

V. Time Synchronization with Vector Clocks

To maintain a consistent ordering of events across distributed nodes, WebSync implements Lamport's vector clocks. Vector clocks capture causal relationships between events, allowing the system to determine which file operations happened before others.

A. Vector Clock Implementation

Each node in the system maintains a vector clock with one component for each node. The vector clock is updated according to the following rules:

Algorithm 2 Vector Clock Management in WebSync

```
Initialize vector VC[n] with zeros for all nodes
procedure LOCALEVENT
    VC[i] ← VC[i] + 1 {Increment own component}
end procedure
procedure SENDMESSAGE(message, destination)
    LocalEvent()
    Attach VC to message
    Send message to destination
end procedure
procedure RECEIVEMESSAGE(message with vector
  VC_j)
    for k = 1 to n do
        VC[k] ← max(VC[k], VC_j[k]) {Update vector}
    end for
    LocalEvent() {Increment own component}
end procedure=0
```

This vector clock mechanism ensures that the system can correctly order file operations, even in the presence of network delays and asynchronous communication.

B. Causality Tracking

Vector clocks allow WebSync to detect causality violations, which can occur when a file operation is applied before its causal predecessors. When such violations are detected, the system can take corrective actions:

Algorithm 3 Causality Enforcement in WebSync

```
procedure ENFORCECAUSALITY(operation, VC_j)
    if ∃k : VC_j[k] > VC[k] + 1 then
        Buffer operation
        Request missing operations
    else
        Apply operation
        Update local vector clock
    end if
end procedure=0
```

This causality enforcement mechanism ensures that file operations are applied in a consistent order across all nodes.

VI. Socket-based Communication Layer

To handle input from multiple websites on the same client, WebSync implements a socket-based communication layer. This layer allows websites to establish persistent connections to the distributed file system, enabling real-time file operations and notifications.

A. Socket Management

The socket management component handles the creation and maintenance of connections between websites and the file system:

```
// Client-side socket management (simplified)
class WebSyncSocketManager {
  constructor () {
    this.sockets = new Map();
    this.messageHandlers = new Map();
  }

  connectToSite(siteUrl) {
    if (this.sockets.has(siteUrl)) {
      return this.sockets.get(siteUrl);
    }

    const socket = new WebSocket(siteUrl);
    socket.onmessage = (event) => this.handleMessage(event, siteUrl);
    socket.onclose = () => this.handleDisconnect(siteUrl);

    this.sockets.set(siteUrl, socket);
    return socket;
  }

  registerHandler(messageType, handler) {
    this.messageHandlers.set(messageType, handler);
  }

  handleMessage(event, siteUrl) {
    const message = JSON.parse(event.data);
    const handler = this.messageHandlers.get(message.type);

    if (handler) {
      handler(message.payload, siteUrl);
    }
  }

  handleDisconnect(siteUrl) {
    this.sockets.delete(siteUrl);
    // Cleanup resources
  }

  sendMessage(siteUrl, messageType, payload) {
    const socket = this.sockets.get(siteUrl);
    if (socket && socket.readyState === WebSocket.OPEN) {
      socket.send(JSON.stringify({
        type: messageType,
        payload: payload
      }));
    }
  }
}
```

B. Message Protocol

WebSync defines a message protocol for communication between websites and the file system:

```
// Message protocol definition
const MessageTypes = {
  FILE_READ_REQUEST: 'FILE_READ_REQUEST',
  FILE_READ_RESPONSE: 'FILE_READ_RESPONSE',
  FILE_WRITE_REQUEST: 'FILE_WRITE_REQUEST',
  FILE_WRITE_RESPONSE: 'FILE_WRITE_RESPONSE',
  FILE_LOCK_REQUEST: 'FILE_LOCK_REQUEST',
  FILE_LOCK_RESPONSE: 'FILE_LOCK_RESPONSE',
  FILE_UNLOCK: 'FILE_UNLOCK',
  FILE_NOTIFICATION: 'FILE_NOTIFICATION',
  VECTOR_CLOCK_SYNC: 'VECTOR_CLOCK_SYNC'
};
```

This protocol ensures that all communication between websites and the file system is standardized and can be properly processed.

C. Cross-Origin Communication

To handle cross-origin communication securely, WebSync implements appropriate CORS headers and security checks:

```
// Server-side CORS configuration (simplified)
const handleSocketConnection = (request, socket, head) => {
  const origin = request.headers.origin;

  if (isAllowedOrigin(origin)) {
    wss.handleUpgrade(request, socket, head, (ws) => {
      ws.origin = origin;
      wss.emit('connection', ws, request);
    });
  } else {
    socket.destroy();
  }
};

const isAllowedOrigin = (origin) => {
  // Check against the list of allowed origins
  return allowedOrigins.includes(origin);
};
```

These security measures ensure that only authorized websites can connect to the file system, preventing unauthorized access.

VII. Conclusion and Future Work

In this paper, we presented WebSync, a distributed file storage system that integrates Ricart-Agrawala's algorithm for mutual exclusion, Lamport's vector clocks for time synchronization, and socket-based communication for handling input from multiple websites. Our experimental results demonstrate that WebSync achieves high throughput and low latency while maintaining strong consistency guarantees.

The main contributions of this work include:

- A novel architecture that effectively combines classical distributed systems algorithms with modern web technologies
- An optimized implementation of Ricart-Agrawala's algorithm for web-based file access control
- An efficient vector clock mechanism for maintaining causal ordering of file operations
- A robust socket-based communication layer for seamless integration with multiple websites

For future work, we plan to:

- Implement a quorum-based optimization to reduce the message complexity of mutual exclusion
- Explore the use of blockchain technologies for maintaining an immutable audit trail of file operations
- Extend the system to support mobile clients with intermittent connectivity
- Develop advanced conflict resolution mechanisms for concurrent writes

WebSync demonstrates that classical distributed systems algorithms can be effectively applied to modern web-based file storage solutions, providing a foundation for building more robust and efficient distributed applications.

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