Zero Knowledge Proof for Online Auctions

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Abstract— **Cryptography is a field of security which deals with the encryption of data in order to ensure Confidentiality, Integrity and Availability (CIA) triad. Authentication and non-repudiation are other factors which are also essential for data security.**

In order for the data to be securely transmitted strong cryptographic algorithms such as RSA, DSA, Diffie-Hellman etc. are used. Modern cryptographic mechanisms allow us to achieve the security, privacy and confidentiality aspects of online auctions. One such cryptographic mechanism is called Zero Knowledge Proof.

Zero Knowledge Proof is a special algorithm which ensures the data integrity by letting the truth be known to the verifier (receiver) without the prover (sender) revealing all the confidential information. Our project aims at utilizing this mechanism in order to ensure transparency and privacy in data transmission.

In an online auction, multiple buyers and sellers from across the world participate in the bidding process via the internet. However, the security feature is at risk if each of these buyers and sellers are not carefully monitored. Therefore, Zero Knowledge Proof (ZKP) Protocol provides a solution by using entity authentication and anonymity to ensure that the users participate in the bidding process without revealing their profile information.

Keywords—*Zero Knowledge Proof (ZKP), Simple Certificate Enrollment Protocol (SCEP), Secure Hashing Algorithm (SHA).*

I. INTRODUCTION

Modern technologies are reshaping the world by promoting less human dependency and efficiency in terms of reduced manual work flow. However, these modern technologies challenge the three important facets of data i.e. confidentiality, integrity and security.

Traditional auctions which take place around the world involves the auctioneers and bidders to be present at a physical place. However, with the digitization aspect put in place online auctions are also becoming prominent. The concept of security, privacy and confidentiality is very essential in this domain.

Modern cryptographic mechanisms allow us to achieve the security, privacy and confidentiality aspects of online auctions. One such cryptographic mechanism is called Zero Knowledge Proof. Zero Knowledge Proof (ZKP) is a special algorithm which ensures the data integrity by letting the truth be known to the verifier (receiver) without the prover (sender) revealing all the confidential information.

The project design and implementation are inspired from eBay website. The project will focus on secure online bidding in terms of ensuring two primary factors i.e., entity authentication and anonymity. Entity authentication is the process of ensuring the identity of the two parties i.e., verifier and claimant in protocol participation. User anonymity is a feature in which the users participating in the bidding process are anonymous i.e., their profile information is hidden.

This study is motivated by the need to:

1. Implement ZKP Protocol which will ensure a fair and privacy-preserving e-auction between both the participants i.e. buyers and sellers.
2. Authenticate bidders and sellers against malicious and unauthorized adversaries.

II. PROBLEM STATEMENT

Our project aims at utilizing Zero-Knowledge Proof mechanism in order to ensure transparency and privacy during data transmission. The purpose of our project is authenticating bidders and sellers of auctions against unauthorized/malicious adversaries.

The scope of the project is to create a secure online auction platform by implementing the ZKP protocol using Simple Certificate Enrollment Protocol (SCEP) curve.

III. LITERATURE SURVEY

A. An Efficient Protocol for Secure Two-Party Computation in the Presence of Malicious Adversaries

They show an efficient secure two-party protocol, based on Yao’s construction, which provides security against malicious adversaries.

Cut and choose techniques are applied to the original circuit and inputs in order to support their construction. The ideal/real simulation paradigm is used to prove the security which is in the standard model (with the absence of random oracle model or common reference string assumptions).

This paper provides the following contributions as listed:
1. Efficient protocol against malicious parties.
2. Simulation based proofs.
3. A black box reduction.

The algorithm used is Yao’s garbled circuit construction.

Findings:
1. It uses a symmetric key encryption scheme that has indistinguishable encryptions for multiple messages and an elusive efficiently verifiable range.
2. The protocol uses both unconditionally hiding and unconditionally binding commitments.
3. The protocol needs to use an Oblivious Transfer Protocol which is secure according to the real/ideal model simulation definition.

Limitations:
1. This approach is not practical as it requires using generic zero-knowledge proofs.
2. Yao’s garbled circuit construction is secure in the presence of semi-honest adversaries.

B. On the Message Complexity of Secure Multiparty Computation

This paper is based on the study of the minimal number of point-to-point messages required for general secure multi-party computation (MPC) in the setting of computational security against semi-honest, static adversaries which in return may corrupt an arbitrary number of parties.

The work done provide a tight characterization of the message complexity of computationally secure MPC in the presence of semi-honest adversaries that can corrupt any number of parties.

The algorithm used here is message complexity of MPC protocol.

Finding: It uses 2-round MPC protocol in the plain model.

Limitation: Considers its own upper and lower bound for semi-honest, static adversaries which may corrupt an arbitrary number of parties.

C. Fast Large-Scale Honest-Majority MPC for Malicious Adversaries

This paper implies that even though the protocols for semi-honest adversaries are far more efficient there are many cases where the security guarantees are not that effective. Thus, this paper presents new protocols where any functionality included by an arithmetic circuit can be securely computed.

The paper firmly supports their protocols stating they are information-theoretically secure in the appearance of a malicious adversaries assuming an honest majority. They present protocol variants for all the fields like small and large fields and exhibits how to effectively instantiate them based on replicated secret sharing and Shamir sharing.

The algorithm used here is secure multiparty computation protocol.

Findings:
1. Uses threshold secret sharing.
2. Makes use of pseudo randomness.

D. A protocol for verification of an auction without revealing bid values

The role of online auctions will be significant for computational resources allocation. This can be achieved by addressing two primary issues:
1. Appropriate usage of auction model.
2. The security parameters must be addressed.

The primary focus of auction security involved privacy in terms of preserving the bidding information against multiple parties including the auctioneer. However, the existing protocols avoids attacks pertaining to privacy-preserving combinatorial auctions such as misrepresentation of bids, removal of valid bids, unfair manipulation of auctions.

This paper focuses on addressing such attacks by implementing a privacy preserving combinatorial auction protocol while maintaining the bids secrecy. This was achieved with the help of Zero Knowledge Proof in which auction verification and result calculation took place simultaneously. In order to implement Zero Knowledge Proof homomorphic auction protocol was used.

The verification protocol was implemented with the help of two well-known ZKP's:
1. Proof of Equality of discrete logarithms and encryption is based on the proof that it can be decrypted into one of two values.
2. In order to implement non-interactive ZKP proofs for random oracle model Fiat-Shamir heuristic and SHA512 hash function was used.

Non-interactive proofs is a proof which can be published by the auctioneer with the absence of interaction with other auctioneers for result verification.

The verification protocol includes threat model, verifiable threshold El-Gamal Decryption, Verifying Shift and Randomize.

The homomorphic auction protocol has an overhead which is added by the verification protocol.

The no. of malicious auctioneers is less than a given threshold. Thus, losing of bid values are kept a secret in order to provide confidence to the participants in the auction result. The security parameter is ensured by transforming the auction protocol into a privacy preserving, verifiable and combinatorial protocol with the addition of verification protocol. This robust protocol can increase the confidence of the participants in the auction result by detecting and eliminating invalid bids or malicious auctioneers.

Limitation:
The allocation of resources for individual tasks is expensive.

E. Optimal Bidding in Online Auctions

The objective of this paper is the determination of optimal bidding policy by constructing algorithms for a given utility function in case of a single item and multiple items for multiple simultaneous or overlapping online auctions.

In order to explain their modeling choices, they require that their build for optimal bidding for a potential buyer, called the agent, satisfies the following requirements:
1. It captures the essential characteristics of online auctions.
2. It leads to computationally feasible algorithm that is directly usable by bidders.
3. The parameters for the model can be estimated from publicly available data.

To achieve their goals, they have taken an optimization, as opposed to a game theoretic approach. The major reason is the requirement of an algorithm which is computationally feasible and directly applicable by bidders based on a given data.

Furthermore, their goal is to impose as few behavioral assumptions as possible and yet come up with bidding strategies that work well in practice.

The incorporation of other strategies is shown into the population bidding distribution thereby suggesting the approach in this paper performs better when competing against other strategies.

The following algorithms are used:

1. Dynamic Programming Framework
2. Bellman Equation
3. Integer Programming Approximation

Limitation:
The proposed method applies more generally to dynamic programming problems that are weakly coupled.

IV. SYSTEM REQUIREMENTS SPECIFICATION

A. Purpose

In a traditional e-commerce environment, buyers and sellers participate in an auction where the seller publishes a price for a particular product and depending upon the highest bid offered by a buyer further negotiation of payment is carried out. Online auctions are the digital framework in which both the participants from across the world participate via the internet. However, online auctions can become vulnerable if a malicious participant unregistered on the website i.e. buyer tries to participate in the auction process. Thus, the purpose of our project is authenticating bidders and sellers of auctions against unauthorized/malicious adversaries.

B. Project Conventions

The following conventions are used for designing our proposed system (represented as a system design diagram):

Acronyms	**Component Name**
Br	Buyer
Sr	Seller
Sv	Server
Tsv	Server Token
DB	Database

C. Intended Audience

This project is intended towards connecting buyers and sellers from around the world for participation in auctions via the internet in a secure environment. The project is implemented under the guidance of our project mentor and coordinator.

D. System Features

The following are the major features of an online auction system:

i. A user-friendly GUI which provides effortless service to all the users of the website.

ii. The data flow and transaction processing are controlled and maintained by the website administrator.

iii. Entity Authentication is used to ensure the identity between both the entities i.e., buyer and seller participating in the auction.

iv. Zero Knowledge Proof (ZKP) Protocol using SCEP curve is used to ensure entity authentication and anonymity.

E. Operating Environment

i. Operating System Platform: Windows

ii. Web Framework Platform: Django

iii. RDBMS Platform: Sqlite3

iv. Programming Language: Python

F. Project Limitation

Multiple clients i.e., buyers and sellers participate in online auctions. Thus, it becomes difficult to ensure trust since the identities of buyer and seller remain hidden.

G. Functional Requirements

Sqlite3 Database
The database storage will be controlled and maintained by the website administrator. It will include data pertaining to list of buyers and sellers, profile information of buyers and sellers, list of categories and products. The administrator has the rights to add/remove categories, products, buyers and sellers.

H. Non-Functional Requirements

Security Features

i. Entity Authentication – Since SCEP curve is used, it finds a point on the curve which ensures identity authentication and verification. This process is carried out by the server in case of both buyer and seller authentication thereby ensuring entity authentication.

ii. Anonymity – The clients i.e., buyer and seller generate a new value which is computed based on the token received from the server and SHA256 encrypted data. This value will act as an id for carrying out transactions over the web interface. Thus, the identity of the clients remains hidden thereby ensuring anonymity.

I. Software Quality Features

i. Availability: The data pertaining to the products must be available on the website in order to provide a seamless experience to the buyers.

ii. Correctness: The data about different products offered by sellers for auction must be correct such as the price of the product.

iii. Maintainability: The data pertaining to the website such as user's data, product data etc. must be properly maintained by the website administrator in a database.

iv. Usability: The website must be user-friendly and interactive for both buyers and sellers.

V. SYSTEM DESIGN

A. The website will comprise of the following webpages:
   i. Home page.
   ii. Products page.
   iii. Categories page.
   iv. Registration page.
   v. Login page.

B. The home page will provide a user-friendly and interactive user interface which will enlist the top products and categories available for auction.

C. The products page is used to enlist the latest products offered by the sellers for auction. The product information such as category, no. of bids, highest bid, total no. of hours available for auction can be viewed.

D. The categories page is used to enlist the different categories available for buyers to participate in auction. The selection of a particular category will result in the display of different products. The selection of a particular product in a category will provide product information such as highest bid, product description, total no. of hours available for auction as well as the option to participate in the auction.

E. The registration page is used for registering the information of users i.e., buyers and sellers on the website. The details provided by the users will be used to ensure anonymity by encapsulating them to generate a random anonymous id. This anonymous id ensures entity authentication by which the users can participate in the bidding process securely without revealing their profile information.

F. The login page is used for logging into the user account using his credentials. Once logged in the user can view the different products/categories available on the website. Each user can also view the dashboard. In case of buyer the list of bids for different products can be viewed. In case of seller the different products which are added for auction can be viewed.

G. Once a user i.e., buyer or seller registers their information with the website the ZKP protocol is used to ensure entity authentication and anonymity.

H. User anonymity is ensured by encapsulating the users profile information to generate a random anonymous id. When the buyer bids for a particular product or when the seller adds a new product for auction a random transaction id gets generated which is secured using ZKP protocol thereby ensuring entity authentication.

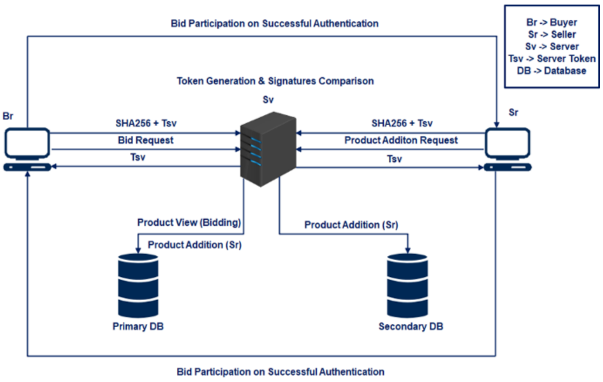


Fig 1. Online Auction System Design

VI. IMPLEMENTATION AND PSEUDOCODE

A. Algorithm

Step 1: Service Request

The client sends a request to the server for participation in an online transaction. In case of an online auction, the clients i.e., buyer and seller send a request to the server. In case of the buyer, the request refers to a bid request for participation in the online auction. In case of the seller, the request refers to addition of a new product in the database.

Step 2: Server Token Generation

The server generates a SHA256 value and a token for the clients which is used for authentication. The server sends the token to its clients respectively.

Step 3: Client Token Generation

The clients i.e., buyer and seller generate a token for its seedphrase or password which is encrypted using SHA256 along with the profile of buyer and seller respectively. This newly computed value is sent to the server for authentication. This value will act as an id for both the clients in order to carry out secure online auction.

Step 4: Client Token & Server Token Computation

The server receives the newly computed value from the clients respectively. The server has its own signature (SHA256 value and token) which is used for comparison with the newly computed value sent by the clients.

Step 5: Server Verification of Client Signature

If the server's signature and client's signature get matched thus the authentication will become successful. Therefore, the buyer can participate in the online auctions since server has ensured buyer's authentication to the seller. The seller can also participate in transaction communication since the server ensures seller's authentication to the buyer. This helps to ensure entity authentication and anonymity. It also allows the seller to add a new product to the database since he/she is an authenticated seller.

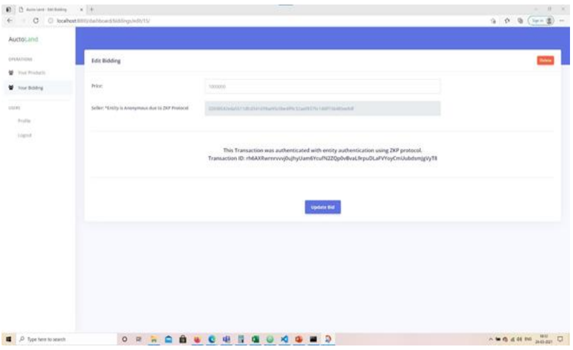
B. Pseudocode

```
customer_hash = get_customer_details() # Customer Hash      Value
seed_value = generate_random_seed() # Any Random Number
final_server_value = sha(customer_hash + seed_value)
if(final_server_value == received_value)
        transaction is authentic
else
        transaction is a failure
```

VII. PROJECT DEMONSTRATION

A. Entity Authentication

i. Buyer



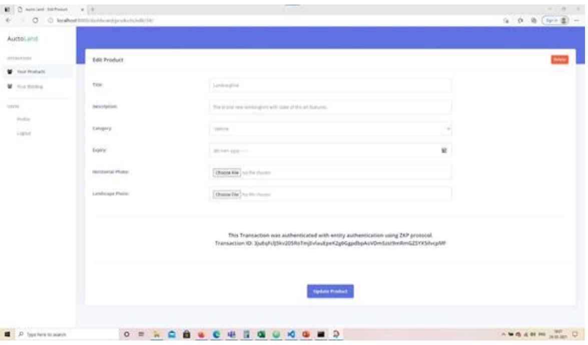
Edit Bidding

Price: 1000000

Seller: *Entity is Anonymous due to ZKP Protocol

This Transaction was authenticated with entity authentication using ZKP protocol.
Transaction ID: rh6AXRwrnrvvvj0ujhyUam6YcufN2ZQp0vBvaL9rpuDLaFVYoyCmUubdumjgVyT8

ii. Seller



AuctoLand

Edit Product

Title:

Description:

Category:

Expiry:

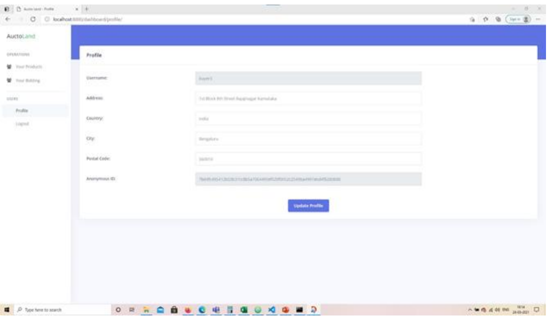
Horizontal Photo: Choose File

Landscape Photo: Choose File

This Transaction was authenticated with entity authentication using ZKP protocol.
Transaction ID: [illegible]

B. User Anonymity

i. Buyer



AuctoLand

Profile

Username:

Address:

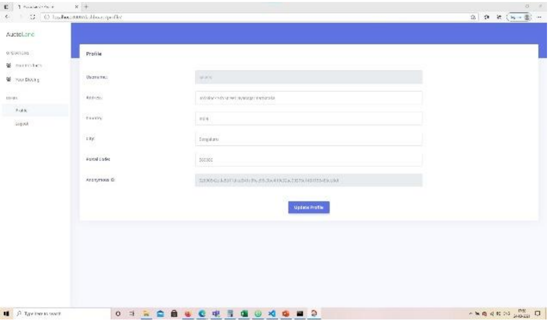
Country: India

City: Bengaluru

Postal Code:

Anonymous ID: [illegible]

ii. Seller



AuctoLand

Profile

Username:

Address:

Country:

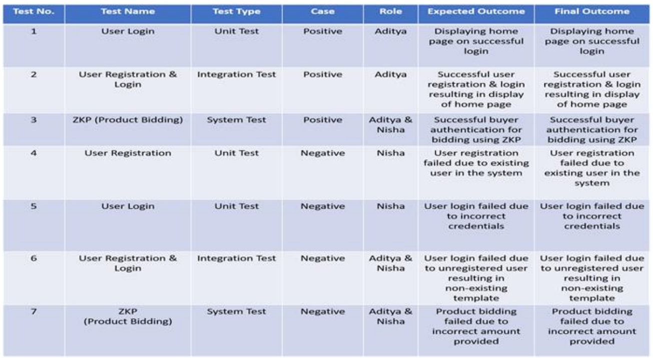
City:

Postal Code:

Anonymous ID: [illegible]

VIII. TEST PLAN AND STRATEGY

UI-licious Testing Tool
UI-licious software testing tool can monitor the application for defaults so that the clients using the software can rectify
those defaults and launch their application faster.
UI-licious can be used on any front-end applications and supports all major browsers, such as Chrome, Firefox, Safari and Internet Explorer.

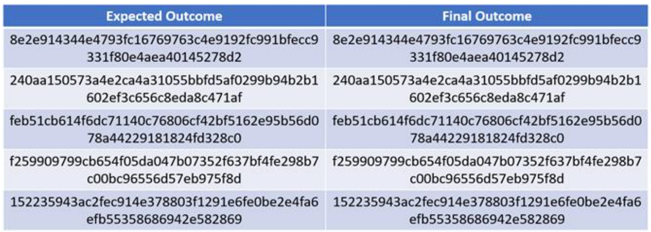


Test No.	Test Name	Test Type	Case	Role	Expected Outcome	Final Outcome
1	User Login	Unit Test	Positive	Aditya	Displaying home page on successful login	Displaying home page on successful login
2	User Registration & Login	Integration Test	Positive	Aditya	Successful user registration & login resulting in display of home page	Successful user registration & login resulting in display of home page
3	ZKP (Product Bidding)	System Test	Positive	Aditya & Nisha	Successful buyer authentication for bidding using ZKP	Successful buyer authentication for bidding using ZKP
4	User Registration	Unit Test	Negative	Nisha	User registration failed due to existing user in the system	User registration failed due to existing user in the system
5	User Login	Unit Test	Negative	Nisha	User login failed due to incorrect credentials	User login failed due to incorrect credentials
6	User Registration & Login	Integration Test	Negative	Aditya & Nisha	User login failed due to unregistered user resulting in non-existing template	User login failed due to unregistered user resulting in non-existing template
7	ZKP (Product Bidding)	System Test	Negative	Aditya & Nisha	Product bidding failed due to incorrect amount provided	Product bidding failed due to incorrect amount provided

IX. RESULTS AND DISCUSSION

i. The user's details are obtained via a registration form. These details are encrypted using a hashing algorithm to generate a hash value. A random seed value (token) is generated by the server. The server's signature is obtained by generating a hash value using the server's token and the user's hash value.

ii. The user generates its own signature by using the token received from the server along with the hash value of the seed phrase to generate a new hash value. The user and server signatures are compared. If the signatures match the user is allowed to participate in the bidding otherwise their request is discarded.



Expected Outcome	Final Outcome
8e2e914344e4793fc16769763c4e9192fc991bfecc9331f80e4aea40145278d2	8e2e914344e4793fc16769763c4e9192fc991bfecc9331f80e4aea40145278d2
240aa150573a4e2ca4a31055bbfd5af0299b94b2b1602ef3c656c8eda8c471af	240aa150573a4e2ca4a31055bbfd5af0299b94b2b1602ef3c656c8eda8c471af
feb51cb614f6dc71140c76806cf42bf5162e95b56d078a44229181824fd328c0	feb51cb614f6dc71140c76806cf42bf5162e95b56d078a44229181824fd328c0
f259909799cb654f05da047b07352f637bf4fe298b7c00bc96556d57eb975f8d	f259909799cb654f05da047b07352f637bf4fe298b7c00bc96556d57eb975f8d
152235943ac2fec914e378803f1291e6fe0be2e4fa6efb55358686942e582869	152235943ac2fec914e378803f1291e6fe0be2e4fa6efb55358686942e582869

iii. Novelty of the Project

The novelty of our project lies in Zero Knowledge Proof (ZKP) which is achieved using entity authentication and user anonymity. The random anonymous id generated using the users profile information provided during the registration process is used to ensure anonymity by which the users can engage in online auction without revealing their profile information. The entity authentication is ensured using a randomly generated transaction id which verifies the user's identity participating in online auction.

X. CONCLUSION AND FUTURE WORK

The sole purpose of our project is to ensure secure bidding in an online platform. The front end is a user-friendly and interactive website which provides the users i.e., buyers and sellers accessing the website a seamless experience. The presence of a database makes it easier to control and maintain the data by the website administrator in order to ensure data security and availability.

Zero Knowledge Proof (ZKP) protocol using SCEP curve is implemented in order to ensure secure online auctions. Simple Certified Enrollment Protocol (SCEP) is a curve which follows a client-server model where multiple clients participate in online auctions based on the server authentication of these clients. SCEP curve is used to ensure entity authentication and anonymity.

The various types of testing such as unit, integration and system testing for both positive and negative cases help to determine the system functionality.

Identity verification is the future work that can be done on ZKP based online auctions. Currently, anonymity is maintained on the basis of user's profile information in the form of a hash value, however, the user's profile is not verified for the details provided by the user.

XI. Abbreviations and Acronyms

Abbreviations/Acronyms	Definitions
ZKP	It is a protocol in which one party proves authenticity of knowledge to another party without revealing the essential information.
Simple Certified Enrollment Protocol (SCEP)	Simple Certified Enrollment Protocol (SCEP) is a curve which follows a client-server model where multiple clients participate in online auctions based on the server authentication.
SHA256	SHA-256 is one of the successor hash functions to SHA-1 and is one of the strongest hash functions. It is computed with 64-bit words.

Figures and Tables

TABLE I. LIST OF FIGURES

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