

A Secure And Dynamic Multi-Keyword Ranked Search Scheme Over Encrypted Data

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Abstract: Due to the increasing popularity of cloud computing, more and more data owners are motivated to outsource their data to cloud servers for great convenience and reduced cost in data management. However, sensitive data should be encrypted before outsourcing for privacy requirements, which obsoletes data utilization like keyword-based document retrieval. In this paper, we present a secure multi-keyword ranked search scheme over encrypted cloud data, which simultaneously supports dynamic update operations like deletion and insertion of documents. Specifically, the vector space model and the widely-used TF_IDF model are combined in the index construction and query generation. We construct a special tree-based index structure and propose a “Greedy Depth-first Search” algorithm to provide efficient multi-keyword ranked search. The secure kNN algorithm is utilized to encrypt the index and query vectors, and meanwhile ensure accurate relevance score calculation between encrypted index and query vectors. In order to resist statistical attacks, phantom terms are added to the index vector for blinding search results. Due to the use of our special tree-based index structure, the proposed scheme can achieve sub-linear search time and deal with the deletion and insertion of documents flexibly. Extensive experiments are conducted to demonstrate the efficiency of the proposed scheme.

Index Terms: Searchable encryption, multi-keyword ranked search, dynamic update, cloud computing.

I. INTRODUCTION

CLOUD computing has been considered as a new model of enterprise IT infrastructure, which can organize huge resource of computing, storage and applications, and enable users to enjoy ubiquitous, convenient and on-demand network access to a shared pool of configurable computing resources with great efficiency and minimal economic overhead [1]. Attracted by these appealing features, both individuals and enterprises are motivated to outsource their data to the cloud,

instead of purchasing software and hardware to manage the data themselves.

Despite of the various advantages of cloud services, outsourcing sensitive information (such as e-mails, personal health records, company finance data, government documents, etc.) to remote servers brings privacy concerns. The cloud service providers (CSPs) that keep the data for users may access users' sensitive information without authorization.

A general approach to protect the data confidentiality is to encrypt the data before outsourcing [2]. However, this will cause a huge cost in terms of data usability. For example, the

existing techniques on keyword-based information retrieval, which are widely used on the plaintext data, cannot be directly applied on the encrypted data. Downloading all the data from the cloud and decrypt locally is obviously impractical. In order to address the above problem, researchers have designed some general-purpose solutions with fully homomorphic encryption [3] or oblivious RAMs [4].

However, these methods are not practical due to their high computational overhead for both the cloud server and user. On the contrary, more practical special purpose solutions, such as searchable encryption (SE) schemes have made specific contributions in terms of efficiency, functionality and security. Searchable encryption schemes enable the client to store the encrypted data to the cloud and execute keyword search over ciphertext domain.

So far, abundant works have been proposed under different threat models to achieve various search functionality, such as single keyword search, similarity search, multi-keyword boolean search, ranked search, multi-keyword ranked search, etc. Among them, multikeyword ranked search achieves more and more attention for its practical applicability.

Recently, some *dynamic* schemes have been proposed to support inserting and deleting operations on document collection. These are significant works as it is highly possible that the data owners need to update their data on the cloud server. But few of the dynamic schemes support efficient multikeyword ranked search.

This paper proposes a secure tree-based search scheme over the encrypted cloud data, which supports multikeyword ranked search and dynamic operation on the document collection. Specifically, the vector space model and the widely-used “term frequency (TF) \times inverse document frequency (IDF)” model are combined in the index construction and query generation to provide multikeyword ranked search. In order to obtain high search efficiency, we construct a tree-based index structure and propose a “Greedy Depth-first Search” algorithm based on this index tree. Due to the special structure of our tree-based index, the proposed search scheme can flexibly achieve sub-linear search time and deal with the deletion and insertion of documents. The secure kNN algorithm is utilized to encrypt the index and query vectors, and meanwhile ensure accurate relevance score calculation between encrypted index and query vectors. To resist different attacks in different threat models, we construct two secure search schemes: the basic dynamic multi-keyword ranked search (BDMRS) scheme in the known ciphertext model, and the enhanced dynamic multi-keyword ranked search (EDMRS) scheme in the known background model. Our contributions are summarized as follows:

- ✓ We design a searchable encryption scheme that supports both the accurate multi-keyword ranked search and flexible dynamic operation on document collection.
- ✓ Due to the special structure of our tree-based index, the search complexity of the proposed scheme is fundamentally kept to logarithmic. And in practice, the proposed scheme can achieve higher search efficiency by executing our “Greedy Depth-first

Search” algorithm. Moreover, parallel search can be flexibly performed to further reduce the time cost of search process.

II. LITERATURE REVIEW & RELATED WORK

Searchable encryption schemes enable the clients to store the encrypted data to the cloud and execute keyword search over ciphertext domain. Due to different cryptography primitives, searchable encryption schemes can be constructed using public key based cryptography [5], [6] or symmetric key based cryptography [7], [8]. Song *et al.* [7] proposed the first symmetric searchable encryption (SSE) scheme, and the search time of their scheme is linear to the size of the data collection. Goh [8] proposed formal security definitions for SSE and designed a scheme based on Bloom filter. The search time of Goh’s scheme is $O(n)$, where n is the cardinality of the document collection. Curtmola *et al.* proposed two schemes (SSE-1 and SSE-2) which achieve the optimal search time. Their SSE-1 scheme is secure against chosen-keyword attacks (CKA1) and SSE-2 is secure against adaptive chosen-keyword attacks (CKA2). These early works are single keyword boolean search schemes, which are very simple in terms of functionality.

Afterward, abundant works have been proposed under different threat models to achieve various search functionality, such as single keyword search, similarity search, multi-keyword boolean search ranked search and multi-keyword ranked search etc. Multi-keyword boolean search allows the users to input multiple query keywords to request suitable documents. Among these works, conjunctive keyword search schemes only return the documents that contain all of the query keywords.

Disjunctive keyword search schemes return all of the documents that contain a subset of the query keywords. Predicate search schemes are proposed to support both conjunctive and disjunctive search. All these multikeyword search schemes retrieve search results based on the existence of keywords, which cannot provide acceptable result ranking functionality. Ranked search can enable quick search of the most relevant data. Sending back only the top- k most relevant documents can effectively decrease network traffic.

Some early works have realized the ranked search using order-preserving techniques, but they are designed only for single keyword search. Cao *et al.* realized the first privacy-preserving multi-keyword ranked search scheme, in which documents and queries are represented as vectors of dictionary size. With the “coordinate matching”, the documents are ranked according to the number of matched query keywords.

However, Cao *et al.*’s scheme does not consider the importance of the different keywords, and thus is not accurate enough. In addition, the search efficiency of the scheme is linear with the cardinality of document collection. Sun *et al.* presented a secure multi-keyword search scheme that supports similarity-based ranking. The authors constructed a searchable index tree based on vector space model and adopted cosine measure together with TF \times IDF to provide ranking results. Sun *et al.*’s search algorithm achieves better-than-linear search efficiency but results in precision loss. O’rencik *et al.* [28]

proposed a secure multi-keyword search method which utilized local sensitive hash (LSH) functions to cluster the similar documents. The LSH algorithm is suitable for similar search but cannot provide exact ranking. In Zhang *et al.* proposed a scheme to deal with secure multi-keyword ranked search in a multi-owner model. In this scheme, different data owners use different secret keys to encrypt their documents and keywords while authorized data users can query without knowing keys of these different data owners. The authors proposed an “Additive Order Preserving Function” to retrieve the most relevant search results. However, these works don’t support dynamic operations.

Practically, the data owner may need to update the document collection after he uploads the collection to the cloud server. Thus, the SE schemes are expected to support the insertion and deletion of the documents. There are also several dynamic searchable encryption schemes. In the work of Song *et al.* [7], the each document is considered as a sequence of fixed length words, and is individually indexed. This scheme supports straightforward update operations but with low efficiency. Goh [8] proposed a scheme to generate a sub-index (Bloom filter) for every document based on keywords. Then the dynamic operations can be easily realized through updating of a Bloom filter along with the corresponding document. However, Goh’s scheme has linear search time and suffers from false positives.

In 2012, Kamara constructed an encrypted inverted index that can handle dynamic data efficiently. But, this scheme is very complex to implement. Subsequently, as an improvement, Kamara proposed a new search scheme based on tree-based index, which can handle dynamic update on document data stored in leaf nodes. However, their scheme is designed only for single keyword Boolean search. In a data structure for keyword/identity tuple named “TSet”. Then, a document can be represented by a series of independent T-Sets. Based on this structure, proposed a dynamic searchable encryption scheme. In their construction, newly added tuples are stored in another database in the cloud, and deleted tuples are recorded in a revocation list. The final search result is achieved through excluding tuples in the revocation list from the ones retrieved from original and newly added tuples. Yet dynamic search scheme doesn’t realize the multi-keyword ranked search functionality.

III. PROPOSED WORK AND OBJECTIVES

A general approach to protect the data confidentiality is to encrypt the data before outsourcing. Searchable encryption schemes enable the client to store the encrypted data to the cloud and execute keyword search over ciphertext domain. So far, abundant works have been proposed under different threat models to achieve various search functionality, such as single keyword search, similarity search, multi-keyword boolean search, ranked search, multi-keyword ranked search, etc. Among them, multi-keyword ranked search achieves more and more attention for its practical applicability. Recently, some *dynamic* schemes have been proposed to support inserting and deleting operations on document collection. These are

significant works as it is highly possible that the data owners need to update their data on the cloud server.

Huge cost in terms of data usability. For example, the existing techniques on keyword-based information retrieval, which are widely used on the plaintext data, cannot be directly applied on the encrypted data. Downloading all the data from the cloud and decrypt locally is obviously impractical. This paper proposes a secure tree-based search scheme over the encrypted cloud data, which supports multi-keyword ranked search and dynamic operation on the document collection. Specifically, the vector space model and the widely-used “term frequency (TF) \times inverse document frequency (IDF)” model are combined in the index construction and query generation to provide multi-keyword ranked search. In order to obtain high search efficiency, we construct a tree-based index structure and propose a “Greedy Depth-first Search” algorithm based on this index tree.

The secure kNN algorithm is utilized to encrypt the index and query vectors, and meanwhile ensure accurate relevance score calculation between encrypted index and query vectors.

To resist different attacks in different threat models, we construct two secure search schemes: the basic dynamic multi-keyword ranked search (BDMRS) scheme in the known ciphertext model, and the enhanced dynamic multi-keyword ranked search (EDMRS) scheme in the known background model.

Due to the special structure of our tree-based index, the proposed search scheme can flexibly achieve sub-linear search time and deal with the deletion and insertion of documents. We design a searchable encryption scheme that supports both the accurate multi-keyword ranked search and flexible dynamic operation on document collection. Due to the special structure of our tree-based index, the search complexity of the proposed scheme is fundamentally kept to logarithmic. And in practice, the proposed scheme can achieve higher search efficiency by executing our “Greedy Depth-first Search”

IV. CONCLUSION

In this paper, a secure, efficient and dynamic search scheme is proposed, which supports not only the accurate multi-keyword ranked search but also the dynamic deletion and insertion of documents. We construct a special keyword balanced binary tree as the index, and propose a “Greedy Depth-first Search” algorithm to obtain better efficiency than linear search. In addition, the parallel search process can be carried out to further reduce the time cost. The security of the scheme is protected against two threat models by using the secure kNN algorithm. Experimental results demonstrate the efficiency of our proposed scheme. There are still many challenge problems in symmetric SE schemes. In the proposed scheme, the data owner is responsible for generating updating information and sending them to the cloud server. Thus, the data owner needs to store the unencrypted index tree and the information that are necessary to recalculate the IDF values. Such an active data owner may not be very suitable for the cloud computing model.

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