Secure Data Retrieval Scheme Using CP-ABE Scheme for Decentralized Disruption-Tolerant Military Networks

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Abstract — The basic idea behind DTN network is that endpoints aren't always continuously connected. In order to facilitate data transfer, DTN uses a store-and-forward approach across routers that are more disruption-tolerant than TCP/IP. However, the DTN approach doesn't necessarily mean that all DTN routers on a network would require large storage capacity in order to maintain end-to-end data integrity.Mobile nodes in military environments such as a battlefield or a hostile region are likely to suffer from intermittent network connectivity and frequent partitions. Disruption-tolerant network (DTN) technologies are becoming successful solutions that allow wireless devices carried by soldiers to communicate with each other and access the confidential information or command reliably by exploiting external storage nodes. Some of the most challenging issues in this scenario are the enforcement of authorization policies and the policies update for secure data retrieval. Ciphertext-policy attribute-based encryption (CP-ABE) is a promising cryptographic solution to the access control issues. However, the problem of applying CP-ABE in decentralized DTNs introduces several security and privacy challenges with regard to the attribute revocation, key escrow, and coordination of attributes issued from different authorities. In this paper, we propose a secure data retrieval scheme using CP-ABE for decentralized DTNs where multiple key authorities manage their attributes independently. We demonstrate how to apply the proposed mechanism to securely and efficiently manage the confidential data distributed in the disruption-tolerant military network.

Keywords —Access control, attribute-based encryption (ABE), disruption-tolerant network (DTN), multiauthority, secure data retrieval.

I. INTRODUCTION

DISRUPTION Tolerant Networks are frequently used in disaster relief missions, peace-keeping missions, and in vehicular networks. Most recently NASA has tested DTN technology for spacecraft communications. In many military network scenarios, connections of wireless devices carried by soldiers may be temporarily disconnected by jamming, environmental factors, and mobility, especially when they operate in hostile environments. Disruption-tolerant network (DTN) technologies are becoming successful solutions that allow nodes to communicate with each other in these extreme networking environments [1]–[3]. Typically, when there is no end-to-end connection between a source and a destination pair, the messages from the source node may need to wait in the intermediate nodes for a substantial amount of time until the connection would be eventually established.

Roy [4] and Chuah [5] introduced storage nodes in DTNs where data is stored or replicated such that only authorized mobile nodes can access the necessary information quickly and efficiently. Many military applications require increased protection of confidential data including access control methods that are cryptographically enforced [6], [7]. In many cases, it is desirable to provide differentiated access services such that data access policies are defined over user attributes or roles, which are managed by the key authorities. For example, in a disruption-tolerant military network, a commander may store confidential information at a storage node, which should be accessed by members of “Battalion 1” who are participating in “Region 2.” In this case, it is a reasonable assumption that multiple key authorities are likely to manage their own dynamic attributes for soldiers in their deployed regions or echelons, which could be frequently changed (e.g., the attribute representing current location of moving soldiers) [4], [8], [9]. We refer to this DTN architecture where multiple authorities issue and manage their own attribute keys independently as a decentralized DTN [10].

The concept of attribute-based encryption (ABE) [11]–[14] is a promising approach that fulfills the requirements for secure data retrieval in DTNs. ABE features a mechanism that enables an access control over encrypted data using access policies and ascribed attributes among private keys and ciphertexts. Especially, ciphertext-policy ABE (CP-ABE) provides a scalable way of encrypting data such that the encryptor defines the attribute set that the decryptor needs to possess in order to decrypt the ciphertext [13]. Thus, different users are allowed to decrypt different pieces of data per the security policy. However, the problem of applying the ABE to DTNs introduces several security and privacy challenges. Since some users may change their associated attributes at some point (for example, moving their region), or some private keys might be compromised, key revocation (or update) for each attribute is necessary in order to make systems secure. However, this issue is even more difficult, especially in ABE systems, since each attribute is conceivably shared by multiple users (henceforth, we refer to such a collection of users as an attribute group). This implies that revocation of any attribute or any single user in an attribute group would affect the other users in the group. For example, if a user joins or leaves an attribute group, the associated attribute key should be changed and redistributed to all the other members in the same group for backward or forward secrecy. It may result in bottleneck during rekeying procedure or security degradation due to the windows of vulnerability if the previous attribute key is not updated immediately. Another challenge is the key escrow problem. In CP-ABE, the key authority generates private keys of users by applying the authority’s master secret keys to users’ associated set of attributes. Thus, the key authority can decrypt every ciphertext addressed to specific users by generating their attribute keys. If the key authority is compromised by adversaries when deployed in the hostile environments, this could be a potential threat to the data confidentiality or privacy especially when the data is highly sensitive. The key escrow is an inherent problem even in the multiple-authority systems as long as each key authority has the whole privilege to generate their own attribute keys with their own master secrets. Since such a key generation mechanism based on the singlemaster secret is the basic method for most of the asymmetric encryption systems such as the attribute- based or identity-based encryption protocols, removing escrow in single or multiple-authority CP-ABE is a pivotal open problem.

II. PROBLEM STATEMENT

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mechanism that enables an access control over encrypted data using access policies and ascribed attributes among private keys and ciphertexts. Especially, ciphertext-policy ABE (CP-ABE) provides a scalable way of encrypting data such that the encryptor defines the attribute set that the decryptor needs to possess in order to decrypt the ciphertext. Thus, different users are allowed to decrypt different pieces of data per the security policy. The problem of applying the ABE to DTNs introduces several security and privacy challenges. Since some users may change their associated attributes at some point (for example, moving their region), or some private keys might be compromised, key revocation (or update) for each attribute is necessary in order to make systems secure.
However, this issue is even more difficult, especially in ABE systems, since each attribute is conceivably shared by multiple users (henceforth, we refer to such a collection of users as an attribute group) Another challenge is the key escrow problem. In CP-ABE, the key authority generates private keys of users by applying the authority's master secret keys to users' associated set of attributes. The last challenge is the coordination of attributes issued from different authorities. When multiple authorities manage and issue attributes keys to users independently with their own master secrets, it is very hard to define fine-grained access policies over attributes issued from different authorities.

III. RELATED WORK

ABE comes in two flavors called key-policy ABE (KP-ABE) and ciphertext-policy ABE (CP-ABE). In KP-ABE, the encryptor only gets to label a ciphertext with a set of attributes. The key authority chooses a policy for each user that determines which ciphertexts he can decrypt and issues the key to each user by embedding the policy into the user's key. However, the roles of the ciphertexts and keys are reversed in CP-ABE. In CP-ABE, the ciphertext is encrypted with an access policy chosen by an encryptor, but a key is simply created with respect to an attributes set. CP-ABE is more appropriate to DTNs than KP-ABE because it enables encryptors such as a commander to choose an access policy on attributes and to encrypt confidential data under the access structure via encrypting with the corresponding public keys or attributes [4], [7], [15].

1) Attribute Revocation: Bethencourt et al. [13] and Boldyreva et al. [16] first suggested key revocation mechanisms in CP-ABE and KP-ABE, respectively. Their solutions are to append to each attribute an expiration date (or time) and distribute a new set of keys to valid users after the expiration. The periodic attribute revocable ABE schemes [8], [13], [16], [17] have two main problems. The first problem is the security degradation in terms of the backward and forward secrecy [18]. It is a considerable scenario that users such as soldiers may change their attributes frequently, e.g., position or location move when considering these as attributes [4], [9]. Then, a user who newly holds the attribute might be able to access the previous data encrypted before he obtains the attribute until the data is reencrypted with the newly updated attribute keys by periodic rekeying (backward secrecy). For example, assume that at time, a ciphertext is encrypted with a policy that can be decrypted with a set of attributes (embedded in the users' keys) for users with. After time, say, a user newly holds the attribute set. Even if the new user should be disallowed to decrypt the ciphertext for the time instance, he can still decrypt the previous ciphertext until it is reencrypted with the newly updated attribute keys. On the other hand, a revoked user would still be able to access the encrypted data even if he does not hold the attribute any more until the next expiration time (forward secrecy). For

example, when a user is disqualified with the attribute at time, he can still decrypt the ciphertext of the previous time instance unless the key of the user is expired and the ciphertext is reencrypted with the newly updated key that the user cannot obtain. We call this uncontrolled period of time windows of vulnerability.

The other is the scalability problem. The key authority periodically announces a key update material by unicast at each time-slot so that all of the nonrevoked users can update their keys. This results in the "1-affects-" problem, which means that the update of a single attribute affects thewhole nonrevoked users who share the attribute [9]. This could be a bottleneck for both the key authority and all nonrevoked users.

The immediate key revocation can be done by revoking users using ABE that supports negative clauses [4], [14]. To do so, one just adds conjunctively the AND of negation of revoked user identities (where each is considered as an attribute here). However, this solution still somewhat lacks efficiency performance. This scheme will pose overhead group elements1 additively to the size of the ciphertext and multiplicatively to the size of private key over the original CP-ABE scheme of Bethencourt et al. [13], where is the maximum size of revoked attributes set. Golle et al. [10] also proposed a user revocable KP-ABE scheme, but their scheme only works when the number of attributes associated with a ciphertext is exactly half of the universe size.

2) Key Escrow: Most of the existing ABE schemes are constructed on the architecture where a single trusted authority has the power to generate the whole private keys of users with its master secret information [11], [13], [14], [2]–[3]. Thus, the key escrow problem is inherent such that the key authority can decrypt every ciphertext addressed to users in the system by generating their secret keys at any time. Chase et al. [4] presented a distributed KP-ABE scheme that solves the key escrow problem in a multiauthority system. In this approach, all (disjoint) attribute authorities are participating in the key generation protocol in a distributed way such that they cannot pool their data and link multiple attribute sets belonging to the same user. One disadvantage of this fully distributed approach is the performance degradation. Since there is no centralized authority with master secret information, all attribute authorities should communicate with each other in the system to generate a user's secret key. This results in communication overhead on the system setup and the rekeying phases and requires each user to store additional auxiliary key components besides the attributes keys, where is the number of authorities in the system.

3) Decentralized ABE: Huang *et al.* [9] and Roy *et al.* [4] proposed decentralized CP-ABE schemes in the multiauthority network environment. They achieved a combined access policy over the attributes issued from different authorities by simply encrypting data multiple times. The main disadvantages of this approach are efficiency and expressiveness of access policy. For example, when a commander encrypts a secret mission to soldiers under the policy ("Battalion 1" AND ("Region 2" OR 'Region 3")), it cannot be expressed when each "Region" attribute is managed by different authorities, since simply multiencrypting approaches can by no means express any general "n - out-of-m " logics (e.g., OR, that is 1-out-of-). For example, let be the key authorities, and be attributes sets they independently manage, respectively. Then, the only access policy expressed with is, which can be achieved by encrypting a message with by, and then encrypting the resulting ciphertext with by (where is the ciphertext encrypted under), and then encrypting resulting ciphertext with by, and so on, until this multiencryption generates the final ciphertext. Thus, the access logic should be only AND, and they require iterative encryption operations where is the number of attribute authorities. Therefore, they are somewhat restricted in terms of expressiveness of the access policy and require computation and storage costs. Chase [15] and Lewko *et al.* [10] proposed multiauthority KP-ABE and CP-ABE schemes, respectively. However, their schemes also suffer from the key escrow problem like the prior decentralized schemes.

In this paper, we propose an attribute-based secure data retrieval scheme using CP-ABE for decentralized DTNs. The proposed scheme features the following achievements. First, immediate attribute revocation enhances backward/forward secrecy of confidential data by reducing the windows of vulnerability. Second, encryptors can define a fine-grained access policy using any monotone access structure under attributes issued from any chosen set of authorities. Third, the key escrow problem is resolved by an escrow-free key issuing protocol that exploits the characteristic of the decentralized DTN architecture. The key issuing protocol generates and issues user secret keys by performing a secure two-party computation (2PC) protocol among the key authorities with their own master secrets. The 2PC protocol deters the key authorities from obtaining any master secret information of each other such that none of them could generate the whole set of user keys alone. Thus, users are not required to fully trust the authorities in order to protect their data to be shared. The data confidentiality and privacy can be cryptographically enforced against any curious key authorities or data storage nodes in the proposed scheme. we describe the DTN architecture

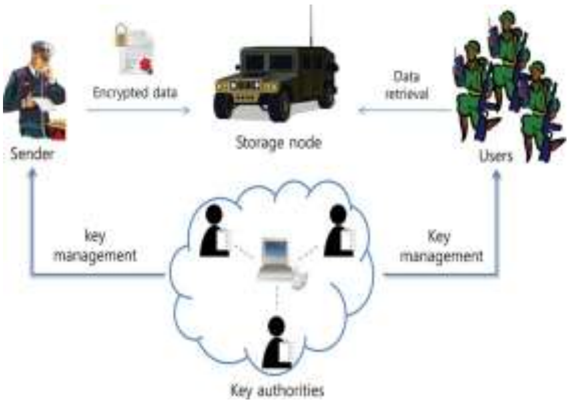


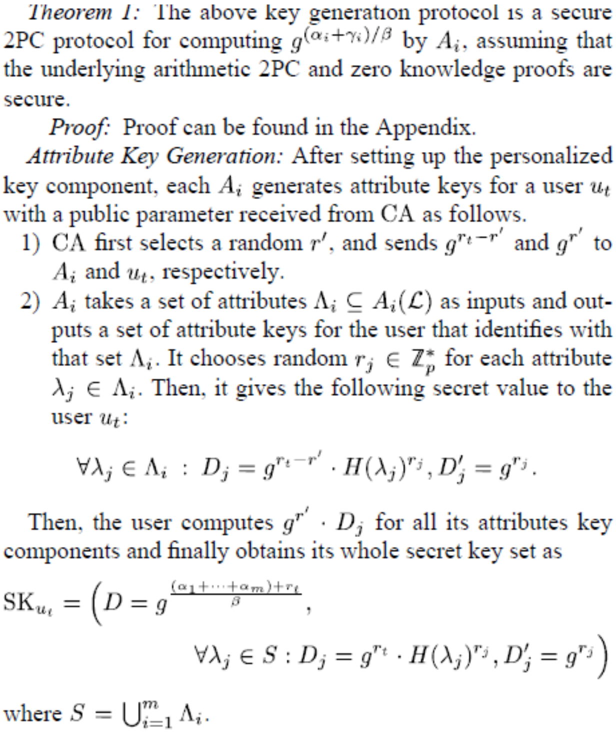
Fig. 1. Architecture of secure data retrieval in a disruption-tolerant military
network.

Fig. 1 shows the architecture of the DTN. As shown in Fig. 1,
the architecture consists of the following system entities.

1) Key Authorities: They are key generation centers that generate public/secret parameters for CP-ABE. The key authorities consist of a central authority and multiple local authorities. We assume that there are secure and reliable communication channels between a central authority and each local authority during the initial key setup and generation phase. Each local authority manages different attributes and issues corresponding attribute keys to users. They grant differential access rights to individual users based on the users ‘attributes. The key authorities are assumed to be honest-but-curious. That is, they will honestly execute the assigned tasks in the system; however they would like to learn information of encrypted contents as much as possible. 2) Storage node: This is an entity that stores data from senders and provide corresponding access to users. It may be mobile or static [4], [5]. Similar to the previous schemes, we also assume the storage node to be semitrusted that is honest-but-curious. 3) Sender: This is an entity who owns confidential messages or data (e.g., a commander) and wishes to store them into the external

data storage node for ease of sharing or for reliable delivery to users in the extreme networking environments. A sender is responsible for defining (attributebased) access policy and enforcing it on its own data by encrypting the data under the policy before storing it to the storage node. 4) User: This is a mobile node who wants to access the data stored at the storage node (e.g., a soldier). If a user possesses a set of attributes satisfying the access policy of the encrypted data defined by the sender, and is not revoked in any of the attributes, then he will be able to decrypt the ciphertext and obtain the data. Since the key authorities are semi-trusted, they should be deterred from accessing plaintext of the data in the storage node; meanwhile, they should be still able to issue secret keys to users. In order to realize this somewhat contradictory requirement, the central authority and the local authorities engage in the arithmetic 2PC protocol with master secret keys of their own and issue independent key components to users during the key issuing phase. The 2PC protocol prevents them from knowing each other's master secrets so that none of them can generate the whole set of secret keys of users individually. Thus, we take an assumption that the central authority does not collude with the local authorities (otherwise, they can guess the secret keys of every user by sharing their master secrets). In this section, we provide a multiauthority CP-ABE scheme for secure data retrieval in decentralized DTNs. Each local authority issues partial personalized and attribute key components to a user by performing secure 2PC protocol with the central authority. Each attribute key of a user can be updated individually and immediately. Thus, the scalability and security can be enhanced in the proposed scheme.

During the key generation phase using the 2PC protocol, the proposed scheme (especially 2PC protocol) requires messages additively to the key issuing overhead in the previous multiauthority ABE schemes in terms of the communication cost, where is number of key authorities the user is associated with, and is the bit size of an element in. However, it is important to note that the 2PC protocol is done only once during the initial key generation phase for each user.



Theorem 1: The above key generation protocol is a secure 2PC protocol for computing $g^{(\alpha_i+\gamma_i)/\beta}$ by A_i, assuming that the underlying arithmetic 2PC and zero knowledge proofs are secure.

Proof: Proof can be found in the Appendix.

Attribute Key Generation: After setting up the personalized key component, each A_i generates attribute keys for a user u_t with a public parameter received from CA as follows.

1) CA first selects a random r', and sends $g^{r_t-r'}$ and $g^{r'}$ to A_i and u_t, respectively.
2) A_i takes a set of attributes $\Lambda_i \subseteq A_i(\mathcal{L})$ as inputs and outputs a set of attribute keys for the user that identifies with that set Λ_i. It chooses random $r_j \in \mathbb{Z}_p^*$ for each attribute $\lambda_j \in \Lambda_i$. Then, it gives the following secret value to the user u_t:

$$\forall \lambda_j \in \Lambda_i \ : \ D_j = g^{r_t-r'} \cdot H(\lambda_j)^{r_j}, D'_j = g^{r_j}.$$

Then, the user computes $g^{r'} \cdot D_j$ for all its attributes key components and finally obtains its whole secret key set as

$$\mathrm{SK}_{u_t} = \Big(D = g^{\frac{(\alpha_1+\cdots+\alpha_m)+r_t}{\beta}},$$
$$\forall \lambda_j \in S : D_j = g^{r_t} \cdot H(\lambda_j)^{r_j}, D'_j = g^{r_j}\Big)$$

where $S = \bigcup_{i=1}^{m} \Lambda_i$.

Therefore, it is negligible compared to the communication overhead for encryption or key update, which could be much more frequently performed in the DTNs.

IV. CONCLUSION

DTN technologies are becoming successful solutions in military applications that allow wireless devices to communicate with each other and access the confidential information reliably by exploiting external storage nodes. CP-ABE is a scalable cryptographic solution to the access control and secure data retrieval issues. In this paper, we proposed an efficient and secure data retrieval method using CP-ABE for decentralized DTNs where multiple key authorities manage their attributes independently. The inherent key escrow problem is resolved such that the confidentiality of the stored data is guaranteed even under the hostile environment where key authorities might be compromised or not fully trusted. In addition, the fine-grained key revocation can be done for each attribute group. We demonstrate how to apply the proposed mechanism to securely and efficiently manage the confidential data distributed in the disruption- tolerant military network.

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