Lightweight Authentication and Access Control for Content-Centric Networks

Ivan O. Nunes and Gene Tsudik
University of California Irvine
{ivanoliv, gene.tsudik, woodc1}@uci.edu

***Abstract*—**

***Index Terms*—Content-Centric Networking**

I. Introduction

Ideas:

1) *krb-ccn* decouples authentication from access control because access rights are not associated with the possession of a key not to the ability of decrypting a the content's ciphertext (as in attribute-based encryption). Therefore, access control policies can be changed without the need to proactively re-distribute access keys.
2) Users's privacy is preserved since the actual content producers are not aware of which is requesting a given content. This is possible because authentication and AC is handled by the KDC and not by the final content producer and because of the lack of source addresses on CCN interests.
3) By leveraging the sinenergy between network names in CCN and Kerberos service-names-based AC, we are able to provide an effective AC policy by granting AC rights to namespaces (e.g., */uci/edu/filesystem/userA/**). In IP Kerberos such AC policies are bounded to principals, with are basically names to services within an organization. Since in CCN all content is named by design, *krb-ccn* eliminates the need for principals, leading to a cleaner and straightforward authentication and authorization system.
4) *krb-ccn* is also designed with efficiency in mind. As in IP Kerberos, the majority of cryptografic operations in the system consist on symmetric-key authenticated encryption. By avoiding computatially expensive operations (sucha as ABC, PKC, and Pairing Based Cryptography), *krb-ccn* becomes suitable for scenarios where content producers are resource constrained devices, such as in an evetual CCN-IoT.
5) The consumer application does not have to be aware of *krb-ccn*. Based on the interest hierarchical name structure, the *krb-ccn* local client is capable of fetching the apropriate TGS/TGT, or issue TGS and TGT requests as needed.

Content-Centric Networking (CCN) is an emerging paradigm that emphasizes the transfer of named data instead of hosts and interfaces. This shifts the security focus from channels a la protocols such as TLS to the content itself. If content is sensitive and must be protected, the architecture demands that it be properly encrypted so that unauthorized consumers cannot view the data. Access control in CCN has been well studied in recent years. The majority of solutions rely on long-lived public and private key pairs to protect data. Specifically, data owners or producers encrypt data under some access control policy with a public key corresponding to an authorized consumer (or set of consumers). The recipient(s) use their corresponding private key to decrypt the content.

In principle, this design achieves its goal of providing access control to content. However, it suffers in two critical problems. The first is revocation. There is an intrinsic time-of-check versus time-of-use problem with the standard CCN access control strategy. Specifically, once content is encrypted under a recipients public key, said recipient will always have access to the data barring destruction of the private key. If a consumers access control rights change after content is published, then said consumer can continue reading the data so long as it can obtain an encrypted copy. Addressing this problem requires that access to content always be preceded by an *online* authorization check. Specifically, before consumer Cr_i accesses content $C(N)$ with name N, it must first acquire access to $C(N)$. Such access will allow Cr_i to read $C(N)$. Moreover, since access to $C(N)$ at time t might be allowed for Cr_i but not $Cr_j \neq Cr_i$, $C(N)$ must only be accessible by Cr_i. Generalizing this further means that each content is uniquely encrypted, on demand, for each consumer at time t. Thus, encrypted content must be bound to the state of an access control policy. Otherwise, caching this content is, in theory, not possible.

The second critical problem is the inadvertent mixing of authentication and authorization. In the standard approach, there is not online authentication or authorization. Possession of a private key sufficiently satisfies both purposes. It is up to the producer to statically enforce its authorization rules by only encrypting content for particular consumers. This mixture of authentication and authorization is problematic for several reasons. Firstly, it binds authorization rules to authentication identities. In applications where authorization checks depend on more than a client identity, this is not sufficient. Secondly, it requires that authentication be done solely by consumer-owned private keys. In fact there are many circumstances where a clients identity is ascertained using information that is not a private key passwords being the more prominent counter example. In summation, it is advantageous to decouple authentication and authorization, even in CCN. Kerberos is one system that allows us to partly address both of these open problems. Specifically, Kerberos decouples authentication and authorization services through the usage of tickets. It also allows services, e.g., content repositories, to be accessed over an ephemeral session. Tickets permit the service to check the liveness of authentication information and, therefore, limit the window of data use beyond revocation.

In this paper, we present Hydra, a system inspired by Kerberos for online access control enforcement in CCN. Hydra separates consumer authentication and authorization into separate services. It uses tickets or cookies to allow consumers to convey authorization permissions to target servers, e.g., content repositories. Servers can use these cookies to determine if requested content should be provided or not. Hydra also introduces a novel naming scheme to bind consumer credentials to protected content objects. This allows only authorized consumers to derive the names of protected content objects. Producers use these derived names when checking authorization rights for target content or namespaces. This naming scheme is orthogonal to Hydra and may be used in other application settings to better make access control decisions.

II. Access Control Restrictions

CCN supports two types of content restrictions: `KeyIdRestriction` and `ContentObjectHashRestriction`, or KeyID and ContentID, respectively. The KeyID restricts content to that which is signed by a key whose hash matches the KeyID. The ContentID restricts content to that which hashes to the ContentID. Each of these restrictions can be used by any entity in the network, especially routers, to verify content.

In this section, we advocate for a new restriction called an `AccessRestriction`, or AccessID. The AccessID is designed to restrict content to that which satisfies a given access control policy. An access control policy is one which binds a given content to a specific decryption key. As such, only the owner of the decryption can generate an AccessID. (This is necessary since, as we will show, AccessIDs serve as committments to a requests. It must not be possible for a malicious user to forge a committment to a request.) However, unlike the two prior restrictions, the AccessID need not be verifiable by any entity in in the network. Confidentiality is an end-to-end goal and not a feature provided by the network.

Given the obvious asymmetry in roles, this implies the use of a digital signatures as the AccessID. For example, let pk and sk be public and private key pairs associated with some access control policy and owned by consumer Cr. One trivial construction for AccessID of N with KeyID k_ID is as follows:

$$\mathsf{Sign}_{sk}(N||k_ID)||pk$$

This would bind AccessID to N and the producer's public key. Moreover, it would allow any network entity to verify this restriction. However, in many cases, this is overly revealing. Routers need not concern themselves with whether or not a content matches the requested AccessID. A better construction would therefore limit exposing this information to the network. Consider the following alternative:

$$\mathsf{Sign}_{sk}(N||pk||k_ID)||H(N||pk||k_ID)$$

This restricts verificaftion of the AccessID to those who know pk, which is not otherwise revealed to the network.

An AccessID is inspired by the work of Ghali et al. [**?**] on *interest-based access control*. The idea is to bind principals to interests and then make coupled authentication and authorization decisions based on this binding.

III. Hydra Design

A. Namespace Based Authorization

There are at least two fundamental problems one must address in any access control system: (1) how access control policies are represented and (2) how they are enforced. Policy representation specifies how policies are mapped onto resources (or content). For example, one representation might map content names to sets of public keys. These keys could be owned by authorized consumers and are used when encrypting content. Encrypting content with name N under a key pk restricts access to the owner of the corresponding private key. The challenge is to devise a representation that scales well with the number of resources (content) and consumers. Regardless of the approach, we claim there is one fundamental feature that must be present for every access control decision: consumer requests must be bound to a principal. This allows the producer or entity serving data to provide the appropriate representation of the target data to the consumer. To achieve this goal, Hydra uses AccessIDs described in the previous section.

The second problem is rooted more in system design. Consider what must be done to satisfy a request for access-controlled content. First, the requestor must be authenticated to bind the request to a principal. Second, the request must be authorized to determine if access to the desired content is permissable. Lastly, the data must be packaged in a protected (encrypted) form for the requestor. Thus, problem (2) is more about how entities are configured to handle the separate authentication, authorization, content distribution steps in CCN.

In past work, these roles were often convoluted. In particular, [**?**], [**?**] assumed that the entity which handles data production was also implicitly responsible for content authentication and authorization. CCN-AC [**?**] and NDN-NBAC [**?**] separated the authentication and authorization service from the data production. Specifically, data owners generate and distribute consumer (principal) private keys to consumers through out-of-band channels. Data producers receive the corresponding public keys through a similar channel. These are used to encrypt randomly generated per-content encryption keys.

Despite this separation, these designs still suffer from the following problems. **First**, authentication and authorization are unnecessarily coupled, leading to an inherent "time of check" versus "time of use" problem. Specifically, consumers obtain private keys from the data owner at time t and use them to decrypt content at time $t' > t$. **Second**, if consumers are forced to fetch their private keys from the data owner, a single point

TABLE I
NOTATION SUMMARY

Notation	Description
$I.name$	Name of the issued interest I
N	A namespace prefix (e.g., /uci/ics/ivan/)
TGT_Name	Ticket-granting-ticket name (e.g., /uci/ics/TGT) that will be routed towards authenticator
TGS_Name	Ticket-granting-service name (e.g., /uci/ics/TGS) that will be routed towards authorizer
sk_C	Consumer Secret Key
pk_C	Consumer Public Key, including public UID and certificate
k_A	Long term symmetric key shared between Authenticator and Authorizer
k_P	Long term symmetric key shared between Authenticator and Producer
$s \leftarrow_{\$} \{0,1\}^{\lambda}$	Random λ-bits number generation
$ct = Enc_k(pt)$	Authenticated Encryption of pt using symmetric key k
$pt = Dec_k(ct)$	Decryption of ct using symmetric key k
$ct = Enc_{pk}(pt)$	Authenticated Encryption of pt using public key pk
$pt = Dec_{sk}(ct)$	Decryption of ct using secret key sk
$\sigma = Sign_{sk}(m)$	Signature on message m using secret key sk
$Verif_{pk}(\sigma, m)$	Signature verification using public key pk

of failure emerges. In particular, it becomes easy to launch a Denial of Service (DoS) attack on the data owner by forcing it to perform expensive cryptographic operations, e.g., signature verifications.

B. Protocol

Hydra is a system designed to address these problems. It has the following features:

- Consumer authentication and content authorization decisions can be separated and performed by separate systems in the network. A Hydra administrator can spawn any number of authentication endpoints to handle client authentication requests. Consumers are unable to fetch data from the authorization agent without having first been authenticated.
- Authorization decisions are centralized to a single system (or set of synchronized systems). This permits each authorization check to be done in real-time without introducing any added delay between the subsequent use.
- XXX
- XXX
- XXX

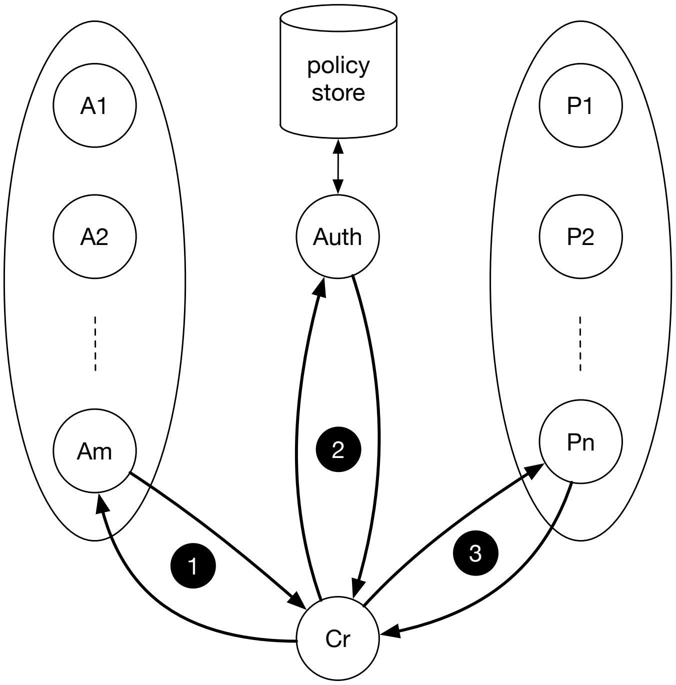


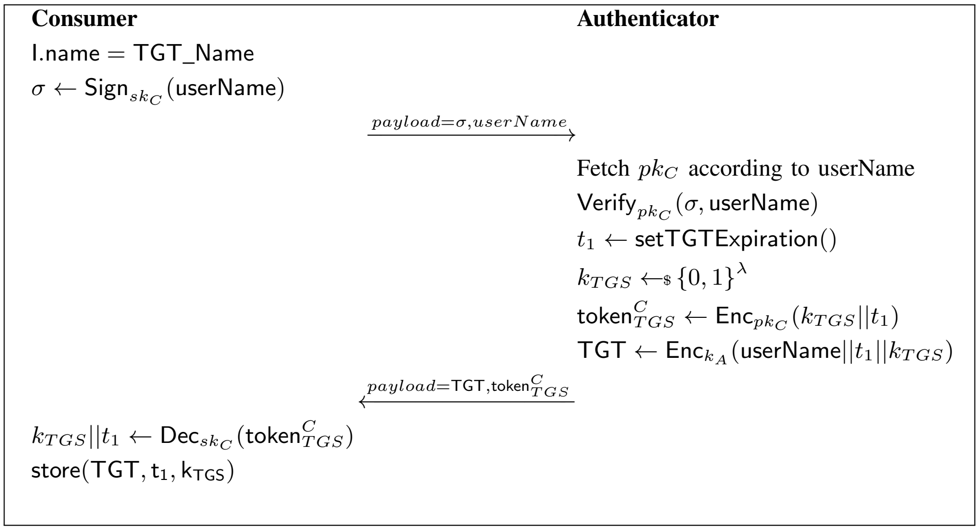
Fig. 1. Hydra system design

Consumer		**Producer**
I.name = N||suffix		
	$\xrightarrow{payload=TGS}$	
		$N'\|\|k_N\|\|t_2 \leftarrow \mathsf{Dec}_{k_P}(TGS)$
		Verify: N' is prefix of I.name
		Verify t_2 expiration
		$D \leftarrow$ ProduceData(I.name)
		$D' \leftarrow \mathsf{Enc}_{k_N}(D)$
	$\xleftarrow{payload=D'}$	
$D \leftarrow \mathsf{Dec}_{K_N}(\mathsf{D}')$		

Fig. 4. Authorization verification protocol

C. Ivan: Comments

1) IMO, the authentication algorithm (Fig.2) should be unrelated to the namespace you want to get access to. Only related to Consumer's claimed Identity. Otherwise the consumer has to go back to the Authenticator every time she wants a different content (3 RTT).
2) Unless we are assuming that there is some magical non-deterministic router that will route the same name through different paths, I.name must specify the content produced by the Authenticator, i.e., the TGT. The same applies for TGS.
3) The TGT as a MAC never expires. My suggestion is to encrypt a timestamp, as in Kerberos, and as we are doing in the authorizer. MAC with an epoch is also an option,



Consumer | **Authenticator**

I.name = TGT_Name

$\sigma \leftarrow \mathsf{Sign}_{sk_C}(\mathsf{userName})$

$\xrightarrow{payload=\sigma,userName}$

Fetch pk_C according to userName

$\mathsf{Verify}_{pk_C}(\sigma, \mathsf{userName})$

$t_1 \leftarrow \mathsf{setTGTExpiration}()$

$k_{TGS} \leftarrow\!\$\, \{0,1\}^\lambda$

$\mathsf{token}^C_{TGS} \leftarrow \mathsf{Enc}_{pk_C}(k_{TGS}||t_1)$

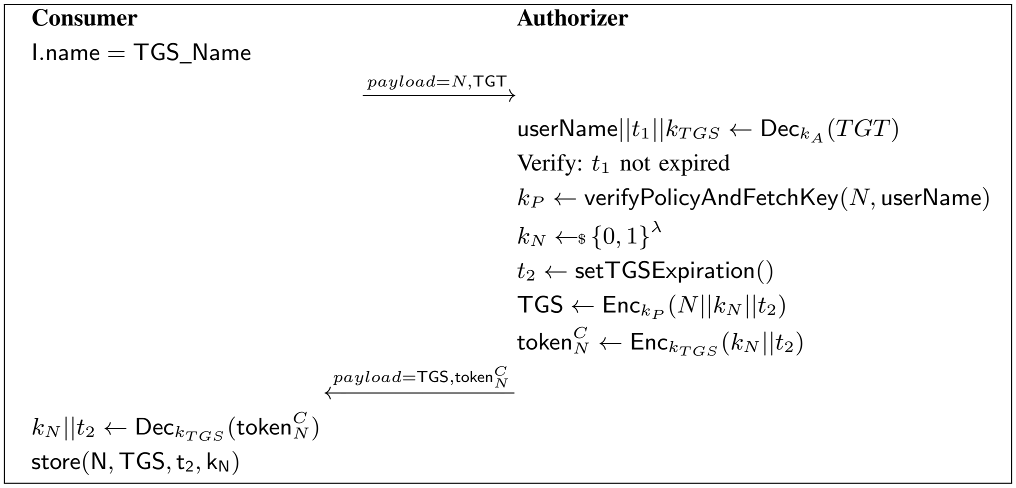
$\mathsf{TGT} \leftarrow \mathsf{Enc}_{k_A}(\mathsf{userName}||t_1||k_{TGS})$

$\xleftarrow{payload=\mathsf{TGT},\mathsf{token}^C_{TGS}}$

$k_{TGS}||t_1 \leftarrow \mathsf{Dec}_{sk_C}(\mathsf{token}^C_{TGS})$

$\mathsf{store}(\mathsf{TGT}, \mathsf{t_1}, \mathsf{k_{TGS}})$

Fig. 2. Consumer authentication protocol



Consumer | **Authorizer**

I.name = TGS_Name

$\xrightarrow{payload=N,\mathsf{TGT}}$

$\mathsf{userName}||t_1||k_{TGS} \leftarrow \mathsf{Dec}_{k_A}(TGT)$

Verify: t_1 not expired

$k_P \leftarrow \mathsf{verifyPolicyAndFetchKey}(N, \mathsf{userName})$

$k_N \leftarrow\!\$\, \{0,1\}^\lambda$

$t_2 \leftarrow \mathsf{setTGSExpiration}()$

$\mathsf{TGS} \leftarrow \mathsf{Enc}_{k_P}(N||k_N||t_2)$

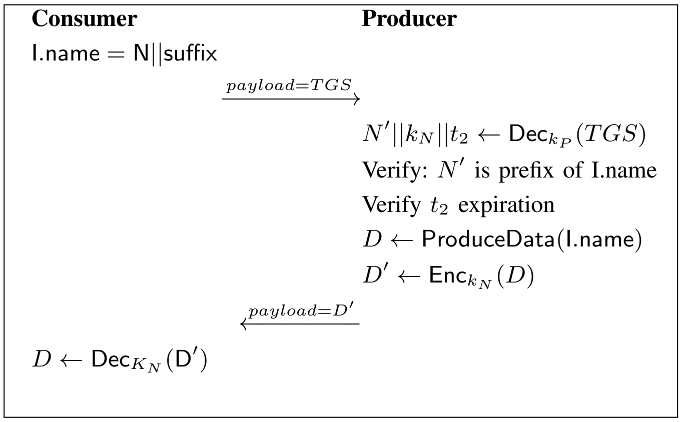
$\mathsf{token}^C_N \leftarrow \mathsf{Enc}_{k_{TGS}}(k_N||t_2)$

$\xleftarrow{payload=\mathsf{TGS},\mathsf{token}^C_N}$

$k_N||t_2 \leftarrow \mathsf{Dec}_{k_{TGS}}(\mathsf{token}^C_N)$

$\mathsf{store}(\mathsf{N}, \mathsf{TGS}, \mathsf{t_2}, \mathsf{k_N})$

Fig. 3. Consumer-data authorization protocol



Consumer | **Producer**

I.name = N||suffix

$\xrightarrow{payload=TGS}$

$N'||k_N||t_2 \leftarrow \mathsf{Dec}_{k_P}(TGS)$

Verify: N' is prefix of I.name

Verify t_2 expiration

$D \leftarrow \mathsf{ProduceData}(\mathsf{I.name})$

$D' \leftarrow \mathsf{Enc}_{k_N}(D)$

$\xleftarrow{payload=D'}$

$D \leftarrow \mathsf{Dec}_{K_N}(\mathsf{D'})$

Fig. 5. Authorization verification protocol including challenge-based consumer authentication

but not a good one.

4) PKE of K_N in the authorization algorithm (Fig 3) could (and maybe should) be symmetric AEAD.
5) $verifyPolicyAndFetchKey()$: Could be implemented as broadcast encryption...
6) Consumer has to receive the expiration date of TGT/TGS. This way Consumer can get back to Authenticator/Authorizer directly, without issuing expired TGT/TGS messages to authorizer/producers.

IV. Conclusions and Future Work

Stuff here, crap there.