# OWCM: One-Way Counter Mode

Danilo Gligoroski and Hristina Mihajloska and Håkon Jacobsen

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# In this talk I will present the material from our two submissions to DIAC 2013

**(as agreed with the organizer)**

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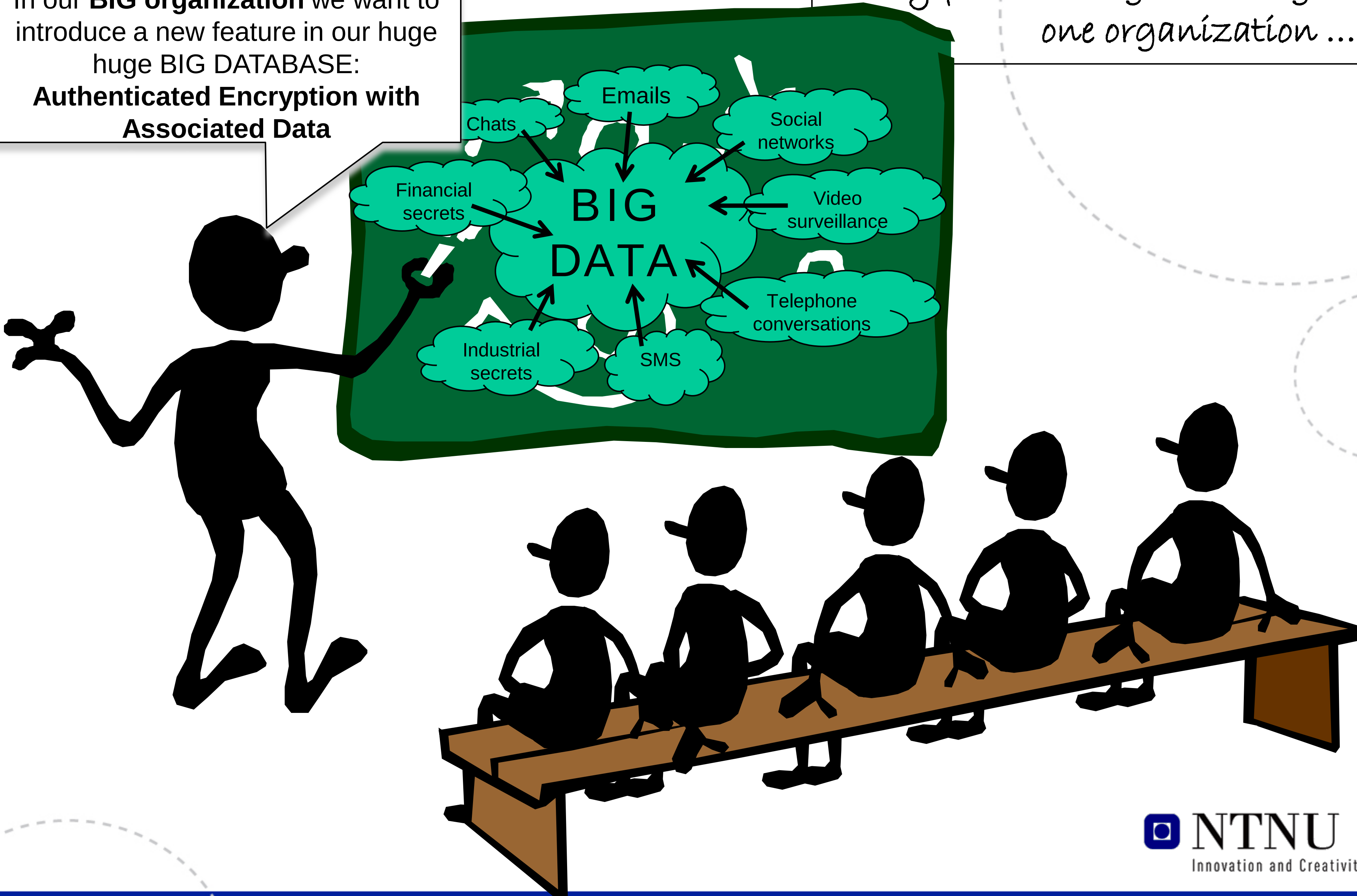
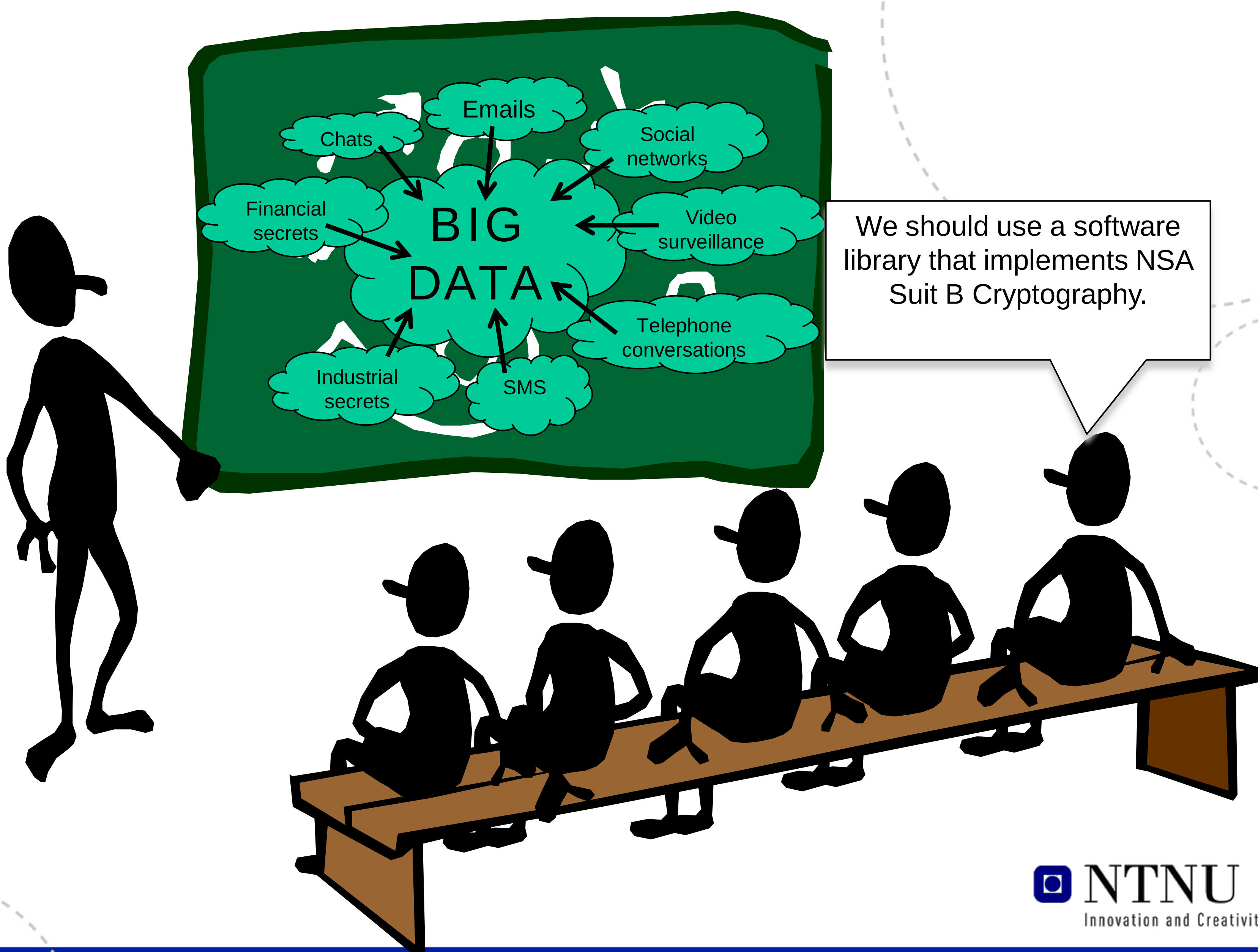
- Should MAC's retain hash properties when the key is known in the next AEAD?
- OWCM: One-Way Counter Mode (initial design)

Introductory advertisement for

Let us start with the following story from a design meeting in one organization ...

In our **BIG organization** we want to introduce a new feature in our huge huge BIG DATABASE:
**Authenticated Encryption with Associated Data**

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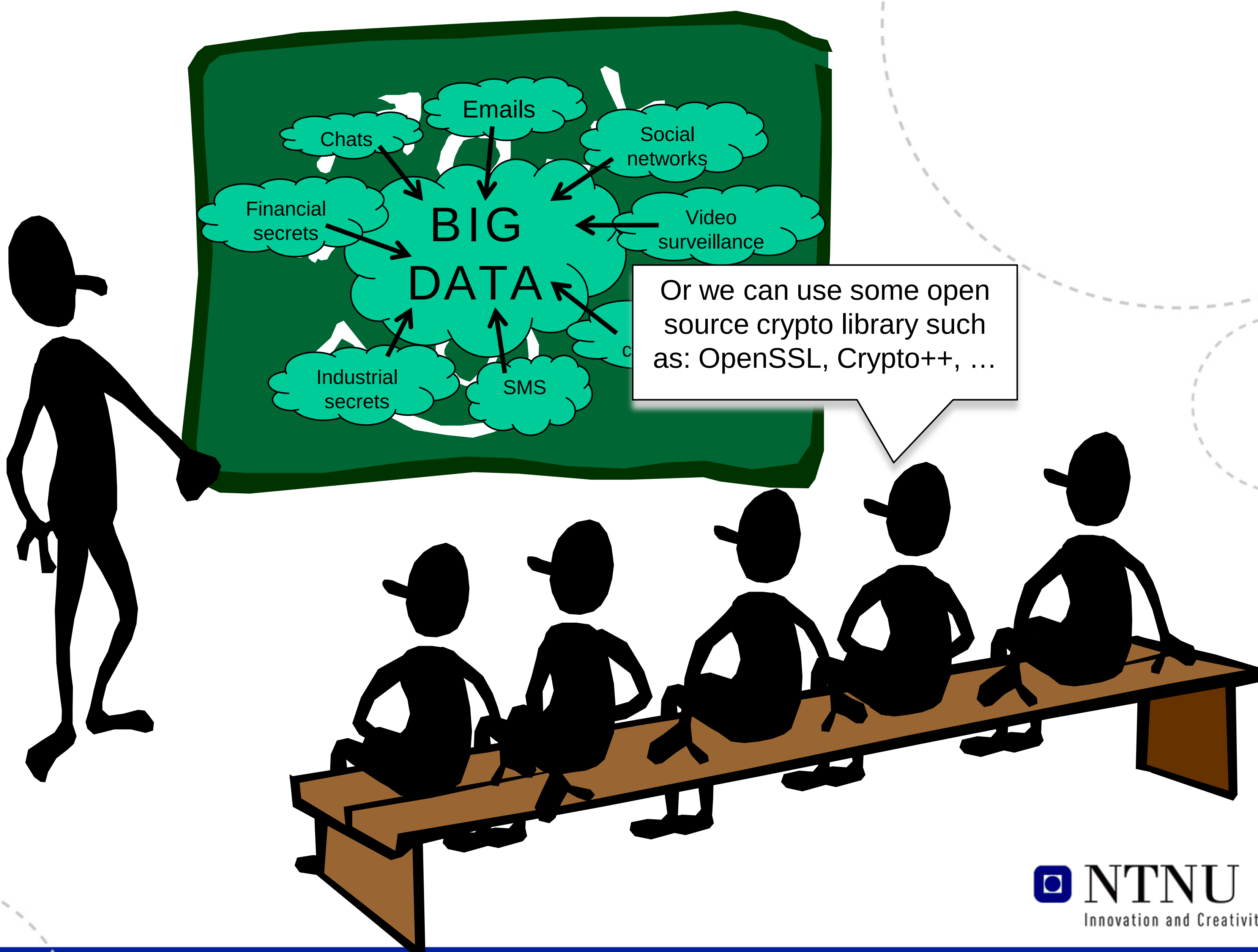
Chats
Social networks
Financial secrets
BIG DATA
Video surveillance
Telephone conversations
Industrial secrets
SMS
We should use a software library that implements NSA Suit B Cryptography.


Emails
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Financial secrets
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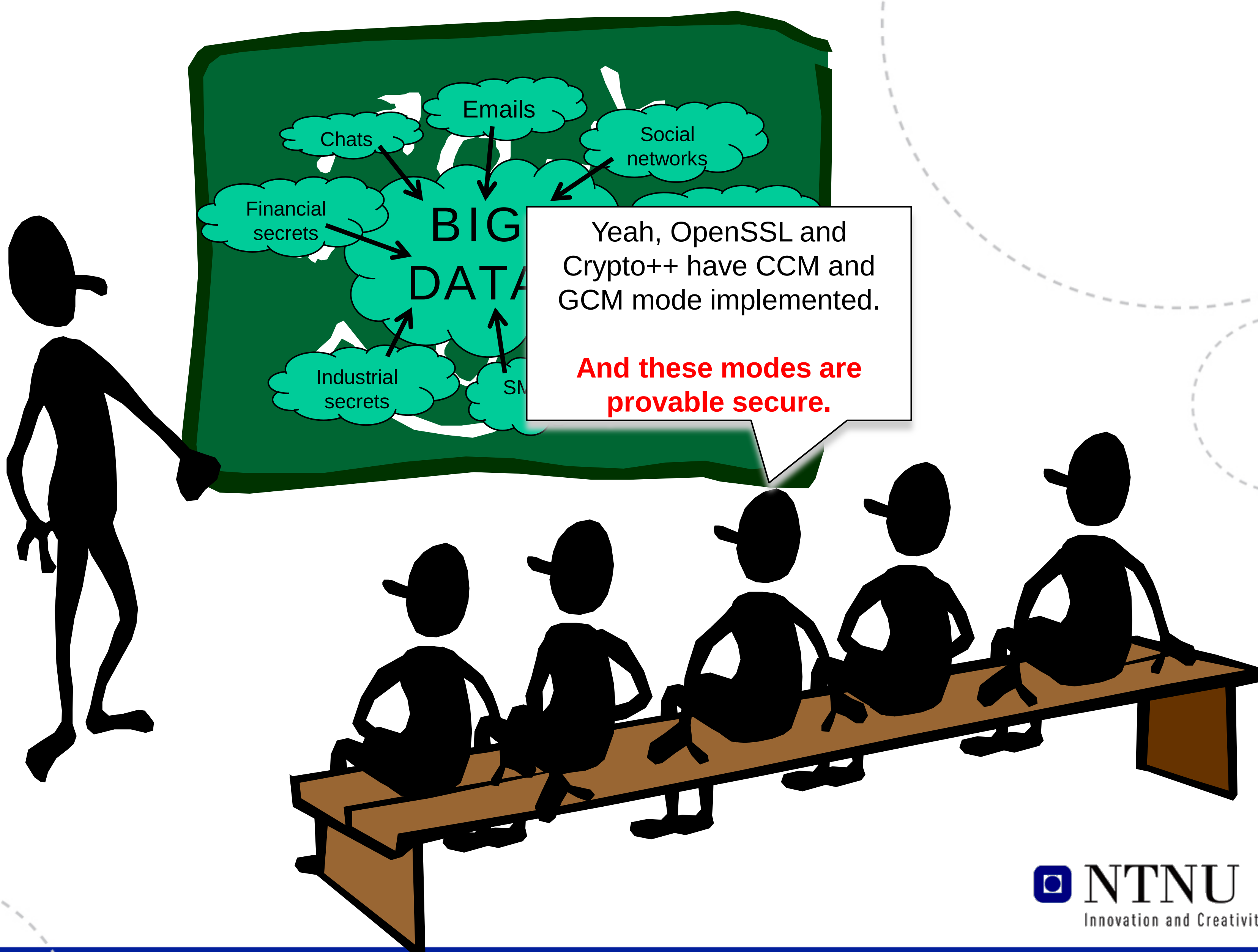
SMS
Or we can use some open source crypto library such as: OpenSSL, Crypto++, …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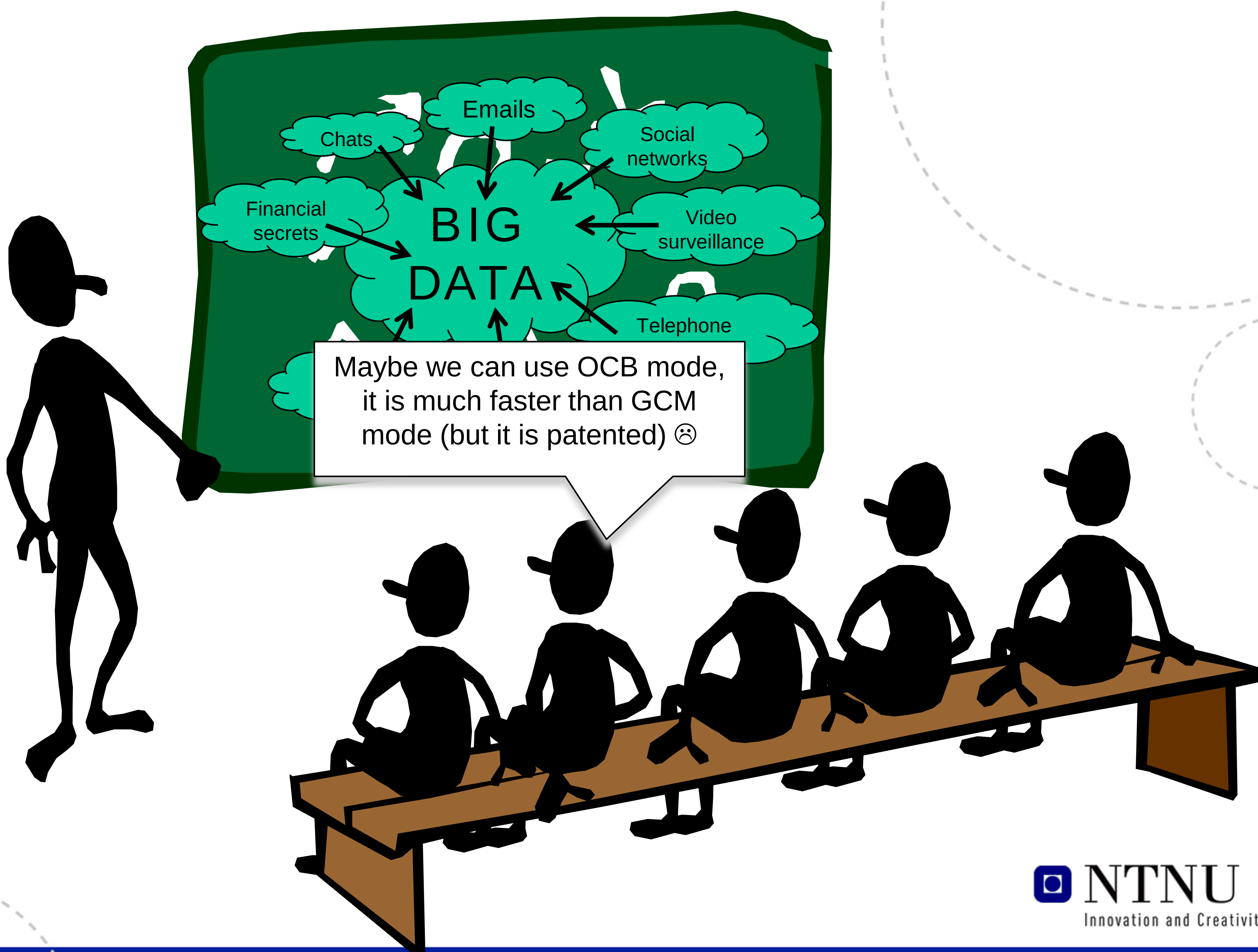
Yeah, OpenSSL and Crypto++ have CCM and GCM mode implemented.
**And these modes are provable secure.**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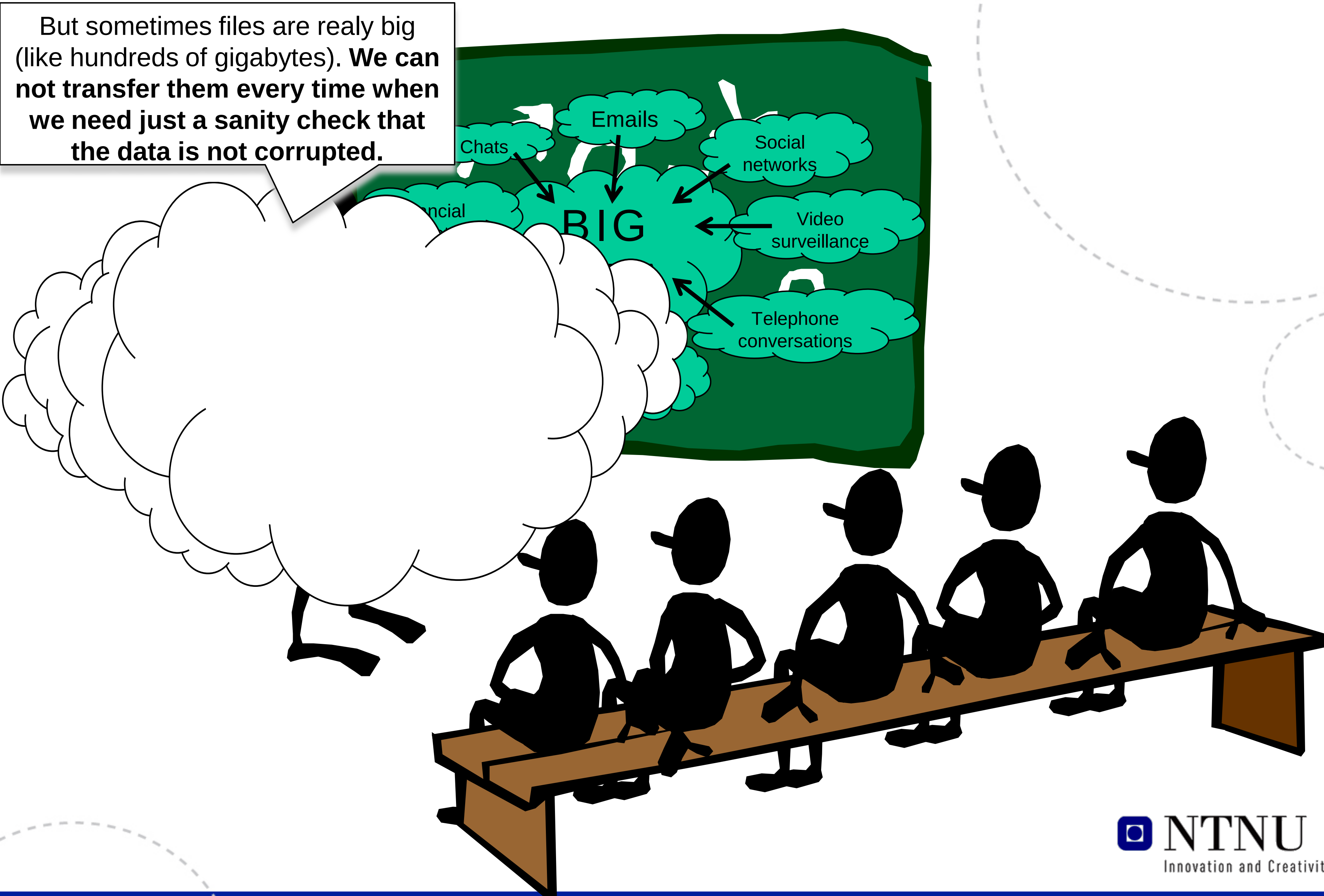
Telephone
Maybe we can use OCB mode, it is much faster than GCM mode (but it is patented) ☹

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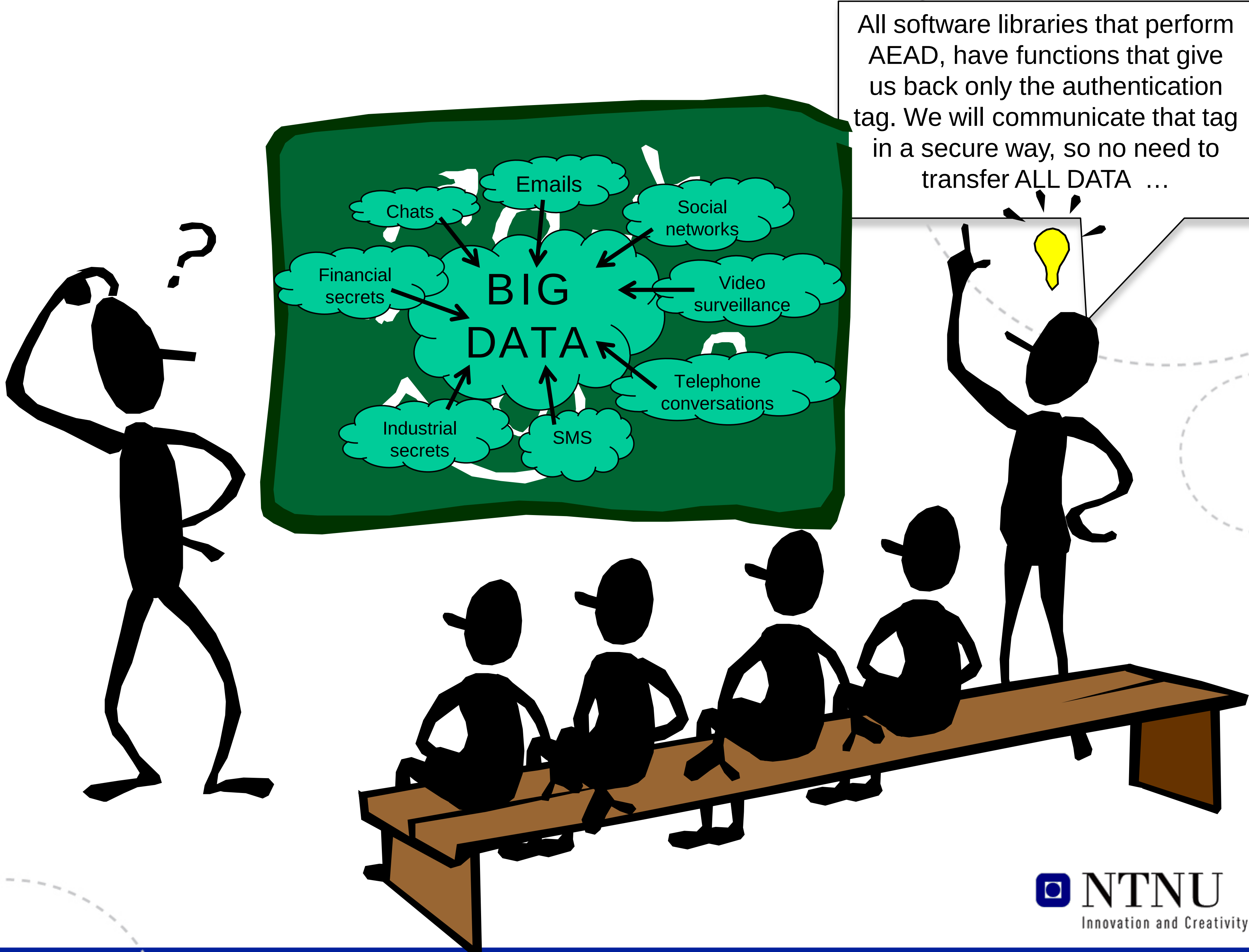
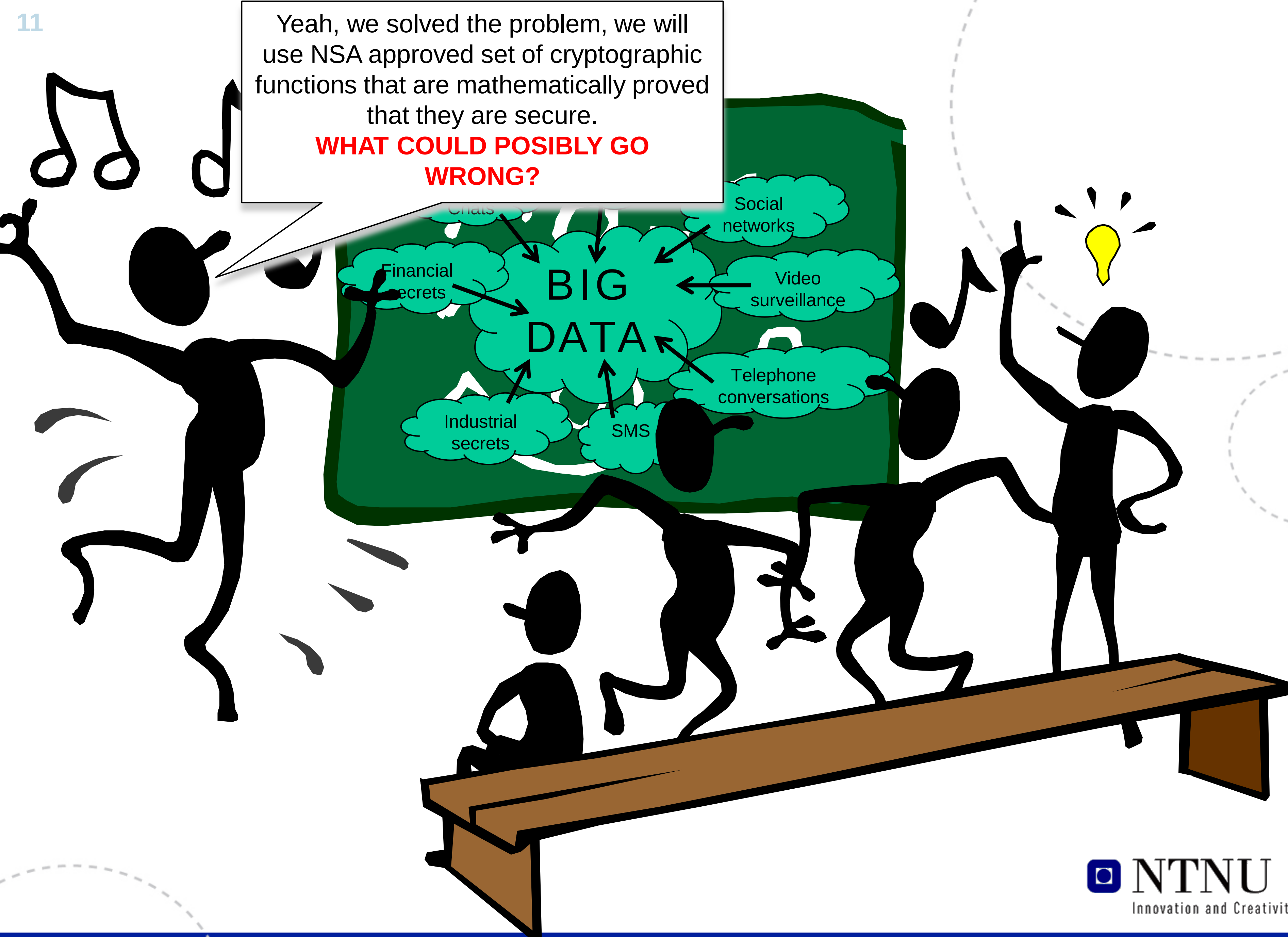

All software libraries that perform AEAD, have functions that give us back only the authentication tag. We will communicate that tag in a secure way, so no need to transfer ALL DATA …
BIG DATA
Emails
Chats
Social networks
Financial secrets
Video surveillance
Telephone conversations
Industrial secrets
SMS

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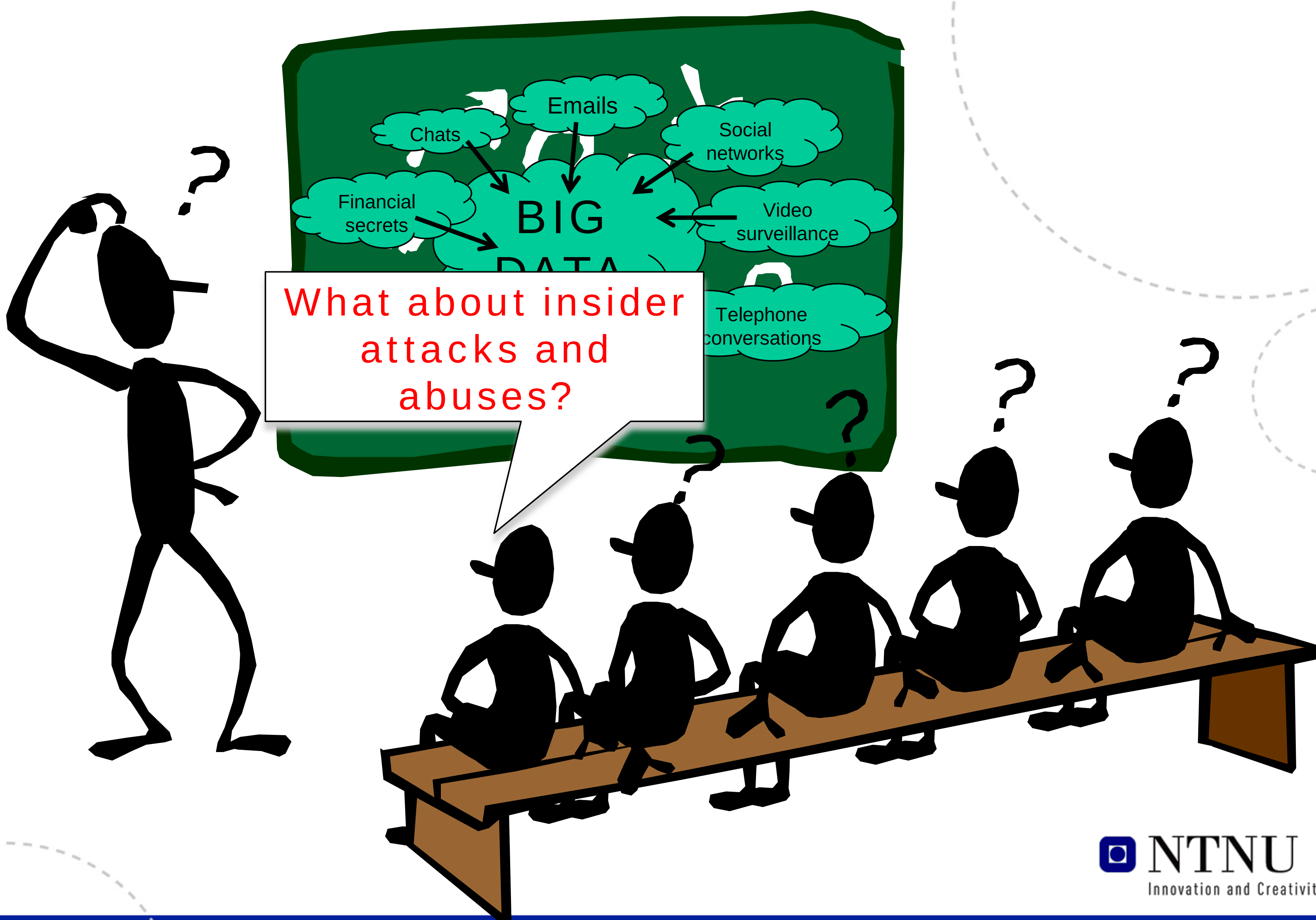
Emails
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What about insider attacks and abuses?

# What about insider attacks and abuses?

White Paper

# Data Leakage Worldwide: The High Cost of Insider Threats

## Executive Summary

The findings from a global security study on data leakage revealed that the data loss resulting from employee behavior poses a much more extensive threat than many IT professionals believe. Commissioned by Cisco and conducted by U.S.-based market research firm InsightExpress, the study polled more than 2000 employees and information technology professionals in 10 countries. Cisco selected the countries based on their diverse social and business cultures, with the goal of better understanding whether these factors affect data leakage.

In the hands of uninformed, careless, or disgruntled employees, every device that accesses the network or stores data is a potential risk to intellectual property or sensitive customer data. Magnifying this problem is a disconnect between the beliefs of IT professionals and the realities of the current security environment for countless businesses. The new findings show that "insider threats" have the potential to cause greater financial losses than attacks that originate outside the company.

CISCO



# Data Leakage Worldwide: The High Cost of Insider Threats

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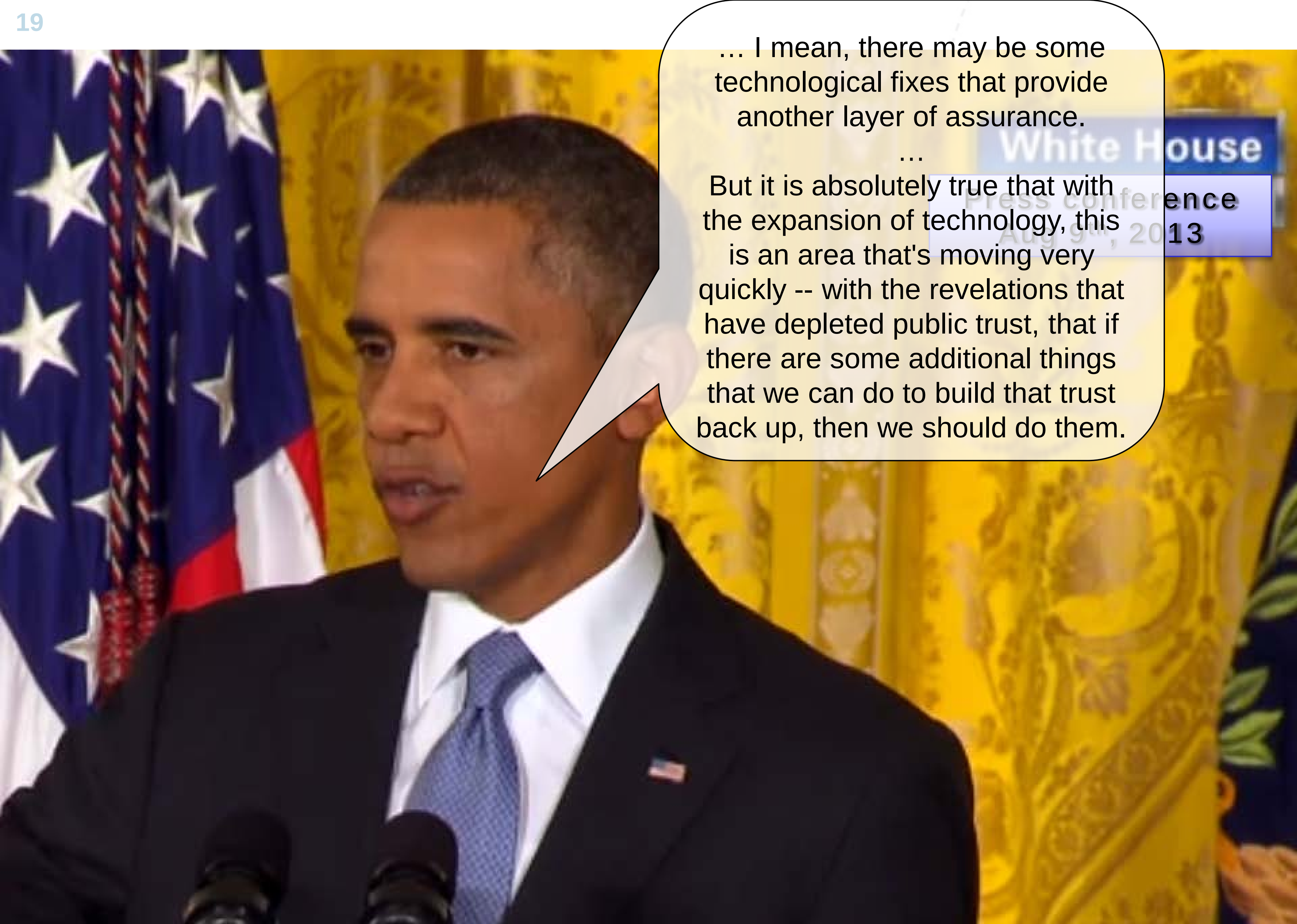
# What about insider attacks and abuses?

- An insider attack is intentional misuse by individuals who are authorized to use computers and networks.
- An insider attack is more dangerous than outsider attack from financial and safety and security losses point of view.
- In the same time detecting and preventing insider attacks is much more difficult than defending from external attacks

We need new thinking for a new era. … and meanwhile technology has given governments, including our own, unprecedented capability to monitor communications.


Press conference
Aug 9th, 2013


And the other thing that's happening is, is that as technology develops further, technology itself may provide us some additional safeguards.
White House
Press conference
Aug 9th, 2013


… I mean, there may be some technological fixes that provide another layer of assurance.
…
But it is absolutely true that with the expansion of technology, this is an area that's moving very quickly -- with the revelations that have depleted public trust, that if there are some additional things that we can do to build that trust back up, then we should do them.
White House
Press conference
Aug 9th, 2013

# CAESAR call for submissions, draft 3

- **Submission requirements**
  - Security goals: A table quantifying, for each of the recommended parameter sets, the intended nu … wing ca
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  - int
  - int
  - integrity for the secret message number (omit if the secret message number has length 0);
  - integrity for the public message number (omit if the public message number has length 0); and
  - any additional security goals and robustness goals that the submitters wish to point out.

**Can CAESAR competition provide an additional safeguard against insider abuses?**

# CAESAR call for submissions, draft 3

- **Submission requirements**
  - Security goals: A table quantifying, for each of the recommended parameter sets, the intended number of bits of security (i.e., the logarithm base 2 of the attack cost) in each of the following categories:
  - confidentiality for the plaintext;
  - confidentiality for the secret message number (omit if the secret message number has length 0);
  - integrity for the plaintext;
  - integrity for the associated data;
  - integrity for the secret message number (omit if the secret message number has length 0);
  - integrity for the public message number (omit if the public message number has length 0); and
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# CAESAR call for submissions, draft 3

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  - integrity…
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  - integrity for the public message number (omit if the public message number has length 0); and
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**What about the robustness against insider attacks and insider abuses?**

# Easy exercise 1: Find two colliding massages for CCM when key K is known

If we choose two consecutive message blocks $P_1$ and $P_2$, the formulas for the internal message authentication state are given below:

$$X_1 = \mathcal{E}_K(X_0 \oplus P_1)$$
$$X_2 = \mathcal{E}_K(X_1 \oplus P_2)$$

where $X_0$ is the accumulated value from the previous internal message authentication state. If we replace the first message block $P_1$ with an arbitrary new value $P_1'$ then we have:

$$X_1' = \mathcal{E}_K(X_0 \oplus P_1')$$

In the next state we want to produce the same authenticated value $X_2$, but now with the new value $X_1'$ and a second message block $P_2'$ that will compensate the introduced new value of $P_1'$:

$$X_2 = \mathcal{E}_K(X_1' \oplus P_2').$$

Thus,

$$X_1 \oplus P_2 = X_1' \oplus P_2',$$

so, $P_2'$ should be:

$$P_2' = X_1 \oplus P_2 \oplus \mathcal{E}_K(X_0 \oplus P_1'). \tag{2}$$

# Easy exercise 2: Find two colliding massages for GCM when key K is known

To find two different plaintexts with the same authentication tag, we choose two consecutive message blocks $P_1$ and $P_2$. The formulas for the internal message authentication state are given below:

$$X_1 = (X_0 \oplus C_1) \bullet H,$$
$$X_2 = (X_1 \oplus C_2) \bullet H,$$

where $X_0$ is the accumulated value from the previous internal message authentication state, and $C_1$ and $C_2$ are the ciphertexts produced from the encryption phase.

If we replace the first message block $P_1$ with an arbitrary new value $P_1'$ then we have:

$$X_1' = (X_0 \oplus C_1') \bullet H.$$

In the next state we want to produce the same authenticated value $X_2$ but now with the new values $X_1'$ and changed second message block $P_2'$:

$$X_2 = (X_1' \oplus C_2') \bullet H.$$

Thus,

$$X_1 \oplus C_2 = X_1' \oplus C_2',$$

where,

$$C_2' = (X_1 \oplus C_2) \oplus X_1'.$$

So, for $P_2'$ we have:

$$C_2 = P_2 \oplus \mathcal{E}_K(\mathrm{CTR2}),$$
$$C_2' = P_2' \oplus \mathcal{E}_K(\mathrm{CTR2}),$$

where $\mathrm{CTR2} = \mathrm{incr}(\mathrm{CTR1}) = \mathrm{incr}(\mathrm{incr}(N||0^{31}1))$ is a counter, produced from the nonce:

$$P_2' = \mathcal{E}_K(\mathrm{CTR2}) \oplus (X_1 \oplus C_2) \oplus (X_0 \oplus C_1') \bullet H. \tag{3}$$

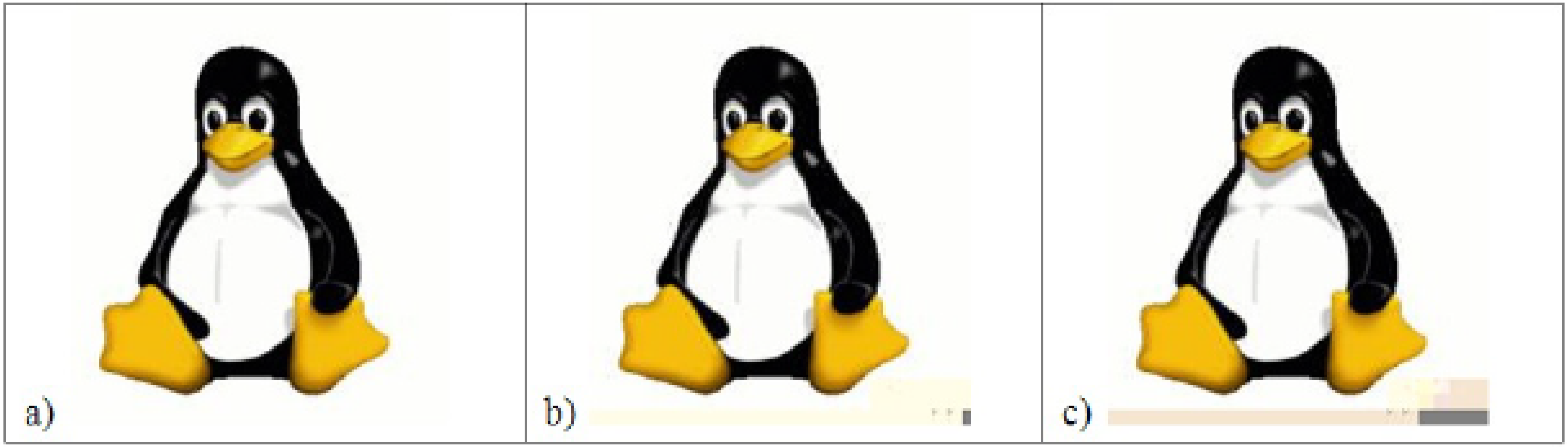


Fig. 1. Simple example of messages with colliding tags for CCM or GCM.

# Easiest exercise 3: Find two colliding massages for OCB when key K is known

The tag is produced from the encrypted value of the *Checksum* which is computed as:

$$Checksum = P_1 \oplus \cdots \oplus P_{m-1} \oplus P_m. \tag{4}$$

Since the tag directly depends on the *Checksum* (4) which depends only on the plaintext, we can have the same checksum between two totaly different files. Just the final block of the second file has to be computed to make the checksum the same.

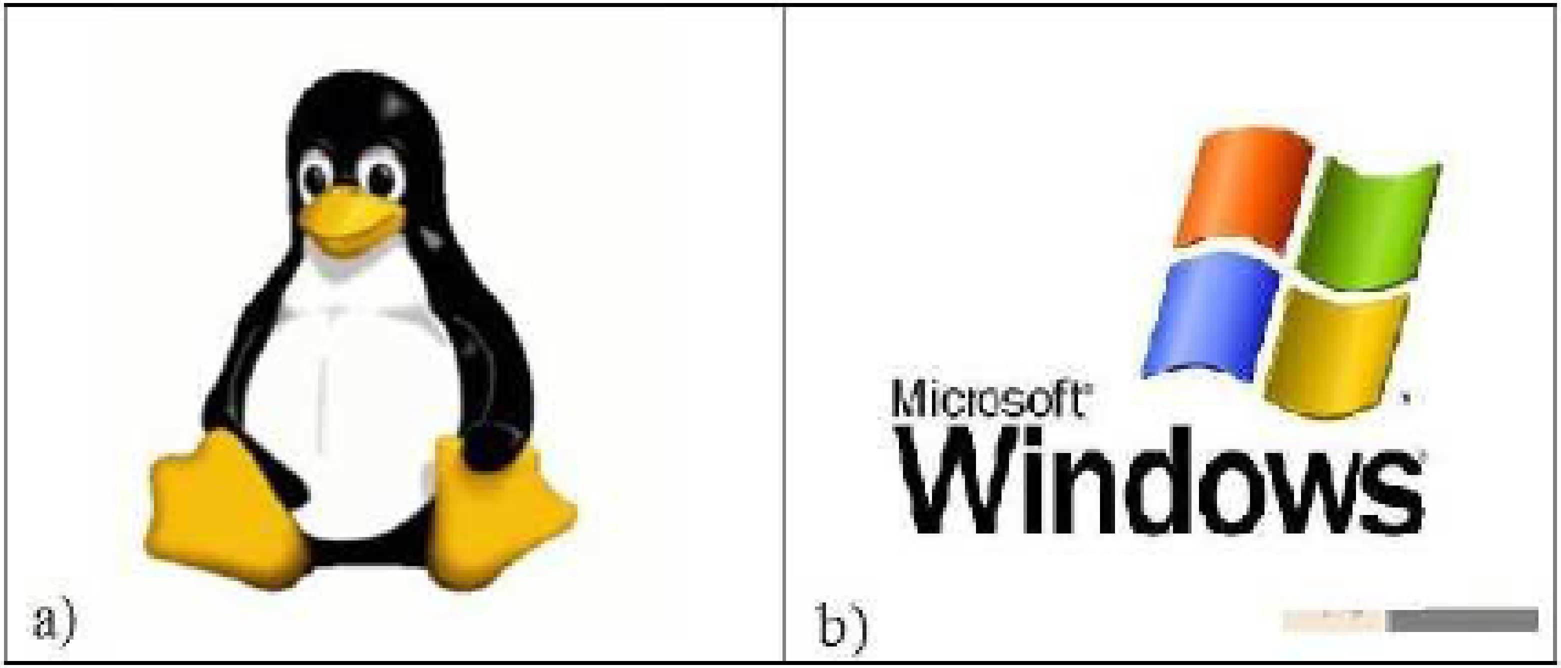


Fig. 2. Simple example of messages with colliding tags for OCB.

# Exploit 1 in "Secure audit logs"

- Adaptation of Bellare-Yee scenario of "Secure audit logs".
- An attacker is breaking into a machine that keeps activity logs that are encrypted by an AEAD scheme.
- He/she has obtained the encryption key by some other means (physical force, stealing, ...).
- In order to protect against such accidental revelation of encryption keys, the authentication tags are kept in a separate and write protected area.
- This way the existing encrypted logs are protected from being overwritten with other fake logs.
- However, if the AEAD scheme was implemented by CCM, GCM or OCB, the attacker can erase his/her previous (unsuccessful) attempts to break-in by simply producing a log file that has the same authentication tag as the originally encrypted log.

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# Exploit 2 in "Multi-cast authentication"

- Adaptation of Mitchell and Walker scenario of "multidestination secure mail problem".
- Suppose Alice wants to send an authenticated message to Bob and Claire in a group chat application.
- Assume further that all group communication goes through a central hub which relays a single message from one party to the other two.
- At the start of the session the application establishes pairwise symmetric keys among the participants, i.e. Alice and Bob shares the key $K_{AB}$, Alice and Claire shares the key $K_{AC}$ and Bob and Claire shares $K_{BC}$.

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# Exploit 2 in "Multi-cast authentication"

Assume that the chat application employs an AEAD scheme. Following the notation of [13], an AEAD scheme is a function $\mathcal{E}\colon \mathcal{K} \times \mathcal{T} \times \mathcal{A} \times \mathcal{S} \times \mathcal{M} \to \{0,1\}^*$, over the space of *keys*, *public message numbers*, *associated data*, *secret message numbers* and *messages*. We write this function more compactly as:

$$C \parallel T \leftarrow \mathcal{E}_K^{N,A}(S, M),$$

where $C \parallel T$ denotes that the ciphertext can be parsed into an "encryption-part" and a "tag-part". Since the nonce and associated data are not very relevant for this exposition, we will for clarity ignore them in the above notation and simply write $\mathcal{E}_K(M)$.

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# Exploit 2 in "Multi-cast authentication"

In order to send the message $X$ to both Bob and Claire, Alice proceeds as follows:

1. She selects a session key $K_S \in \mathcal{K}$ which will be used for this one message only.
2. She computes the ciphertext $C \parallel T \leftarrow \mathcal{E}_{K_S}(X)$.
3. Using the keys she shares with Bob and Claire individually, Alice prepares the following message which is sent to both Bob and Claire:

$$C \parallel \mathcal{E}_{K_{AB}}(K_S \parallel T) \parallel \mathcal{E}_{K_{AC}}(K_S \parallel T). \tag{1}$$

When Bob and Claire receive this message they can extract $K_S$ and $T$ using the keys they share with Alice, and verify the authenticity of the message.

The idea of this scheme is that since $\mathcal{E}$ is an authenticated encryption scheme, Claire cannot modify $C$ without it being detected by $T$. Additionally, she cannot simply recompute a new ciphertext with the key $K_S$, since she cannot get to the old $T$ value encrypted with the key shared between Alice and Bob.

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# Exploit 2 in "Multi-cast authentication"

Unfortunately, if the authenticated encryption cipher makes it easy to find colliding tags for different messages when the key is known, the above scheme can easily be broken. In particular, Claire can spoof a message to Bob as if it came from Alice. For instance, if the application uses any one of CCM, GCM or OCB as its authenticated cipher, Claire can create another ciphertext $C' \| T$, with $C' \neq C$, using any of the techniques described in Section 3. Assuming Claire is able to intercept the message from the hub to Bob, she can swap $C$ with $C'$ in (1) and Bob will accept this to be a valid message from Alice.

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# Should MAC's retain hash properties when the key is known in the next AEAD?

- There exist many scenarios where it is required that the MAC function retains the properties of a cryptographic hash function, when the key is known.
- However, the current popular AEAD schemes (such as CCM, GCM or OCB) do not have this feature.
- **Arguably**, protocols and applications built on AEAD schemes having this property **will be more robust**, which is in accordance with one of the goals of CAESAR (Competition for Authenticated Encryption: Security, Applicability, and **Robustness**).

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# OWCM: One-Way Counter Mode (initial design)

- Initial design of our AEAD scheme based on the counter mode combined with a use of one-way compression function.
- Can be seen as a modification of the GCM scheme, where the operations in GHASH are replaced by a use of a double-pipe one-way compression function.
- The way how we combine the use of the one-way compression function is similar as that used in the HMAC scheme.
- Our goal was to design a robust AEAD that will offer the uniqueness of the MAC tags even if the secret key is revealed.
- The specific construction of the used one-way function and its efficiency is still under our investigation.
- We would like to hear comments, critique and suggestions from fellow cryptographers attending DIAC 2013.

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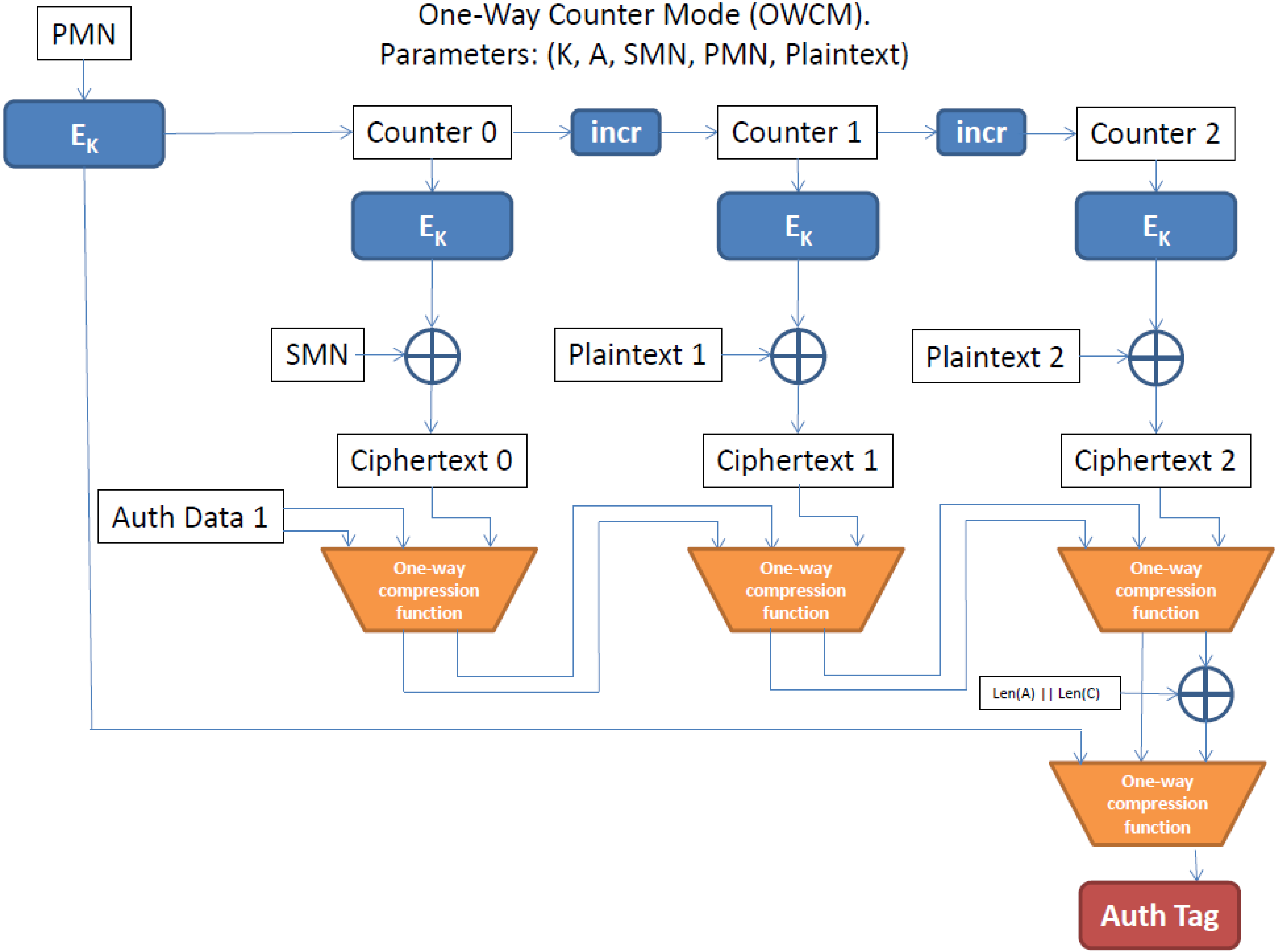
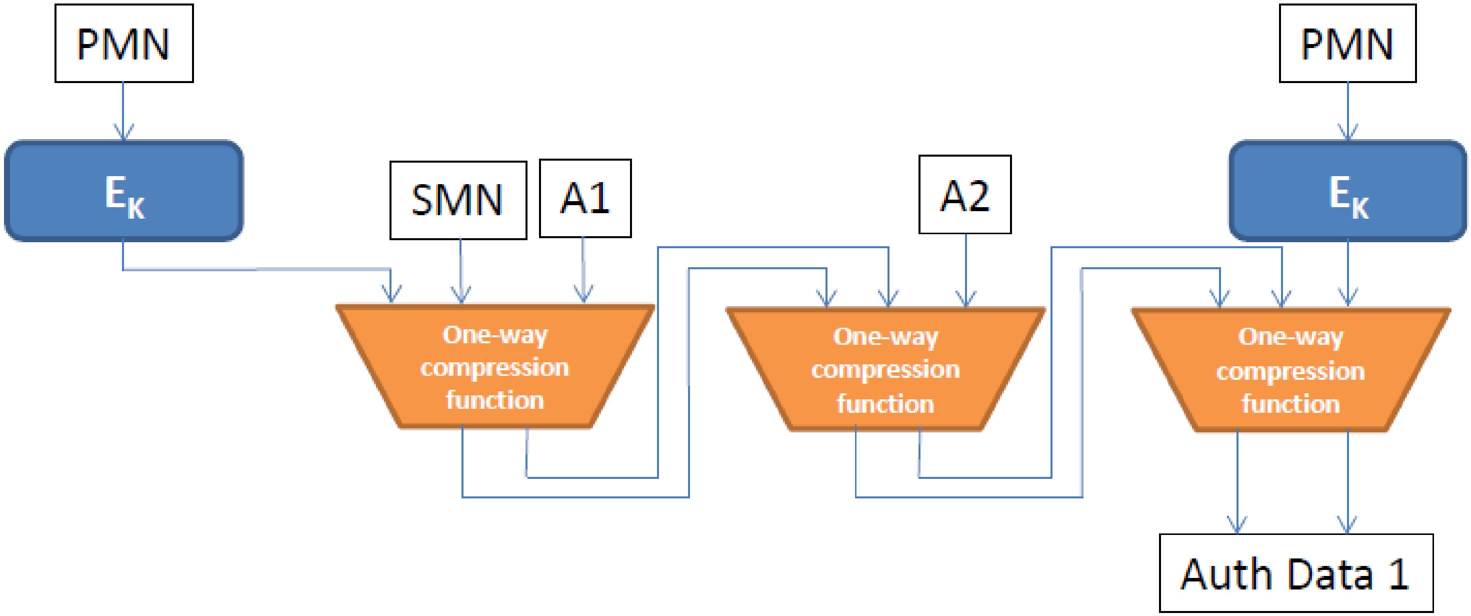
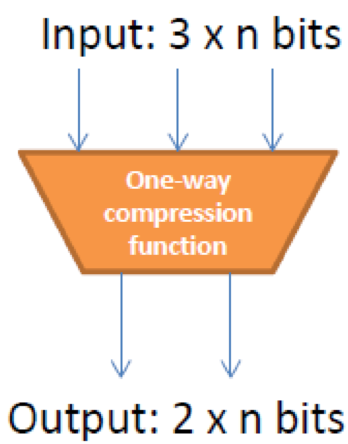
One-Way Counter Mode (OWCM).
Parameters: (K, A, SMN, PMN, Plaintext)



One-Way Counter Mode (OWCM).
Parameters: (K, A, SMN, PMN, Plaintext)



# Thank you for your attention!

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# Appendix 1

# Should MAC's retain hash properties when the key is known in the next AEAD?

Danilo Gligoroski[1] and Hristina Mihajloska[2] and Håkon Jacobsen[1]

[1] Department of Telematics, Norwegian University of Science and Technology (NTNU), Trondheim, NORWAY, {danilog, hakoja}@item.ntnu.no
[2] "Ss Cyril and Methodius" University, Faculty of Computer Science and Engineering (FINKI), Skopje, MACEDONIA, hristina.mihajloska@finki.ukim.mk

**Abstract.** The purpose of this note is to initiate a discussion at DIAC 2013 about the AEAD ciphers with the following property: "*Users of the cipher can easily find different messages that produce same authentication tags.*". We offer several realistic scenarios how to exploit this property in an AEAD cipher. As an easy exercise we describe how one of the communicating parties that posses the secret key can find different messages that give same authentication tag for CCM, GCM and OCB. We point out that none of these scenarios can happen if the authentication is done by the use of cryptographic hash functions such as new SHA-3 or the older HMAC scheme. This final point raise again the necessity of having ultra-fast one-way cryptographic functions.

## 1 Introduction

Cryptographic literature (for example *Handbook of Applied Cryptography* [10]) dealing with the problems of authenticated encryption considers schemes that provide:

- Message authentication that provide data origin authentication with respect to the original message source (and data integrity, *but no uniqueness*).
- Message authentication that provide data origin authentication with respect to the original message source (and data integrity, *AND uniqueness*) - in [10, Remark 9.8, pp. 325] referred to as *MAC resistance with known key.*

Most existing security models for AE [3] and its newer variant AEAD [2] have security proofs where the forgery attempts are done by third parties i.e., the models are designed to detect intentional, unauthorized modifications of the data, and accidental modifications but only by third parties.

However, as noticed in [10, Remark 9.8, pp. 325] if the authentication is performed with a cryptographic hash function[3], for example in the standard *Encrypt-then-MAC* (EtM) scheme using HMAC [8], then the scope of protection against intentional and unauthorized modifications can be meaningfully

[3] There referred to with the abbreviation MDC - Modification Detection Codes.

increased to also include the communicating parties (which holds the keys). In particular, we might want the MAC to retain some of the properties of a hash function when the key is known. We will give examples of some scenarios where this feature can be useful in Section 2.

Unfortunately, the property of upgrading to a hash function under a known key (as in EtM-with-HMAC), can lead to a significant drop in efficiency. To address the need for an efficient AEAD scheme, several schemes have been proposed (OCB [7]) and standardized (CCM [15] and GCM [9]). In these models the problem of non-trusting communicating parties is not addressed at all. Note, that this makes the implicit assumption that the communicating parties trust each other, or the mutual integrity of the messages have to be guaranteed by other cryptographic mechanisms such as digital signatures or HMACs, which return us to the first situation of using the slower EtM-with-HMAC.

CAESAR (Competition for Authenticated Encryption: Security, Applicability, and Robustness) [5] has the term *Robustness* as one of its main goals. Our position is that authenticated ciphers that do not offer distinct tags for distinct messages are possibly not robust ciphers. Additionally, when AEAD schemes are used in protocols and applications, implementers might wrongly assume that different messages will always lead to different tags.

We would like to initiate a discussion on whether this is an issue that should be considered for CEASAR submissions. To paraphrase Bernstein [6] from his recent post to the `crypto-competitions@googlegroups.com` mailing-list (discussing some other requirements, but the statement is also applicable for the issues we discuss in this note):

> "Ignoring these requirements doesn't make them go away. Ciphers that fail to solve the problems simply force users to deploy their own solutions, producing a complicated, fragile system, whereas it's relatively easy to integrate solutions directly into the ciphers."

## 2 Exploits of AEAD ciphers with easy tag collisions

### 2.1 Exploit in "Secure audit logs"

The following exploit scenario is adopted from the Bellare-Yee article [4] about the "Secure audit logs". An attacker is breaking into a machine that keeps activity logs that are encrypted by an AEAD scheme. He/she has obtained the encryption key by some other means (physical force, stealing, ...). In order to protect against such accidental revelation of encryption keys, the authentication tags are kept in a separate and write protected area. This way the existing encrypted logs are protected from being overwritten with other fake logs. However, if the AEAD scheme was implemented by CCM, GCM or OCB, the attacker can erase his/her previous (unsuccessful) attempts to break-in by simply producing a log file that has the same authentication tag as the originally encrypted log.

### 2.2 Multi-cast authentication

The following scenario is an adoption of the *multidestination secure mail problem*, discussed by Mitchell and Walker [12, 11], to the setting of ciphers providing authenticated encryption.

Suppose Alice wants to send an authenticated message to Bob and Claire in a group chat application. Assume further that all group communication goes through a central hub which relays a single message from one party to the other two. At the start of the session the application establishes pairwise symmetric keys among the participants, i.e. Alice and Bob shares the key $K_{AB}$, Alice and Claire shares the key $K_{AC}$ and Bob and Claire shares $K_{BC}$. Exactly how these keys are established is immaterial.

Assume that the chat application employs an AEAD scheme. Following the notation of [13], an AEAD scheme is a function $\mathcal{E}\colon \mathcal{K}\times\mathcal{T}\times\mathcal{A}\times\mathcal{S}\times\mathcal{M} \to \{0,1\}^*$, over the space of *keys*, *public message numbers*, *associated data*, *secret message numbers* and *messages*. We write this function more compactly as:

$$C \parallel T \leftarrow \mathcal{E}_K^{N,A}(S, M),$$

where $C \parallel T$ denotes that the ciphertext can be parsed into an "encryption-part" and a "tag-part". Since the nonce and associated data are not very relevant for this exposition, we will for clarity ignore them in the above notation and simply write $\mathcal{E}_K(M)$.

In order to send the message $X$ to both Bob and Claire, Alice proceeds as follows:

1. She selects a session key $K_S \in \mathcal{K}$ which will be used for this one message only.
2. She computes the ciphertext $C \parallel T \leftarrow \mathcal{E}_{K_S}(X)$.
3. Using the keys she shares with Bob and Claire individually, Alice prepares the following message which is sent to both Bob and Claire:

$$C \parallel \mathcal{E}_{K_{AB}}(K_S \parallel T) \parallel \mathcal{E}_{K_{AC}}(K_S \parallel T). \tag{1}$$

When Bob and Claire receive this message they can extract $K_S$ and $T$ using the keys they share with Alice, and verify the authenticity of the message.

The idea of this scheme is that since $\mathcal{E}$ is an authenticated encryption scheme, Claire cannot modify $C$ without it being detected by $T$. Additionally, she cannot simply recompute a new ciphertext with the key $K_S$, since she cannot get to the old $T$ value encrypted with the key shared between Alice and Bob.

Unfortunately, if the authenticated encryption cipher makes it easy to find colliding tags for different messages when the key is known, the above scheme can easily be broken. In particular, Claire can spoof a message to Bob as if it came from Alice. For instance, if the application uses any one of CCM, GCM or OCB as its authenticated cipher, Claire can create another ciphertext $C' \parallel T$, with $C' \neq C$, using any of the techniques described in Section 3. Assuming Claire is able to intercept the message from the hub to Bob, she can swap $C$ with $C'$ in (1) and Bob will accept this to be a valid message from Alice.

## 3 Examples: How to find tag collisions for CCM, GCM and OCB

### 3.1 How to find tag collisions for CCM

CCM is the abbreviation for Counter with Cipher Block Chaining-Message Authentication Code [15]. CCM authenticated encryption with associated data basically combines the counter (CTR) mode for a data encryption and CBC-MAC mode for a data authentication. It works only with an approved symmetric key block cipher algorithm whose block size is 128 bits, such as AES [1]. Only one underlying key is used for both the authentication and the encryption part. The input to CCM includes three elements: 1) data that will be both authenticated and encrypted, called the payload $P$; 2) associated data, $A$ that will be authenticated but not encrypted; and 3) a unique value, called a nonce $N$, that is assigned to the payload and the associated data.

To process each message block, a counter is encrypted with the underlying block cipher and the result is XORed to the message for ciphertext production. The message is also XORed with the accumulator which is then encrypted. The accumulated value corresponds to the internal message authentication state, and is kept being accumulated and updated until all the messages are processed. After all blocks have been processed, the output is XORed with the first encrypted nonce, producing the authentication tag. At the end of processing of each message block, the counter is also incremented for the next message block encryption.

We give one scenario how to find colliding messages for CCM.

If we choose two consecutive message blocks $P_1$ and $P_2$, the formulas for the internal message authentication state are given below:

$$X_1 = \mathcal{E}_K(X_0 \oplus P_1)$$
$$X_2 = \mathcal{E}_K(X_1 \oplus P_2)$$

where $X_0$ is the accumulated value from the previous internal message authentication state. If we replace the first message block $P_1$ with an arbitrary new value $P_1'$ then we have:

$$X_1' = \mathcal{E}_K(X_0 \oplus P_1')$$

In the next state we want to produce the same authenticated value $X_2$, but now with the new value $X_1'$ and a second message block $P_2'$ that will compensate the introduced new value of $P_1'$:

$$X_2 = \mathcal{E}_K(X_1' \oplus P_2').$$

Thus,

$$X_1 \oplus P_2 = X_1' \oplus P_2',$$

so, $P_2'$ should be:

$$P_2' = X_1 \oplus P_2 \oplus \mathcal{E}_K(X_0 \oplus P_1'). \tag{2}$$

### 3.2 How to find tag collisions for GCM

GCM is the abbreviation for Galois/Counter Mode [9]. The encryption stage is similar to CCM, but authentication is realized via universal hashing of the produced ciphertext blocks over a binary Galois Field $GF(2^{128})$ instead of the second encryption in CCM. After all message blocks have been processed, the output is XORed with the length of the message and associated data, and authenticated just in the last step to produce a tag together with already encrypted nonce.

To find two different plaintexts with the same authentication tag, we choose two consecutive message blocks $P_1$ and $P_2$. The formulas for the internal message authentication state are given below:

$$X_1 = (X_0 \oplus C_1) \bullet H,$$
$$X_2 = (X_1 \oplus C_2) \bullet H,$$

where $X_0$ is the accumulated value from the previous internal message authentication state, and $C_1$ and $C_2$ are the ciphertexts produced from the encryption phase.

If we replace the first message block $P_1$ with an arbitrary new value $P_1'$ then we have:

$$X_1' = (X_0 \oplus C_1') \bullet H.$$

In the next state we want to produce the same authenticated value $X_2$ but now with the new values $X_1'$ and changed second message block $P_2'$:

$$X_2 = (X_1' \oplus C_2') \bullet H.$$

Thus,

$$X_1 \oplus C_2 = X_1' \oplus C_2',$$

where,

$$C_2' = (X_1 \oplus C_2) \oplus X_1'.$$

So, for $P_2'$ we have:

$$C_2 = P_2 \oplus \mathcal{E}_K(\mathrm{CTR2}),$$
$$C_2' = P_2' \oplus \mathcal{E}_K(\mathrm{CTR2}),$$

where $\mathrm{CTR2} = \mathrm{incr}(\mathrm{CTR1}) = \mathrm{incr}(\mathrm{incr}(N||0^{31}1))$ is a counter, produced from the nonce:

$$P_2' = \mathcal{E}_K(\mathrm{CTR2}) \oplus (X_1 \oplus C_2) \oplus (X_0 \oplus C_1') \bullet H. \tag{3}$$

In Fig. 1 the images a) and c) give the same tag. Note that image a) is the original message, image b) has changed one block in the original message and in the image c) we have used equations (2) or (3) with the values for the second changed block in order to produce the same tag.

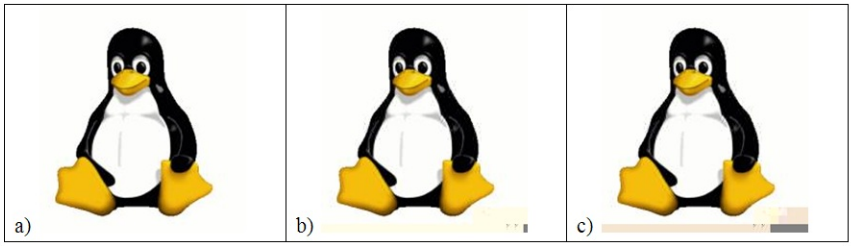


**Fig. 1.** Simple example of messages with colliding tags for CCM or GCM.

### 3.3 How to find tag collisions for OCB

OCB3 is the AEAD modification of Offset CodeBook mode [14](OCB). It uses a multiplication in $GF(2^{128})$ but in a simpler way than in GCM. For every message block, each noninitial offset is computed from the prior one by multiplying it by a constant (an operation that has been called *doubling*). OCB3 uses different initial offsets for encryption and authentication phases. For the first one, offset is calculated as a nonce- and key-dependent value, but in the latter it starts from 0. This scheme is on-line: one does not need to know the length of the associated data, the plaintext nor the ciphertext in order to proceed with encryption or decryption.

The tag is produced from the encrypted value of the *Checksum* which is computed as:

$$Checksum = P_1 \oplus \cdots \oplus P_{m-1} \oplus P_m. \tag{4}$$

Since the tag directly depends on the *Checksum* (4) which depends only on the plaintext, we can have the same checksum between two totaly different files. Just the final block of the second file has to be computed to make the checksum the same.

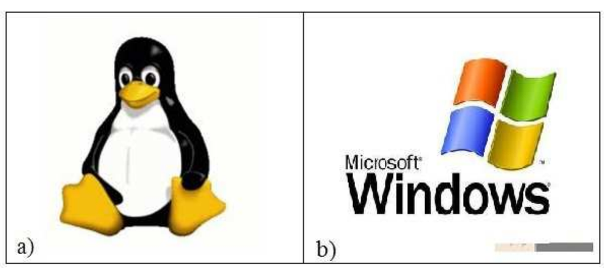


**Fig. 2.** Simple example of messages with colliding tags for OCB.

In Fig. 2 we can replace the image a) with any image b), and we just compensate the final block of b) in order to produce the same *Checksum* and then the same tag.

## 4 Conclusion

We have shown that there exist scenarios where it is required that the MAC function retains the properties of a cryptographic hash function, when the key is known. However, the current popular AEAD schemes (such as CCM, GCM, or OCB) do not have this feature. Arguably, protocols and applications built on AEAD schemes having this property will be more robust, which is in accordance with one of the goals of CAESAR. At the forthcoming DIAC 2013 we would like to initiate a discussion about this topic.

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