X-pire! – A digital expiration date for images in social networks

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Abstract

The Internet and its current information culture of preserving all kinds of data cause severe problems with privacy. Most of today’s Internet users, especially teenagers, publish various kinds of sensitive information, yet without recognizing that revealing this information might be detrimental to their future life and career. Unflattering images that can be openly accessed now and in the future, e.g., by potential employers, constitute a particularly important such privacy concern. We have developed a novel, fast, and scalable system called X-pire! that allows users to set an expiration date for images in social networks (e.g., Facebook and Flickr) and on static websites, without requiring any form of additional interaction with these web pages. Once the expiration date is reached, the images become unavailable. Moreover, the publishing user can dynamically prolong or shorten the expiration dates of his images later, and even enforce instantaneous expiration. Rendering the approach possible for social networks crucially required us to develop a novel technique for embedding encrypted information within JPEG files in a way that survives JPEG compression, even for highly optimized implementations of JPEG post-processing with their various idiosyncrasies as commonly used in such networks. We have implemented our system and conducted performance measurements to demonstrate its robustness and efficiency.

1 Introduction

The past decade has brought dramatic changes in the way we live and work. The wide acceptance of social networks’ free dissemination of personal information, the proliferation of networked devices that provide a means for such communication anytime, anywhere, and the resulting abundance of published information present significant opportunities. However, this information culture of acquiring and preserving all kinds of data also causes severe problems with privacy. Most of today’s Internet users, especially teenagers, publish various kinds of sensitive information, yet without recognizing that revealing this information might be detrimental to their future life and career. Unflattering images – typically published within social networks – that can be openly accessed now and in the future, e.g., by potential employers, constitute a particularly important such privacy concern. This scenario is especially problematic since published information is cached by search engines, duplicated by mirrors and aggregators, and thus available essentially forever.

In contrast to the current situation, archiving large amounts of data was traditionally expensive and cumbersome, and a large-scale acquisition of sensitive information was close to impossible. In fact, it was the exception rather than the rule that personal information was
explicitly archived; hence most such information became unavailable over time. (Moreover, even if photographs were properly stored, papers were properly filed, etc. these data were typically not accessible without explicit consent of the user.) The Internet with its current information culture and its infinite memory thus clashes with people’s established expectation about the life-time of the information that they divulge to the public. This observation is substantiated by a work of Mayer-Schönberger [21], who nicely compares modern electronic storage in the age of information technology with the traditional way in which paper documents are archived. His major observation was that retrieving information was traditionally often close to impossible after a certain period of time, and that this situation fuels the expectations of average users as far as expiration of data is concerned. In our current information culture, however, acquiring and preserving large amounts of data is quick and easy.

The challenge is now to imitate the traditional expiration of data by developing a digital expiration date that lives up to the demands of the modern information culture – both in terms of user privacy and the seamless integration into common user activities in the Internet, such as publishing and consuming digital content. If published data becomes unavailable after a certain time, then this closely resembles the behavior of the paper-based world and thus brings the situation in-line with the prevailing user expectations.

1.1 Our Contribution

We have developed a novel, fast, and scalable system called X-pire! that allows users to set an expiration date for images in social networks (e.g., Facebook and Flickr) and on static websites, without requiring any form of additional interaction with these web pages. Once the expiration date is reached, the images become unavailable. Moreover, the publishing user can dynamically prolong or shorten the expiration dates of his images later, and even enforce instantaneous expiration. In the following, we describe our overall approach and highlight major design decisions.

High-level view on the protocol. We implement the digital expiration date for images as follows: Images are encrypted by a symmetric key that is stored on a centralized keyserver. Access to the key is granted only until the expiration date set by the publisher during the encryption process. After encrypting an image, it is stored on a webserver to be viewed by the public. In order to view protected images, the key is retrieved from the keyserver and used to replace the encrypted image by its decrypted version. The keyserver additionally supports management functionality for already created keys; in particular this allows for prolonging and shortening the expiration date of keys. The latter can even be used to let images expire instantaneously.

The major technical challenge: Dealing with JPEGs. Images are typically stored as JPEG files in static websites and in social networks. We thus have to embed encrypted images into JPEG files in a way that adheres to the JPEG format. Rendering this approach possible for social networks – where by far the largest number of sensitive images are published – is conceptually challenging, since social networks typically re-encode images using JPEG compressions. Thus, simply uploading the encrypted data $c$ would result in the publication of a re-encoded version $c'$, in which the encryption would be fully destroyed. As a consequence, nobody would be able to decrypt the image anymore; it would expire instantaneously. To remedy this situation, we have developed a novel technique for embedding encrypted information within JPEG files in a way that survives JPEG compression. Solving this problem was not only challenging in theory. The implementations of JPEG used in the Internet are often highly optimized versions that do not strictly follow the JPEG standard and thus disregard accuracy in favor of performance (examples include rounding errors, lossy conversions, etc.). Our technique needs
no explicit support from existing webservers or social networks, and thus allows for a seamless integration into the existing infrastructure.

**Mitigating the data duplication problem.** When protected images are published using our approach they can be viewed by the public until the expiration date is reached. Thus, an attacker will also be able to view these images in this time period (under the assumption that no additional protection mechanisms are in place, e.g., images are only visible to the friends of the user within the privacy settings of Facebook). The attacker is thus in principle able to store the keys needed for their decryption, and consequently to use them to decrypt these images even after their expiration date. Although this limitation is inherent to the problem, and thus equally applies to other approaches that strive for a digital expiration date (see the Related Work section below), we are the first to consider this case to the best of our knowledge. Using our centralized approach for the keyserver allows us to set up effective countermeasures to prevent an attacker from acquiring keys in a large-scale, automated manner. First, in order for users to retrieve a key, our approach requires them to send a hash of the encrypted image that they intend to view. Since computing this hash requires to download the encrypted image that is much larger than a key, it serves as convincing evidence that the corresponding band-width was consumed, thereby rendering a simply key-requesting attack much more costly. Second, we rate limit the retrieval of a large number of keys. Finally, our approach enables the publisher to additionally require users to solve Captchas before viewing the image (e.g., one for every photo album they are viewing). We stress that our protocol, and in particular its capability to deal with JPEGs, would work as well in a decentralized setting, see Section 1.2 on Related Work.

**Efficient, scalable, one-click implementation.** We have implemented our system and conducted performance measurements to demonstrate its efficiency. The software integrates seamlessly into the user’s workflow when surfing on the Internet. The natural solution was to implement the client applications as browser plug-ins such that the existing workflow is not interrupted by starting an external application. In the viewing process no user interaction with the software is required; to publish an image, the user needs only to drag-and-drop this image into the application, and enter a desired expiration date.

1.2 Related Work

Meyer-Schönberger [21] presents a nice introduction to the problems caused by the infinite memory of our information culture. He proposes to tag sensitive data with an expiration date and to require all servers handling such data to obey the expiration date. However, many servers would presumably not be interested in cooperating since their business model relies crucially on the collection and openly distribution of user data. Also a legal requirement forcing servers world-wide to obey to delete data seems out of reach in the near future. Moreover, it is technically difficult to audit whether the server actually deleted the data. Within the last years several attempts have ought to solve the problems that arose with the Internet’s infinite memory.

The first group of solutions adds an expiration date to data. It is implemented by encrypting the data itself with a symmetric encryption key and restricting the access to these keys afterwards. We stress that none of these works is capable of dealing with scenarios where published data is subsequently manipulated, e.g., re-encoding of JPEGs as commonly done in social networks such as Facebook. Similarly, the threat of storing keys during validity has not been considered thus far.

The first works that pursued this solution path aimed at securely deleting data including copies in archives. However, these works mainly target corporate use, and come with different requirements and design principles that are incompatible with our setting. In particular,
all servers are aware of the encrypted nature of the data, post-processing of the data is not supported, an adversary grabbing all keys while the data is available is not considered, and in some proposals the keyservers additionally aids in decrypting the data. The first such system we are aware of is [2], which provided the basic principles. A prominent system is the Ephemerizer [28 29], which was later improved [24].

Vanish [8] constitutes a recent, promising approach along similar lines by storing shares of the keys in dynamic hash tables (DHTs), a data structure that underlies P2P-networks. The DHT will by design stop replicating the key after a certain time, so the key is basically lost after that and the encrypted data becomes unavailable. An attack against the proposed implementation was recently published [37], using a Sybil attack on the DHT. An improved design of DHTs should fix this problem, at the cost of relying on a (slightly) more specialized design. We stress again that images and post-processing in general is not supported by this approach. Another difference is that we decided to ground our approach on a centralized keyserver solution, in order to mitigate the threat of key storage / data duplication, see Section 2.3. However, we emphasize that our proposed techniques for dealing with JPEG post-processing are applicable to their decentralized approach as well. Another current limitation of this approach is that the time after which data is no longer replicated by common implementations is often too short to be useful (8 hours for the proposed implementation). In case longer timeouts are needed, keys have to be kept "alive" by actively taking measures.

The EphCom system [24] is very similar to Vanish, but uses a clever trick to store the keys in the cache of DNS servers, based on the presence of generated hostnames. Similar to Vanish, post-processing of protecting data and the threat of retrieving keys during validity is not considered, and for publishing data that expires at a specific time one needs to find a (large) number of domains that have the same TTL; their study shows that TTLs of more than 7 days are rather uncommon.

The second group of solutions aims at securing privacy-sensitive content published in social networks, but based on a different assumption: The central difference is that these approaches store all data on an external, trusted server, which we believe does not scale reasonably well given the vast amount of images published every day. One example is FaceCloak [20], similar approaches include [19] and [9].

Our techniques for robustly embedding information within JPEG files furthermore resemble steganographic techniques to embed data into images and other data formats, e.g., [3]. Since these steganographic techniques additionally have to ensure that they embed information in an undetectable manner, existing solutions do not achieve sufficiently good data rates to robustly embed encryptions of high quality images into images that are accepted by social networks. We thus had to developed our own routine for embedding arbitrary data into JPEG images with a data rate that is sufficient for social networks.

1.3 Paper Outline

Section 2 provides a general overview of our approach. The full technical details of the system as well as necessary background information are provided in Section 3 and Section 4. Our implementation is described in Section 5, which is followed by the results of an experimental analysis of the implementation in Section 6. We provide a discussion on X-pire! and its functionality in Section 7, before we conclude and present future work in Section 8.
2 Schematic Overview of X-pire!

We have developed a novel, fast, and scalable system that allows users to set an expiration date for images in social networks (e.g., Facebook and Flickr) and on static websites, without requiring any form of additional interaction with these web pages. The expiration date is chosen by the user who publishes the data. Alternatively, users can decide to specify an undefined expiration date at the time of publishing their images, and instantiate / alter it later. Once the expiration date is reached, the images become unaccessible.

2.1 Protocol Overview

A high-level overview of the protocol and the involved participants is given in Figure 1. The involved participants of the protocol are the content publisher $P$, the content server $C$ (which is often a social network), and the viewer $V$. We add a specialized keyserver $K$ to the setup, who is trusted not to hand out keys after their expiration date has been reached.

Our approach distinguishes three phases: 1) the content publishing phase, i.e., adding the expiration date and storing the resulting images, 2) the viewing phase, i.e., visiting the corresponding websites containing these images, and 3) the update phase, i.e., shortening or prolonging the expiration date of published images.

2.1.1 Publishing Phase

When publishing an image $d$, the publisher $P$ first contacts the keyserver $K$ with the request for a key. The keyserver creates a new key $k$ and returns it to the publisher. $P$ now encrypts the image $c \leftarrow E_k(d)$, hashes this ciphertext $\text{hash} \leftarrow H(c)$, and sends the hash $\text{hash}$ and the expiration date $\expdate$ back to the keyserver, which adds the hash and the expiration date to the respective entry. $K$ finishes the key creation by sending the key ID $id_k$ back to the publisher. The encrypted data $c$ is embedded into a valid JPEG image (see Section 2.2) and stored on the content server $C$.

The reason to store keys rather than encrypted images is that keys are much easier to handle due to their small size. Thus users can utilize the large storage capacity offered by the websites/social networks, and avoid turning the keyserver into a performance bottleneck.

2.1.2 Viewing Phase

When a user wants to view an encrypted image $c$ on a website, the user sends its hash $H(c)$ and the key identifier $id_k$ of the key $k$ retrieved from the image to the keyserver. The keyserver checks that the expiration date has not yet been reached, checks the correctness of the additional data,
and (if all these checks passed successfully) sends back the key $k$. If the key gets delivered, i.e., the expiration date of the key $k$ has not yet been reached, the image $c$ decrypted, and the user is able to view the image $d$. The reason to send the hash $H(c)$ is to provide convincing evidence that the corresponding image was really downloaded. This renders a simply key-requesting attack much more costly in terms of band-width consumption.

2.1.3 Update Phase

We provide a comprehensive key-management interface that allows users to later review all previously generated keys along with a description of the corresponding images. This enables the publisher to update existing expiration dates. In particular, a publisher can prolong or shorten existing expiration dates, and even enforce instantaneous expiration of published images if desired. We describe the protocol in more detail in Section 3.

2.2 Embedding encryptions to JPEG

Our approach requires the encryption data $c$ to be stored on the content-server $C$. This task is inherently more difficult for images, since social networks such as Facebook and Flickr scale and re-encode images before storing them (in contrast to scenarios where data is not subsequently manipulated [8, 34]). First, this means that an upper bound on file size and image dimensions is enforced upon uploaded images. Second, and more important, the image is re-encoded using JPEG compression. Thus, simply uploading the encrypted data $c$ would result in the publication of a re-encoded version $c'$, in which the encryption would be fully destroyed. As a consequence, nobody would be able to decrypt the image anymore; it would expire instantaneously. Therefore, a robust embedding is required. Common steganographic techniques do not achieve sufficiently good data rates to robustly embed high quality images in images facing such constraints. We have developed a novel, robust embedding of arbitrary data into JPEG images that achieves sufficiently good data rates such that encrypted images can be embedded into JPEG images that are accepted by social networks. We describe this embedding in detail in Section 4.

2.3 On the centralized approach

Decentralized solutions are often considered superior to centralized ones, as they typically offer better performance and scalability. In the situation we are facing in this paper, however, we believe that a centralized approach has advantages that outweigh the benefits of decentralization, as described in detail below. We hence decided to ground X-pire! on a centralized keyserver, but we stress that our technique for dealing with post-processing of images, which arguably constitutes our main contribution, can be similarly incorporated to decentralized systems like Vanish [8].

- Using a centralized keyserver allows us to increase the costs for an attacker to retrieve keys by requesting users to provide convincing evidence that they actually know the data for which they are requesting the key for. This is ensured by storing and matching the hash of the encrypted data.
- Using a central keyserver we can limit the rate of key requests possible from single IP-addresses and IP-ranges.
- If desired, our approach enables the publisher to additionally require users to solve Captchas before viewing the image (e.g. one for every photo album they are viewing). This can be easily realized by having the centralized keyserver generate the Captcha, and it effectively raises the bar that a large number of keys will be downloaded using automated crawling.
We describe more details about the measures taken against collecting keys in Section 3.

Besides these security issues, a central keyserver also provides more flexibility in the expiration dates than decentralized solution attempts. In addition to providing faster access, a centralized approach exceeds a peer-to-peer setting in terms of scalability in this scenario, where only short keys are stored. Moreover, it is arguably more privacy-friendly to trust a dedicated keyserver rather than trusting the social networks, whose business model relies crucially on the collection and openly distribution of user data. A centralized keyserver does not have a business incentive to act unexpectedly, but rather would lose its credibility if it becomes public that the server acts inappropriately with these keys. We currently provide our own dedicated keyserver, but we additionally released the keyserver application such that other trustworthy authorities or individuals can set up a keyserver as well. In the case that a user is not willing to trust any of these keyservers, he can still set up a personal keyserver himself to avoid such trust dependencies.

2.4 Implementation

We provide a complete working implementation of the protocol. The Browser extensions are implemented as a Firefox plug-in that is functional on all major platforms (Windows, Linux, Mac). The image embedding part as described above is currently implemented to work on Facebook [4], Flickr [6], and wer-kennt-wen [36] (a famous German social network). We do not expect major problems in adding support for further social networks, since all social networks we are aware of rely on common techniques for JPEG compression based on the libJPEG. To store an image, the plug-in prompts for the files, and performs all operations described above. It stores the processed files in a temporary directory, from where they can be uploaded by any upload-mechanism that is offered by the social network.

When users are visiting a website, the plug-in searches for protected images, automatically retrieves the required keys from the keyserver, and displays the decrypted image inline on the page without any further user interaction. If the plug-in is not installed, these images show a brief statement that the required plug-in is missing, along with a link where the plug-in can be downloaded. A detailed description of the process of detecting and displaying protected images can be found in Section 5.

3 Detailed Protocol Description

In this section, we give a detailed description of the protocol that underlies our approach. The protocol considers three participants: the data publisher \( P \), the data viewer \( V \), and the keyserver \( K \). Consequently, our software is split into three applications: the X-pire!-Publisher, the X-pire!-Viewer, and the X-pire!-Keyserver. The X-pire!-Publisher establishes a communication channel between the publisher and the keyserver, and adds an expiration date to the desired images before they are uploaded to, e.g., Facebook, in the usual manner. The X-pire!-Viewer permits the viewers to display these uploaded images, provided that the respective expiration dates have not yet been reached. In order to display these images, the X-pire!-Viewer establishes a communication channel between the viewer and the keyserver. Finally, the X-pire!-Keyserver creates, stores, and hands out the necessary keys as described above, and it allows publishers to subsequently update the expiration dates of their keys.

\(^1\)We sometimes additionally speak about a content server \( C \): an arbitrary server of one of the supported social networks that takes care of storing and providing the content that is created by our protocol. However, this entity \( C \) is not required to take part in the actual protocol.
In the following, we describe these communication protocols in detail. We distinguish three phases: the content publishing phase, the viewing phase, and the update phase.

3.1 Publishing Phase

In the publishing phase, the publisher requests a key by invoking a key creation process on the keyserver (CreateKey) and by providing his account information cred. The keyserver generates the key $k$ and sends it along with a session ID $id_s$ back to the publisher (see below for how $id_s$ is used). The publisher receives the key and encrypts the image $d$ that he wants to upload with $k$ as

$$c \leftarrow E_k(d).$$

For encryption we use the Advanced Encryption Standard (AES) \cite{25} with a key length of 256 bits and Cipherblock Chaining Mode (CBC) \cite{22}.

The ciphertext $c$ needs to be embedded into another image file container to obtain a valid image file emb (details of the embedding are shown in Section 3.4):

$$emb \leftarrow Embed(container, c)$$

Without embedding $c$ into emb it would not be possible to upload it as an image to a social network since $c$ constitutes a ciphertext and hence does not fit the format of an image file.

We stress that developing a suitable embedding is difficult, since social networks commonly apply image post-processing techniques, and thus to be suitable, an embedding must be resistant to JPEG recompression.

After encrypting the image $d$ to the ciphertext $c$, the publisher replies by sending the hash of the newly encrypted image $c$ back to the keyserver. The hashes are computed by applying the SHA256 \cite{26} hash function $H$ to the encrypted images:

$$hash \leftarrow H(c).$$

The hashes are sent to the keyserver by invoking AddHashes on the server side using the previously received session ID $id_s$ and the following additional payload:

1. expdate: the expiration date chosen by the user,
2. hash: the hash of $c$, and
3. description: an identifier to describe (collections of) images; it has to be explicitly set by the user.

In order to complete the publishing phase, the keyserver stores the key $k$, the expiration date expdate, the description description and the hash $hash$ to its database thereby creating the unique key ID $id_k$, which is also stored. Finally, it acknowledges the key creation process by returning $id_k$ of the previously created key $k$ to the publisher.

The hash is required because it serves as convincing evidence that the whole data has been downloaded before the key was requested. Finally, the identifier description plays two important roles in our protocol.

First, it is used for a subsequent key management. Together with the creation date and the expiration date, the description yields a unique identifier that later enables users to identify specific encryption keys, e.g., for prolonging or shortening the expiration date. In particular, by changing the expiration date it is possible to let images expire instantaneously if desired. Furthermore, all images prepared in the same step using one description share the same expiration date.

Second, it allows for grouping images, and for a controlled use of Captchas. If several images are prepared for uploading at the same time using the same description, all images are encrypted
with the same key. This allows for syntactically grouping images, and for a simpler decryption functionality, where only one key needs to be requested for one set of images. Moreover, it allows for a controlled usages of Captchas: The publisher can decide to require Captchas for additional security. In this case, every viewer will have to solve a Captcha before the correct image is displayed. Images with the same description will receive one joint Captcha. The idea behind a set of images using the same description and therefore having the same encryption key is that, e.g., whole albums can be viewed after providing the solution to a single Captcha. From a security perspective, disabling Captchas, or only asking for one Captcha per collection of images, reduces the security and increases the vulnerability to automated crawling attacks. However, for reasons of efficiency and seamless integration, we prefer to keep the number of Captchas low.

3.2 Viewing phase

After the image $emb$ with the embedded ciphertext $c$ has been created, it can be uploaded to the target web site, e.g., to Facebook. From that time onward, it can be viewed using the viewer plug-in by any eligible user that has access to the (encrypted) image on Facebook. The viewer is required to decrypt the prepared images and to correctly display them, provided that they have not yet reached their expiration date. Without the viewer, only the container images providing a link to the viewer application are shown; the actual image stays encrypted.

When a user enters the website of one of the supported social networks with a browser that has the viewer application installed, the viewer starts to search for encrypted images. If it detects an encrypted image, it starts the decryption process. The viewer extracts the key identifier $id_k$ as well as the address of the server storing the key (keyserver) and computes the SHA256-hash of the encrypted image. This information is used to invoke the GetKey process at the keyserver. The server performs a key lookup, and distinguishes two cases: If the expiration date has already been reached, it returns an error code indicating the expiry; if the expiration date has not yet been reached, the server checks whether the settings of the key require the viewer to solve a Captcha to see the decrypted picture.

If no Captcha is required, the server sends the requested key along with $id_s$ back to the viewer. The viewer uses the retrieved key to decrypt the detected image. Afterwards, the detected image is locally replaced by the decrypted one.

If a Captcha is required, the server sends a CAPTCHA_REQUESTED request to the viewer. The viewer requests a challenge from the Captcha service using the public key of the keyserver, the user solves this challenge and sends it together with the solution to the keyserver. The keyserver uses its private key and verifies together with the Captcha service whether the solution was correct. If a wrong solution for the Captcha is sent to the keyserver, the server notifies the viewer that the solution was wrong and invalidates the challenge during its verification with the Captcha service. The viewer then decides whether to give up or try again by requesting a new Captcha. If the correct solution is provided, the server sends the requested key along with $id_s$ to the viewer as described above. Adding Captchas results in additional communication between the Captcha service and the viewer as well as between the Captcha service and the keyserver.

3.3 Update Phase

Our protocol allows users to manage and update the keys that they have already created with the keyserver. The keyserver offers a web interface that provides all necessary functionality to identify already existing keys using a unique identifier comprised of the description, the create date, and the expiration date, and to modify the current settings. The main functionality of the key management is to allow the publisher to prolong or shorten the expiration dates for
keys that have already been created. In particular, it allows a user to enforce an instantaneous expiration of his images.

3.4 The Embedding

The main goal of our approach is to find a method for adding an expiration date to an image that is subsequently hosted on an existing web site. Because encrypting images and later restricting the key access while retaining a valid image files is the only possibility to solve this problem, we must embed all data needed for the decryption into the image file itself. To publish images to the internet users can either provide them inside of plain HTML-pages by the $\langle \text{img} \rangle$-tag (users need to have access to the source of these pages in order to add images) or provide them within special Internet services like social networks (e.g. Facebook or Flickr) where users provide their images as image files to an upload-interface. To the best of our knowledge, although social networks support several image formats for uploading, all existing social networks store the final image as a JPEG file. Therefore, our approach provides a solution for JPEG files. Since the expiration date is implemented by encrypting data and restricting the access to the keys needed for decryption to the time until the expiration date is reached, all information needed to retrieve the key for decrypting the image needs to be stored inside of the JPEG file:

- the keyserver address $\text{keyserver}$ to place the query,
- the key ID $id_k$ to identify the needed key,
- the version ID $version$, and
- the encrypted image $c$ to compute the hash $hash$ and to decrypt the image itself later.

We have to decide where in a valid JPEG file the data can be embedded, without causing the file to be rejected by upload-interfaces. Inside of the $\langle \text{img} \rangle$-tag, HTML expects one of the supported image formats (e.g. JPEG, PNG, GIF). If a JPEG file is encrypted by standard methods, the outcome is a ciphertext and not an image file. Therefore, it is necessary to embed the ciphertext into another “container”-JPEG such that the outcome is still a valid JPEG. In general, one can think of two approaches to achieve this: one either stores the encryption within a header field, or inside the actual image data. We will discuss both approaches in detail in Section 4.2 after we have introduced relevant background information on JPEG in Section 4.1, but we anticipate the major lessons learned and results here: Embedding the encryption in the header information is significantly more efficient and easier to handle; however, virtually all social networks remove all header information for uploaded images, rendering this approach completely useless for those sites. The alternative – embedding within the actual image data – is significantly more challenging because our embedded encryption must survive the JPEG recompression that these sites apply to the image data. We developed a suitable such embedding that renders the approach possible and practical for social networks.

4 Surviving JPEG Compression

In this section we first provide general background information about the JPEG standard. Afterwards we discuss in detail the two embedding approaches mentioned above.

4.1 Details on JPEG

The JPEG standard was developed by the Joint Photographic Experts Group in 1992 [16] and is the current de-facto standard for compressing images in the Internet. A JPEG image is most commonly stored in a file according to the JPEG File Interchange Format (JFIF) [10]. This standard defines the complete structure of the file and describes how and where to store all the
Figure 2: Overview of JPEG encoding and decoding

4.1.1 RGB to YCbCr Conversion

The starting point for creating a BDCT image is an RGB image consisting of \( x \) by \( y \) pixels. RGB images store for every pixel \((x, y)\) the red, green and blue color components. All three color channels together are converted to the YCbCr color model that consists of the luminance channel \( Y \) and the two chrominance channels \( C_b \) and \( C_r \). The luminance channel \( Y \) provides information about the brightness, whereas the two chrominance channels \( C_b \) and \( C_r \) provide color information. The conversion between the two color models is not necessarily lossy. However, divisions often introduce rounding errors when real valued results are converted back to integer values, and both the input RGB-values and the resulting YCbCr-values are typically integer values.

As an optional step, the color model conversion might be followed by subsampling. Subsampling was not included in the original JPEG standard, but was later published as an extension [17]. Subsampling reduces the size of a channel by downsampling it in a horizontal and/or vertical direction. Subsampling is typically applied only to the chroma channels; we hence assume here that the luminance channel is left unchanged. A common case for highly compressed JPEG images is a 2x2 chroma subsampling where only half of the information in the horizontal and vertical directions is kept. Thus, if we have an image size of \( x \) by \( y \) pixels (which is also the size of the luminance channel), the chroma channels each have only \( x/2 \) by \( y/2 \) pixels, and thus they are only 1/4 of their original size. We refer to [11, 27, 17] for more detailed information about subsampling.

After the color model conversion and the optional subsampling, the image is level-shifted by subtracting 128 from all values. This produces a signed result with smaller values. Next, the image is split up into blocks. Each block consists of 8 by 8 pixels (default size for BDCT) and is extracted from the image as shown in Figure 7 in Appendix A. The image block’s values are called the DC-component (the value at position \((0,0)\)) and AC-components (all other values).

4.1.2 Discrete Cosine Transform

The extracted blocks are used as input for a discrete cosine transform (DCT). The DCT function gets as input an image block with integer values and outputs a block with real values.
4.1.3 Quantization

Quantization plays a crucial role for the compression of a JPEG image and is performed by dividing an image block by the so-called quantization table. A quantization table consists of 64 values, and each value corresponds to one value inside an image block (see Figure 8 in Appendix A for a quantization table used by Facebook). The division is done by dividing a value from the image by its corresponding value from the quantization table and rounding the result. The values of the quantization table define the compression rate and can be user-defined. Every single value has to be in the interval from 1 to 255. If all values inside the quantization table are 1, no compression is in place; the higher the values, the higher the compression rate. The quantization tables are stored inside of the JFIF-file and used again later during the decoding of the image.

4.1.4 Huffman Encoding

Finally, the DC coefficients (the values at position (0, 0) of each block) are difference-encoded, a zig-zag reordering is applied, and the result is Huffman-encoded. The difference encoding works as follows: every DC coefficient is replaced by the result of subtracting the previous blocks’ DC coefficient from the current DC coefficient. Although Huffman encoding optimizes the final image size, the encoding is lossless, similarly for the difference encoding and the reordering. The information needed for a later Huffman decoding is stored inside of the so-called Huffman tables; they differ for the DC and AC components and for the luminance and chrominance channels. All four tables are stored analogously to the quantization tables, i.e., they are stored inside of JFIF files for a later decoding.

In order to decode a JPEG image, the procedure is simply reversed. Starting with the JPEG file, a Huffman decoding is applied first. Then the reordering is removed which is followed by undoing the difference encoding. A dequantization is then applied using the same quantization matrices that were used during the encoding. After the inverse discrete cosine transform has been applied, the values are shifted back (undoing the level shifts from the encoding) and finally the YCbCr color channels are converted to the RGB colorspace.

4.2 Robustly embedding encryption into JPEG

We have pursued two main approaches for including the ciphertext in the JPEG image. The straightforward way is to embed the encrypted image into a special header field of a JFIF file; the alternative approach is to embed the encryption into the actual image data of a JFIF file. Whenever the websites that host the image retain header information, placing the encryption in the header is clearly the best method in terms of performance. However, this approach is not feasible for common social networks, since they immediately remove all header fields contained in images. For social networks, we thus have to embed the ciphertext in the image data of the JFIF file. However, when images are uploaded to a website via a web-interface, such as for social networks, they are often recompressed. This recompression is highly problematic for us: By the cryptographic properties of secure encryption schemes, we will only be able to decrypt the encrypted image if it is recovered with 100% accuracy (bitwise). Otherwise the decryption will fail, or provide non-sensical results. In order to achieve the goal of 100% accuracy, we have to embed the encryption into a JFIF file so that the embedding survives the JPEG recompression. In the following, we present and discuss both approaches.
4.2.1 Embedding encryption inside of header fields

The JPEG standard supports comments inside the image header, which can be also used for storing the encrypted image. The length of each comment field is limited, but the number of comment fields inside the header is unconstrained.

This solution solves the problem for web applications where images are provided for viewing without any further modifications. The classic example is a static website where images are stored on the webserver and linked using the \texttt{img}-tag of the HTML standard. We have implemented the embedding into headers fields as one of the supported solutions for these classic websites. For these websites, placing the encryption in the header is clearly the best method in terms of performance.

4.2.2 Embedding encryption inside of image data

When images are uploaded to social networks they are often scaled and recompressed. The problem of scaling is solved in our approach by providing encrypted images inside a container image that exactly matches the sizes expected by social networks so that rescaling does not occur. We describe in the following how we address the problem of image recompression.

Embedding an encrypted image into the image data in a way that it survives JPEG recompression turned out to be a challenging task. For the sake of exposition we first describe an intuitive approach for embedding the encrypted image inside of image data that we initially pursued, and then described where it fails. After that, we explain the modifications we had to make to actually solve the problem.

The first approach we pursued when we recognized that social networks decompress JPEG images and then compress them again with their own settings (compression ratio, header fields etc.), was to compute a preimage for the JPEG image that we wanted to upload to the social network, i.e., the image that contains the encryption. The underlying idea was to embed the data into a container image and to take this container image with the embedded data as the starting point. Let us call it \textit{Image}. Knowing that \textit{Image} is exactly the image we want to have on the website later, it is necessary to go through the compression steps done by the social network in the opposite direction. We want to know precisely which \textit{Image}' we have to provide for the upload such that after the compression the outcome on the website is exactly \textit{Image}. To achieve this, all functions applied during the compression have to be inverted step by step. After we compute \textit{Image}' we must provide an \textit{Image}'' without any JPEG compression to the social network, such that decoding it results exactly in the computed preimage \textit{Image}'. However, going this direction turned out to be infeasible because this approach includes inverting the Huffman-encoding without having the Huffman-tables. Without the tables, the information needed to decode the image is not available and therefore the decoding can only by done by brute force.

Our second approach was to modify our input image such that the compression step using the quantization table cancels out. This would provide us with a resulting image in which we can control the content of the luminance channel. To achieve a canceling out of the quantization, its inverse needs to be applied beforehand. Therefore, we modify the quantization table used for encoding the JPEG image that is initially uploaded to the social network. This causes the dequantization done during the image decoding inside of the upload routine to exactly apply the inverse of the quantization done later during the encoding. Let \textit{A} be the quantization table used by the social network, then we can use a quantization table \textit{A}' for the initial image that is achieved by a point-wise division with \textit{A} as follows:
$A = (a_{i,j}), A' = (a'_{i,j}) = \left(\frac{1}{a_{i,j}}\right)$ for $i, j \in \{0, \ldots, 7\}$

This solves the problem of embedding encryptions into JPEG images such that they survive the JPEG recompression, at least in theory: This approach worked perfectly well with our implementation, which strictly follows the JPEG standard.

4.3 Dealing with libJPEG and its idiosyncrasies – how to achieve robustness in practice

However, when using the libJPEG implementation\(^2\) this approach broke down completely. The computations done in libJPEG are highly optimized and introduce, for example, rounding errors that our mathematical accurate computations according to the JPEG standard did not have. In general, a small amount of loss is not really a problem for images since users do not detect such small differences, but in our case we need enough accuracy to reconstruct the embedded data 100% correctly to perform the subsequent decryption. In this setting our reconstruction rate was only 10%, which made it impossible to amplify this approach using error-correcting codes. Since the social networks our software targets use libJPEG, the limited accuracy of libJPEG also rendered our second approach infeasible.

**libJPEG-Details.** Before we analyze how to circumvent the accuracy problems introduced by libJPEG, we will have a closer look at what libJPEG does. The library is entirely implemented in C. A typical workflow for an application using libJPEG for image manipulation is as follows: let libJPEG decompress the source image, define parameters for the resulting image, and let libJPEG compress the image again using the defined parameters. Performing only a specific operation of the JPEG compression process, e.g., the quantization in Figure 2, by just calling a “quantize” method is not possible, as the library combines steps of the process for optimized performance. Moreover, operations like scaling are combined with the DCT computation, at some places precision is sacrificed in favor of speed, and many special cases of the same operation are handled by individual functions. As a result, using libJPEG as intended, i.e., to perform a whole image compression process, is easy, whereas performing JPEG compression steps one by one as shown in Figure 2 is close to impossible.

All social networks in the Internet we are aware of either use libJPEG directly, or use image manipulation programs like GD [7], and ImageMagick [13] that rely on libJPEG. To the best of our knowledge, all of them follow the intended workflow. They just call the library to perform the intended operations without doing any in-depth manipulation.

For our approach, however, it is crucial that we can interfere with the JPEG compression and decompression processes. This requires an in-depth understanding of the libJPEG functions and increases the work needed to embed the necessary functionality.

\(^2\)libJPEG is a popular and widely used implementation of the JPEG standard, written and maintained by the Independent JPEG Group [14]. All social networks we are aware of use libJPEG directly, or use image manipulation programs that rely on libJPEG.
Dealing with libJPEG. Since libJPEG’s inaccuracy rendered our mathematically-correct approach infeasible, it was necessary to have an approach for embedding data that survives the compression done by the quantization step. Since the quantization tables used for the compression are publicly known – usually they do not change for one service and can be extracted from every JPEG image –, we must try to embed data such that applying the division inside the quantization does not destroy the embedded information.

If we have a look at the quantization table used for example by Facebook, we can see that the highest value used in the luminance table is 36. The values inside of one image block that are divided by the quantization values are 8-bit unsigned integers. If we look at the binary representation of such a value, a division by 36 does not destroy the two most significant bits. Therefore, we embed two bits as the two most significant bits in every value of every block inside of the luminance channel. In order to improve the results and to gain more stability, we also always set the fifth bit to one and bits zero to four to zero. This protects bits six and seven from being affected by rounding errors, as it prevents even significant deviations in the lower bits from reaching the upper bits.

Embedding two bits works as long as the divisor needs at most six bits in binary representation. For all social networks of which we are aware, the maximal divisor has at most six bits. In general, when quantization tables with higher values are used, it might only be possible to embed one bit or even none. If smaller values are used, it would be possible to embed more than two bits per byte. For the future, one could use the knowledge of the quantization tables to design an approach that dynamically optimizes the number of bits to be embedded per coefficient. With the current approach of embedding two bits per byte we have an upper bound on the amount of bits we can embed: 1/4 of the original luminance data, two bits per pixel of the luminance channel instead of eight. If subsampling is used for the luminance channel, the maximum amount that can be embedded decreases accordingly. However, the amount of information that we can embed using our technique is more than sufficient for embedding encrypted images into cover images that are permitted by the social networks, and thus for realizing the desired expiration date. The white boxes in Figure 2 show at which point of the JPEG encoding and decoding processes the ciphertext bits are embedded and extracted.

Note that although we have eliminated most loss by embedding the encrypted data only in the two most significant bits, a small amount of loss can still occur, e.g., because of internal rounding mistakes. Thus, it is necessary to apply an error-correction method. The current approach uses Reed-Solomon codes \[32\] with a configuration \((N, K)\) of \((255, 191)\). This means one error correction unit consists of 255 bytes, 191 bytes data and 64 bytes of additional information. The introduced overhead reduces the real space for embedding information to 3/16 of the original payload since the 64 parity bytes per block have to be embedded as well. Using this configuration it is possible to recover the correct ciphertext even if up to 12.5% of each error correction unit is lost. The complete workflow starting with embedding bits until the final extraction of the encrypted image is shown in Figure 3.

We recompress our images before we embed them with quality settings similar to the ones used in social networks. Consequently, although we embed data only into the two most significant bits per byte, our method can be applied to achieve essentially the same image quality in practice as images that have been uploaded directly to social networks like Facebook. We refer to Appendix B for bounds on possible image sizes and illustrative images.

\[3\] We never encountered more than 5% incorrect bits in our experiments with this approach, i.e., a significantly weaker error-correcting code with a smaller overhead would have been sufficient. However, we decided to deploy a stronger code to catch unexpectedly bad results that might arise. For the same reason, we currently only embed two bits in every value of every block, even though our experiments indicated that more bits could have been embedded in most cases.
5 Implementation

We have implemented the publisher and the viewer as Mozilla Firefox extensions, so that the user can prepare protected images when browsing his social network site without switching programs. The extraction of protected images is completely automated and opaque to the user.

Both the publisher and the viewer application share a core library that provides encryption, JPEG manipulation, and error correction, as well as a high-level communication functionality.

![Figure 4: Creation time](image1.png)  ![Figure 5: Time to display websites](image2.png)  ![Figure 6: Time to decrypt images](image3.png)

The core library used by both applications is responsible for the actual handling of protected images, i.e., modifying JPEGs, encryption and decryption, computing hashes, and error correction. It is implemented in C and C++. The reason for the separation of core library and client applications is the availability of fast and well-tested libraries for cryptography, JPEG manipulation, and error-correcting codes in C, as well as the lack thereof in Javascript. However, Javascript is much better suited for high-level server communication than C or C++ and is therefore used for the communication task. In particular, we rely on OpenSSL for hashes and encryption, libJPEG for JPEG manipulation, and our own implementation of Reed-Solomon codes for error correction. For embedding data into JPEGs for social networks, we extended libJPEG with a small module that is called during the DCT and the IDCT computation. We combined our code for embedding data into the JPEG header for images on static websites and the modified version of libJPEG into a C++ library that provides high-level functions for generating and reading of protected images to our applications.

Our code requires functions to be called from C libraries directly. Although Gecko engine 2 (the engine underlying Firefox 4) will allow this directly, the current version of the Gecko engine does not. As a result, we had to add an XPCOM component to our extension. Using the XPCOM framework we are able to call routines from native code in the extension as we would do it with Javascript or XUL functions. Thus, the final step in our implementation was to extend our library to be compatible with XPCOM and to add the result as a component to our Firefox extension.

The image lookup itself is performed by handler functions in the viewer which check websites for protected images. These functions check every \texttt{⟨img⟩}-element on a whitelisted website (we use a social network whitelist to reduce the overhead introduced by our technique, see Section 6).
being a protected image, whether it is statically present or dynamically inserted using Javascript. The latter is the case for most images on social networks, as their websites are usually created dynamically. If a protected image is found, the viewer decrypts it and replaces the \langle img \rangle-tag containing the protected image locally with a new one containing the whole decrypted image data in base64 encoded form. Although the use of base64 encoded image data in \langle img \rangle-tags is not part of the HTML standard yet, it is considered as good as standard and nearly all browsers support this feature. For the user, this replacement is seamless and does not require any interaction.

Besides the two client applications, our approach further contains the keyserver. It is implemented in Scala [33], a programming language targeting at the Java Virtual Machine (JVM) [35]. In addition, we use the Lift-framework [18] for web application development and PostgreSQL [30]. The latter is used to store the keys sent by the users. All communication between the X-pire! extension and the keyserver is implemented using XMLHttpRequests in Javascript. Further, data is transferred using HTTPS, thus ensuring secure and reliable communication.

To prevent attackers from collecting keys, our implementation permits the use of Captchas as described before. We use Google reCAPTCHA [31] as a concrete implementation. reCAPTCHAs are based on text extracted from old books which could not be recognized by OCR tools. The whole communication with the Google servers is also secured by HTTPS.

6 Experimental Analysis

Introducing an extra step into the workflow of uploading and viewing images on the Internet also introduces some extra time needed to complete the calculations. We performed several client-side benchmarks to evaluate the time needed to encrypt and embed images and to evaluate the overhead that is incurred by the X-pire! plug-in while viewing websites. In addition, we compared the two methods of embedding an encrypted image into a container JPEG: embedding the payload into the header field and embedding the payload into the luminance channel.

The benchmarks were run on a notebook with 4GB RAM and a 2.2 GHz Intel Core 2 Duo CPU using Mac OS X 10.6.4 as the operating system.

To evaluate the time needed for encryption and embedding, we performed the encryption and embedding computations 50 times for different numbers of images. The actual time needed for a given number of images was evaluated as the average over all measurements for a particular number of images. The results are depicted in Figure 4. As expected, embedding data into the header field is much faster than the luminance channel method. Both methods scale linearly.

To measure the overhead when viewing websites, we created static HTML-pages rather than using existing websites. The reason for this is that a single real world page like Facebook consists of several elements which are provided by different servers. Moreover, with each reload, the page looks different and consists of different elements. Further, if only one server that contributes elements to a website such as Facebook is not responding, incorrect timing results will be obtained.

Again, we benchmarked with different numbers of pictures and 50 runs per series. Figure 5 and Figure 6 show the overhead results. On a web page which contains no images that are recognized by the viewer, the overhead of using the plug-in in comparison to not using the plug-in is not measurable (Figure 5). On websites with protected images, the luminance channel method is again slower than the header field method (Figure 6). Fully decrypting images using the header field method is as fast as checking whether a possible candidate is really a protected image using the luminance channel method (Figure 5). Neither the header storing method, nor the bit embedding method scales linearly; we expect that this happens due to the way Firefox implements Javascript DOM handlers and events [23].
We also analyzed how the centralized server approach scales in terms of number of active sessions and number of simultaneous requests. The machine used as a server was an off-the-shelf office computer with 4GB RAM and an Intel Core i3 540 CPU with two cores and multithreading enabled. We used Ubuntu 10.04 Server Edition as the operating system, Jetty 6 [15] as the Java webserver, and ApacheBench [1] as the benchmark tool. We assigned a maximum of 2GB heap space to the JVM running the Jetty instance. Since Jetty does not provide a way to display the number of active sessions, we can only give rough upper bounds derived from the total number of session creating requests. Using this method, we were able to create about 820,000 sessions which resulted in nearly 2GB of memory usage. At this point, the JVM garbage collector slowed the system down to the point where the server stopped responding to our requests. So even when using off-the-shelf equipment, our keyserver is able to handle a reasonable number of users.

In a different benchmark evaluating the server’s scalability in terms of CPU load, we were able to perform about 3000 requests per second with the same session, effectively reaching a CPU usage between 90% and 100% on all cores according to htop [12].

7 Discussion

X-pire! has raised a huge discussion in Germany and received an overwhelming attention in the German media. Reports about X-pire! occurred in most of the major printed press, in major TV channels, and in the radio. The discussion on X-pire! mainly occurred in online media.

Most of the criticism of X-pire! happened because people had wrong expectations and knowledge about the functionality of X-pire!. We provide our paper now to the public not only to provide in-depth information to all people interested in this approach, but also to clearly state once more what X-pire! can do, and what not. We believe that our approach is pretty close to what is achievable from a technical point of view.

X-pire! is able to provide the following functionality:

- Encryption of JPEG images and associating them with an expiration date.
- Uploading these images to social networks such as Facebook or Flickr.
- Viewing the images after the upload to a social network with our browser plug-in in supported browsers.
- Captchas to increase the cost heavily for one attacker when collecting huge amounts of keys.

What X-pire! is not intended to provide:

- Does not prevent users from intentionally copying images after they got decrypted; this is always possible.
- Users installing malware to collaboratively collect keys and store them on a third-party server whenever a picture is viewed; this is comparable to intentionally copying images that could also be stored unencrypted on another server.

Especially the latter is suggested as a break of our system by [5]. However, we never claimed that X-pire! offers any form of protection against this kind of attacks. While this kind of attack could only be hardened, it can never be fully prevented as it constitutes the technical limit of what can be achieved. Further protection has to be provided e.g. by law enforcement.

Related to the attack described above, some people have the opinion that the privacy improvement through X-pire! is limited. Of course one would prefer if the aforementioned limitations would be avoided technically (which is not possible), but, even in the presence of these limitations.
limitations, X-pire! improves the user’s privacy heavily. Without a huge amount of intentionally bad users that collaboratively destroy the privacy of single users, this system provides a functional expiration date. This is clearly an improvement in comparison to one single attacker being able to simply write a crawler to collect all existing images. Only a huge bunch of either intentionally bad users or widely installed malware can collect keys or images efficiently.

8 Conclusion and Future Work

We have developed a novel, fast, and scalable system called X-pire! that allows users to set an expiration date for images in social networks (e.g., Facebook and Flickr) and on static websites, without requiring any form of additional interaction with these web pages. Once the expiration date is reached, the images become unavailable. A major technical challenge for rendering the approach possible for social networks – where by far the largest number of sensitive images are published – was to develop a novel technique for embedding encrypted information within JPEG files in a way that survives JPEG compression in real-world implementations. An additional feature of our approach is that the publishing user can dynamically prolong or shorten its expiration dates later, and even enforce instantaneous expiration. We have implemented our system and conducted performance measurements to demonstrate its efficiency. Our system can be applied to other data formats such as text messages as well, but we decided to focus on images first because of their distinguished importance for user privacy and their underlying technical challenges. Our current focus is to support additional social networks and other data formats in order to increase the usability of the approach.

References

[1] ApacheBench. Online at http://httpd.apache.org/docs/2.0/programs/ab.html

[2] Dan Boneh and Richard J. Lipton. A revocable backup system. In Proc. 6th Usenix Security Symposium, pages 91–96, 1996.

[3] Sam Burnett, Nick Feamster, and Santosh Vempala. Chipping away at censorship firewalls with user-generated content. In Proc. 19th Usenix Security Symposium, 2010.

[4] Facebook. Online at http://www.facebook.com

[5] Hannes Federrath, Karl-Peter Fuchs, Dominik Herrmann, Daniel Maier, Florian Scheuer, and Kai Wagner. Grenzen des digitalen radiergummis. Datenschutz und Datensicherheit - DuD, 35:403–407, 2011.

[6] Flickr. Online at http://www.flickr.com

[7] GD Graphics Library. Online at http://www.libgd.com

[8] Roxana Geambasu, Tadayoshi Kohno, Amit Levy, and Henry M. Levy. Vanish: Increasing data privacy with self-destructing data. In Proc. 18th Usenix Security Symposium, 2009.

[9] Saikat Guha, Kevin Tang, and Paul Francis. NOYB: Privacy in Online Social Networks. In Proceedings of The First ACM SIGCOMM Workshop on Online Social Networks (WOSN ’08), 2008.

[10] Eric Hamilton. Jpeg file interchange format. Online at http://www.jpeg.org/public/jfif.pdf, 1992.
[11] Calvin Hass. JPEG Chroma Subsampling. Online at http://www.impulseadventure.com/photo/chroma-subsampling.html, 2008.

[12] htop - an interactive process viewer for Linux. Online at http://htop.sourceforge.net/.

[13] ImageMagick. Online at http://www.imagemagick.de.

[14] Independent JPEG Group. libjpeg. Online at http://www.iijg.org.

[15] Jetty Webserver. Online at http://jetty.codehaus.org/jetty.

[16] JPEG Standard, ISO/IEC 10918-1 — ITU-T Recommendation T.81. Online at http://www.w3.org/Graphics/JPEG/itu-t81.pdf, 1992.

[17] JPEG Standard, ISO/IEC 10918-3 — ITU-T Recommendation T.84. Online at http://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-T.84-199607-I!PDF-E&type=items, 1996.

[18] Lift Web Framework. Online at http://www.liftweb.net.

[19] Matthew M. Lucas and Nikita Borisov. Flybynight: mitigating the privacy risks of social networking. In Proceedings of the 7th ACM workshop on Privacy in the electronic society, pages 1–8, 2008.

[20] W. Luo, Q. Xie, and U. Hengartner. Facecloak: An architecture for user privacy on social networking sites. In Proc. of 2009 IEEE International Conference on Privacy, Security, Risk and Trust (PASSAT 2009), pages 26–33, 2009.

[21] Viktor Mayer-Schoenberger. Useful void: The art of forgetting in the age of ubiquitous computing. KSG Working Paper No. RWP07-022. Available at SSRN: http://ssrn.com/abstract=976541, 2007.

[22] Morris Dworkin. Recommendation for block cipher modes of operation - methods and techniques. Online at http://csrc.nist.gov/publications/nistpubs/800-38a/sp800-38a.pdf

[23] Mozilla developer center: Xul/events mutation dom events. Online at https://developer.mozilla.org/en/XUL/Events#Mutation_DOM_events

[24] Srijith Nair, Mohammad Dashti, Bruno Crispo, and Andrew Tanenbaum. A hybrid pki-ibc based ephemizer system. In New Approaches for Security, Privacy and Trust in Complex Environments, volume 232, pages 241–252. Springer, 2007.

[25] NIST. Advanced Encryption Standard (AES) (FIPS PUB 197). Online at http://csrc.nist.gov/publications/fips/fips197/fips-197.pdf

[26] NIST. Secure Hash Signature Standard (SHS) (FIPS PUB 180-2). Online at http://csrc.nist.gov/publications/fips/fips180-2/fips180-2withchangenotice.pdf.

[27] William B. Pennebaker and Joan L. Mitchell. JPEG still image data compression standard. Chapman and Hall, 1993.

[28] Radia Perlman. The ephemizer: making data disappear. Technical report, Sun Microsystems, Inc., 2005.
A Further information on JPEG

Figure 7 shows how single blocks are extracted from a single image.

After the block extraction, a quantization as described in Section 4 is applied. The quantization table used by Facebook is shown in Figure 8.

Figure 7: JPEG block extraction

Figure 8: Quantization table used by Facebook (luminance channel)
| Social Network | max. Resolution | Image Bytes incl. ECC | Bytes w/o ECC incl. ECC | Bytes w/o ECC |
|---------------|-----------------|----------------------|------------------------|--------------|
| Facebook      | 720x720px       | 468000               | 117000                 | 87750        |
| Flickr        | 1024x1024px     | 976896               | 244224                 | 183168       |
| wer-kennt-wen | 620x620px       | 341000               | 85250                  | 63937.5      |

Table 1: Amount of bytes that can be embedded into the cover image

![Figure 9: Image uploaded using X-pire!; it has the identical image quality as the Facebook image on the right side](image1)

![Figure 10: Image uploaded using only Facebook](image2)

## B Image quality when using X-pire!

Table 1 shows the maximum amount of bytes that can be embedded into the cover images for the aforementioned social networks. The maximum possible resolution is the maximum pixel size stored by the social network. All bigger pictures are resized to fit these limits. Besides the total amount of image bytes contained in our cover image, we provide the amount of bytes that can be embedded into it (including the error correcting codes) and the number of bytes that can be actually used for storing the image to be embedded. Since social networks store images only up to a specific resolution, the maximal file size accepted for embedding is the file size of the image to be embedded already after it has been resized and re-encoded to a resolution accepted by upload interfaces of social networks. Hence it is possible for example to provide a 3500x2700px image that has a file size of 3.6MB to X-pire! and after scaling it to 720x720px and re-encoding it for Facebook it can still be embedded into a cover image.

The images below show that the image quality remains unchanged when our method of uploading an image in a cover image is used. Figure 9 shows a 300x300px area of an image uploaded using our approach, whereas Figure 10 shows the same area of an image uploaded using only the Facebook interface.