Steganalysis

Cybersecurity and National Defence

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Abstract

This paper provides a general view about steganalysis with hints to steganography.

Steganography is the art of hide information into a cover type (the mean of transmission used to hide the message) [1]. Steganalysis is the analysis used to find whether in a cover type there is an hidden message.

We will cover the state of art of the most important and used methods of steganalysis for different cover types:

- images: stego-key search, difference image histogram method, closest color pair method, JPEG steganalysis
- audio: non compressed and compressed methods, phase coding, Mp3 steganalysis
- text
- TCP/IP

Moreover, we will give describe the general types of analysis that one can perform:

- statical
- visual
- spread spectrum
- signature
- transform domain
- universal

At the end we will conclude explaining why steganography and steganalysis are important, also joining those two subjects with a wider theme like security in sending information.

Contents

1 Introduction

Steganography is the technique of hiding a message inside another message or a physical object.[1] The word *steganography* comes from the Greek word *steganographia*, which is the combination of *steganós* meaning "covered" and *-graphia* meaning "writing".

The first testimonials of the use of steganography date back to 440 BC in Greece mentioned by Herodotus in his *Histories*: Histitateus sent a message to Aristagoras by writing a text message on the shaved head of one of his servants and then waited till the hair of the servant had regrow to sent him to Aristagoras. Moreover steganography has been used for centuries in different ways such as secret inks, morse code hidden inside physical objects or encoded in eyes blinking (Jeremiah Denton, tortured prisoner-of-war in 1966 during the korean war, encoded in this way an help message during a TV report) or microdots embedded in paper or in clothes used by espionage agents during and after the World War II.

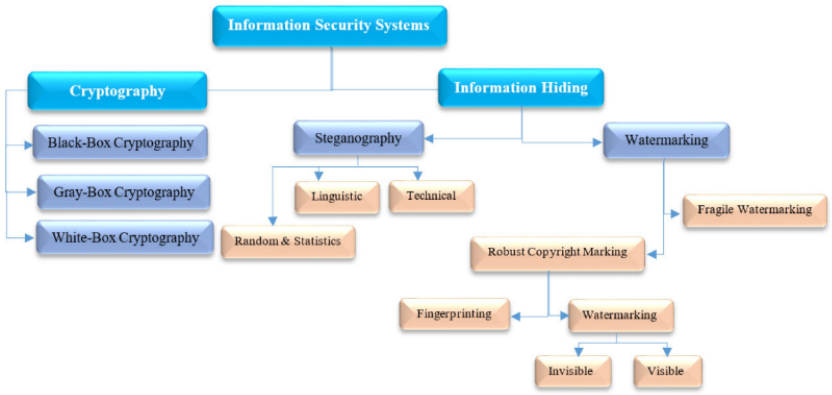
In digital steganography a message or a file is concealed within another file; in particular, electronic communications may contain a steganographic coding inside a information vehicle such as a document, a program or a media file (image, audio or video). Media files are ideal for hiding messages since due to their large size, the modification needed to encode a steganographic coding cause a subtle change that is unlikely to notice for someone who is not looking for it. This is one of the greatest differences of steganography with respect to cryptography: in cryptography the encrypted messages are visible so they attract interest and it's more likely that they will be subject to some type of attacks to be decoded.

In this paper we will focus on steganalysis, the study of detecting and, if possible, recovering hidden messages encoded using steganography, the way in which it can be performed, examples of its application in known cases and the threats and opportunities regarding the cybersecurity implications of its use in digital and communications systems.

We can call steganalysis successful (and consequentially that the steganography is broken) when there is the evidence of an hidden message in the cover signal. Moreover, the embedded information can also be crypted, in that case the attacker (the one who tries to find the hidden message) will have to perform cryptanalysis in order to decrypt the information.

The Field on Information Security Systems is indeed vast and will require much more space than the one we have. Here we attach a map which describes shortly the structure.

Figure 1: Map of Information Security Systems [2]



2 Steganography

As we already stated, steganography is used to hide a message in a *cover type*. We can define a cover type as the mean used to communicate, which can be a text file, an image, an audio recording, but also people, like in the case of the servants that we have mentioned earlier, etc...

In all these cases, the message has been *embedded* into the cover type. Here we can make a distinction between steganography and watermarking since in both cases a message is encoded into a communication's mean, but with different purposes.

2.1 Methods

Steganographic methods may be grouped under two different classifications.

For the first, we distinguish injective and generative steganography. While injective steganography consists in finding an optimal way of injecting the message for a given cover type, generative steganography aims at generating an adequate container optimal for hiding a sought message.

As for the second classification, we mainly discriminate between substitutive and constructive steganography.

Substitutive steganography targets the noise in signals, to substitute the atmospheric noise with a secret message, whether it concerns audio or digital image signals. Most commonly, it may be achieved by replacing the LSB (Least Significant Bit), which is most susceptible to error, with the hidden message in the matrix of signals. Several drawbacks arise, such as the limited size of the message to be inserted to avoid amplified distorsions of the original signals, the resilience to various degrees of compression and signals transformations, and lastly the transparency of the message. We leave for a further discussion the different available tradeoffs, selectively mitigating some of the aforementioned drawbacks.

Similarly, constructive steganography integrates a noise model. The main drawback is that it is hard to produce, and by design fragile to attacks.

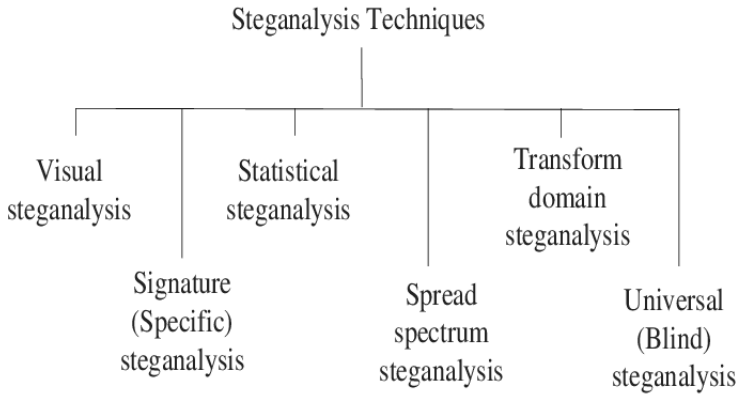
3 Steganalysis

Steganalysis is the branch of study dedicated at analysing the methods and the vectors used to transmit an hidden message in order to retrieve such message whenever it is present. Unlike cryptanalysis where the message may even be apparent but encrypted, in steganalysis the study of the message starts from a suspect.

3.1 Methods

Hereinafter we will present the methods used in steganalysis in order to obtain the secret message. The following image illustrates all of them. Here we simply want to introduce them in a rigorous way, but they will be treated in the specific cases when dealing with the cover types.

Figure 2: Steganalysis techniques



3.1.1 Statistical

Statistical steganalysis consists in using tools borrowed by Statistics in order to spot anaomalies in the cover message. These anomalies can be usually detected by searching in the data for patterns or by simply analysing some alteration of the modelled probability distribution of the data in the message. Often Neural Networks are involved in this type of steganalysis.

3.1.2 Visual

This is a very rudimental yet effective way of determining if a message was modified or not. This technique relies on the human eye and ita ability to spot anomalies in the format of a message which may pave the way for suspects.

3.1.3 Spread Spectrum

This is a technique borrowed by signal analysis which consists in treating the data on which we want to perform the analysis as a signal. Following this reasoning it is almost immediate to see that the stego message embedded into our data is nothing but noise in our signal. Finally the steganalysis is performed in this case just like any other type of signal analysis.

3.1.4 Signature

Signature is deeply correlated to the field of Watermarking. In many cases the data on which it was performed the steganography could have been signed. The insertion of the stego message inside the signed data may thus lead to the alteration in the digital dignature, making the message visible to the receiver.

3.1.5 Transform Domain

Even in this case the goal is to start from considering the data we are analysing as a signal. Then we try to transport this signal from a domain into another so that to make it invisible to the end user.

3.1.6 Universal

This is a type of analysis performed in a sort of bloind mode. In this case we don't care aboutt he medium through which the message was sent but we perform a series of operations(reading LSB for example) which have little to nothing to do with the message itself.

3.2 Cover types

In the following sections, we will treat several *cover* in which steganography can be applied to hide data. In particular we will focus on some of the most common methods and how is possible to do a steganalysis process in order to detect and in some cases even retrieve the embedded information. Notice that different cover types requires completely different approaches due to intrinsic factors such as size, presence of redudant data, perceptibility of modification by a human or formats in which the bits of the cover are stored.

4 Images

Images are likely to be chosen to hide secret messages due to the low sensibility of the *human visual system* (HVS) to some particular attributes such as small changes in luminance or brightness or contrast near figures edges. There are several methods to apply steganography to an image, in the following sections we will treat some of the most common hiding techniques and some of the steganalysis methods to attack them.

4.1 Stego-key search and encryption

When in the following sections we will mention modification applied to *LSB* of some data characterizing the images, it's crucial to mention that not always all LSB are modified nor are modified in subsuqeunt blocks. More complex steganographic techniques imply the use of some pseudo-random walk followed when deciding which data to modify, generated by some *stego-key* (usually stego-key will be mapped in a set of possible seeds by a hash map) [3].

It's also possible to apply an *encryption* algorithm before embedding the message in order to make steganalysis harder, since the attacker cannot find any recognizable bit sequence, when searching for the message.

The use of such systems makes the steganalysis process much harder since it becames unfeasible the use of a brute force approach: the complexity would be proportional to the cardinality of the set of possible seeds time the one of the set of possible encryptions.

Moreover, even if the LSB are modified in blocks and no encryption is applied, the steganalysis methods are useful to comprehend (without need to find recognizable bit sequences) if the images contains secret messages in a systematic way.

4.2 LSB embedding method

LSB embedding method is arguably the most popular steganographic method, due to its simplicity, high imperceptibility and high capacity. In this method, the image is decomposed into *bits plane* (8 bits per pixel for grayscale and 24 for color images, one for each color channel) and the *least significant bit* (LSB) is substituted with the message to be hidden. Note that even if the message is encrypyted, due to its simplicity, this method is easily detectable with a statistical steganalysis attack [4].

4.3 Difference Image Histogram method

The *Difference Image Histogram method* is derived by the easier idea of analysing the *histogram distribution* of a natural image and its stegoimage. Anyway, when we are steganalysing an image, we *do not* have the natural image, so what we could do is comparing the histogram distribution of the suspect image with a set of natural images, but the problem is that the variation between two different images is *bigger* than the distribution variation between a natural image and its stegoimage. [5]

The proposed way to proceed is the following [6], starting from the test image (that we will call h, considering h a grayscale image or a color image under some assumptions) we generate:

1. an image f given by h with flipped LSB
2. an image g given by h zeroing the LSB

3. images D_h, D_f, D_g, created by the respective image of each one with the following formula:

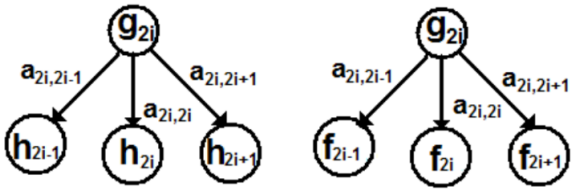
$$D(i,j) = I(i+1,j) - I(i,j)$$

where I is the image denoted by the subscript and the couple (i,j) a unique pixel of the image

At this point, we can analyse the histograms of the three generated images D_h, D_f, D_g:

$$H = \{h_i | i = -255,\ ...,\ +255\},\ F = \{f_i | i = -255,\ ...,\ +255\},\ G = \{g_i | i = -255,\ ...,\ +255\}$$

Figure 3: Transition values from G to H and F



then, we define the following values:

$$\alpha_i = \frac{a_{2i+2,2i+1}}{a_{2i,2i+1}}$$
$$\beta_i = \frac{a_{2i+2,2i+3}}{a_{2i,2i-1}}$$
$$\gamma_i = \frac{g_{2i}}{g_{2i+2}}$$

As found out by X. Ping and T. Zhang in [6]:

- if $\alpha_i \approx 1, \forall i \in \{-255, -254, ..., 255\}$ then the image contains some hidden message;
- otherwise, for natural images, $\alpha_i \approx \gamma_i$ is satisfied.

4.4 Closest Color Pair method

Another method used to detect hidden messages on the LSB plane is the *Closest Color Pair method*.

Whhen an image has a steganographed message in te LSB plane, the number of close colors increases [7]. Given two pair of colors $C_1 = [R_1, G_1, B_1],\ C_2 = [R_2, G_2, B_2]$, the condition of them being close is:

$$(R_1 - R_2)^2 + (G_1 - G_2)^2 + (B_1 - B_2)^2 \leq 3$$

We apply a LSB embedding steganography algorithm on the image and we compute the number of close color pairs in both images.

Now, we define:

- P as the number of close color pairs; P' as the number of close color pairs of the stegoimage;
- U as the number of color pairs; U' as the number of color pairs of the stegoimage

Then, we compute:

$$R = \frac{P}{\binom{U}{2}},\ R' = \frac{P'}{\binom{U'}{2}}$$

We know that if

$$\frac{R}{R'} \geq Th,\ Th = 1.1$$

then the image is a natural image, otherwise it contains an hidden message. All the proofs are in [7].

4.5 JPEG steganalysis

JPEG images are one of the most used format on Internet web sites, due to their high compression rate, while maintaining a good quality.

4.5.1 DCT Domain embedding methods

The DCT Domain embedding methods modify the compression coefficients in order to hide data inside the image. The JPEG format uses a *discrete cosine transform* (DCT) to transform every 8x8-pixel block into 64 DCT coefficients, that are used to calculate the pixels when the image is displayed. The simplest and most used DCT Domain embedding method substitute the *LSB* of the coefficients with the secret message: since the modification is done in the frequency domain, there is no human perceivable change in the image. However, this modifications can be detect by analyzing the DCT coefficients which change significantly with respect to a natural image [8].

4.5.2 Chi-square test

The Chi-square test is a statistical steganalysis test, which aims at determining whether an image shows distorsion from embedding hidden data.

1. Let n_i be the frequency of the DCT coefficient i in the image, we assume that an image with hidden data has similar frequency for adjacent coefficients so we compute the arithmetic mean $y_i^* = \frac{n_{2i}+n_{2i+1}}{2}$ to derive the expected distribution
2. The expected distribution is compared with the observed one $y_i = n_{2i}$
3. The chi-square distribution for the difference between the expected and the observed DCT coefficients is calculated as follows:
$$\chi^2 = \sum_{i=1}^{\ni+1} \frac{(y_i - y_i^*)}{y_i^*}$$
where $\ni$ are the degrees of freedom, which are one less than the categories in the DCT coefficients histogram
4. The probability that there is an embedded message can be computed as the complement of the *cumulative distribution function* of the chi-square distribution

Note that, as presented in the stego-key section, different algorithms modify the coefficients not sequentially or following different orders, so the steganalysis process is usually performed by calculating the probability of the presence of an embedded message considering different portions of the image at the same time [8].

5 Audio

Steganography in audio is more challenging with respect to images, because the *human auditory system* (HAS) operates over a wide dynamic range, while maintaining a high sensitivity to perturbations and noises. Howerer, there are still some "holes" where data can be hidden. The HAS has a quite small differential range, so loud sounds mask out quiet sounds, moreover it is unable to perceive absolute sound phase, but only relative one.

Another important factor to consider when dealing with sound are the transmissions enviroments. Audio signals can be transmitted through a digital channel (eventually being resampled), through an analog channel or "over the air" played by a speaker and received by a microphone. Depending on the transmission channel there could be huge modification that can make the steganalysis process impossible, but also that can compromise irreparably the hidden message, damaging also the steganographer [4].

Due to the several issues presented above, steganalysis in audio signals is more complex with respect to other cover types. In the following sections we will cover some of the possible ways in which steganography and steganalysis is applied in audio signals.

5.1 Non-compressed and compressed methods

We can distinguish two different types of audio steganography: steganography on *non-compressed* audio files and on *compressed* ones. The first ones aims at exploiting the vulnerabilities of the *HAS* presented above, whereas the second ones perform minor modifications to embedd data based on the way in which the compression is perfomed [9].

5.2 Phase coding

The phase encoding method works by modifying the *absolute phase* of audio signals to convey information, while maintaining the *relative phase* in order to not compromise imperceptibility.

5.2.1 Encoding procedure

The encoding procedure can be performed as follows [4]:

1. The sound is broken into a series of N short segments

2. A *discrete Fourier transform* (DFT) is applied to every segment constructing two matrices: one for the *phase* $\phi_n(\omega)$ and the other for the *magnitude* $A_n(\omega)$ of every segment
3. The phase difference between each adjacent segment is stored
4. The binary set of data which has to be hidden is represented as $\frac{\pi}{2}$ or $-\frac{\pi}{2}$ respectively 0 or 1
5. The phase matrix is recomputed embedding the message by modifying the phase difference between adjacent segments with the encoding presented at the previous point
6. Finally the *modified phase matrix* and the original magnitude matrix are used to reconstruct the sound signal b applying the inverse DFT

5.2.2 Steganalysis techniques

The steganalysis techniques for phase coding system follows a procedure similar to the encoding ones, since is based on a statistical analysis of *phase discontinuites*, but which requires the use of a classification algorithm in order to distinguish between natural and modified signals.

As proposed in [10], the steganalysis can be perfomed as follows:

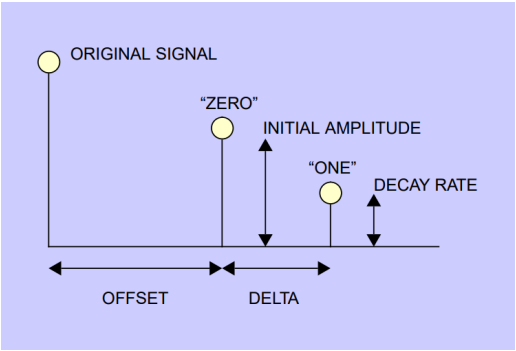
1. The signal is divided into segments to which is applied a *fast Fourier transform* (FFT) in order to extract the phase difference between adjacent segments
2. The phase difference is monitored calculating statistical features of the sample
3. *SVM classifier* (support-vector machines) is used to detect if the signal has been modified or not

A SVM classifier, after a proper training, is able to clearly distinguish between elements by mapping them into two different classes by means of linear regression and statistical calculus. This method is applied varying the length of segements to which the FFT is applied.

5.3 Echo embedding methods

The echo embedding methhods hide data introduzing or varying an *eco*. Data are hidden by varying *initial amplitude*, *decay rate* and *offset*.

Figure 4: Echo kernels and parameters



5.3.1 Encoding

Encoding procedure is performed by dividing the signal into smaller portions and the echoing each portion as an independent signals by an audio mixing process. The coder use two different delay times to represent a binary zero(offset) and a binary one(offset+delta), both below audible threshold, considering the initial amplitude and that the decay rate follows and exponential behaviour. The final signal is formed by recombining all independent encoded signal portions. The transitions between one and zero are done by slightly modify the zero and one kernel in order to maximize imperceptibility.

5.3.2 Steganalysis

The steganalysis process of echo encoded signals is done by doing a statistical analysis on the *cepstrum*, which is the result of the Fourier transform on the decibel spectrum of the signal. As presented in [9], the cepstrum is calculated in a sample window possibly smaller than the encoding segment length. The sampling window is moved over the length of the signal and the cepstrum recomputed each time. Then, the results can be analyzed by classifying every sampled cepstrum in one of four possible categories:

- Inside a zero embedded segment

- Inside a one embedded segment
- Crossing from a one(zero) to a zero(one)
- Crossing from a one(zero) to a one(zero)

This classification is possible due to the fact that the cepstrum plotting exhibits peaks when encountering a delay defined by the 0 or 1 kernels. Moreover, cepstrum peak location aggregation rate (CPLAR) is introduced as the ratio between detected peaks and number of sampled windows. CPLAR is used to discriminate between natural and steganographed audio signals. This method is also capable of detecting the length of the segmentation used by the coder.

5.4 Mp3 steganalysis

The last type of audio steganalysis that we will briefly treat regards the *Mp3* format, which is one of the most used compressed sound formats, since it provides a high compression rate and a good quality.

The Mp3 compression algorithm consist of two nested loops. The *inner loop* does the quantization of the data and determines the suitable quantizer step in function of the available quantity of bits. Whereas the *outer loop* controls the distorsion of the encoding and keeps it beyond the percpetion level.

The most common steganographic algorithms apply some modifications on the encoding algorithm, for instance, modify the termination condition on the inner loop and hide the data during the compression process or modify the compression coefficients or parameters saved (for instance by replacing the LSB).

To perform a steganalystic process on an Mp3 file is necessary to do a statistical analysis on the lenght of the quantization steps or on the *MDCT* (modified discrete cosine transform) coefficients, the transform used in the compression algorithm. The analysis methods are similar to ones presented in the other sections in this paper, since they rely on some previous knowledge of what is expected and on calculations that will tell if there is or not a message encrypted.

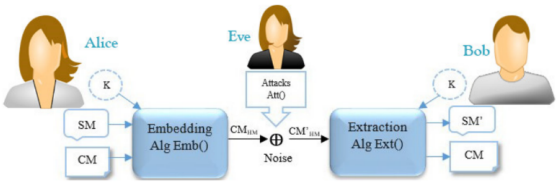
6 Text

In this section we will illustrate in general the principle of work of the MTHS using the famous Simmons' prisoner problem. The information conveied in this part referes mainly to [2].

6.1 Modern Text Hiding Schema

The scenario proposed by Simmons present two prisoners, Alice and Bob who wishes to communicate, and Eve an active warden who tries to disturb the communication.

Figure 5: Modern Text Hiding Schema



The proposed image intuitively explains the logic of the schema. Alice who whishes to send a Secret Message(SM) to Bob, will produce a Cover Message(CM), *i.e.* an innocent message which will work as a carrier. She will then embedd the SM into the CM using a steganographic algorithm and, optionnally[1], securing it with a key(K). In the end she will pass the message to Eve, who will analyse it before giving it to Bob. Eve, an active warden, will use steganalysis tools in order to break the cover taylored by Alice and will possibly distort the message in order to make it unreadable to Bob. Once the message arrives to Bob, he will apply the inverse steganographic algorithm in order to read the message. Since the message could be courrupted Bob will have to perform some error correction in order to make the message readable again(whenever this is possible). To summarize the principal charachteristics of the message sent by Alice are:

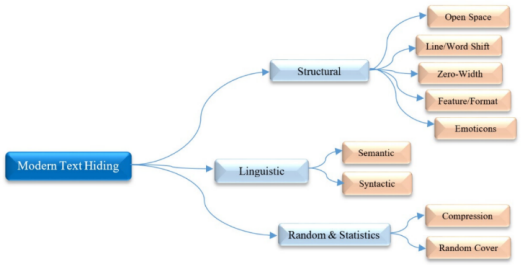
- *invisibility*: the message should not be noted by Eve
- *capacity*: the CM must be large enough to embedd all the SM
- *distortion roboustness*: the SM should resist the noise produced by Eve in the channel

[1]This is the domain of cryptography

6.2 Steganography in text

Now let us abandon the prison world to move to the digital domain. We now want to propose intuitively some algorithm which could be exploited to cover hidden messages into text. The field of hidden-text encoding owes its growth to two main factors: the introduction of the Unicode Standard and the growth in popularity of social media and messenger applications. The number of "invisible" characters introduced by the Unicode standardization can be exploited by steganographic algorithms just as invisible ink was exploited in handwritten steganography. Combining this result with the fact that the modern society produces every year more data than ever before in human history, the possibilities and the threats brought by steganography in the digital world are basically limitless.

Figure 6: Text Hiding techniques



As you can see the field is vast even here and unfortunately we will only treat the most interesting points of the numerous ramifications.

6.2.1 Structural

This set of techniques consist in altering the structure of the document rather than actively modifying the file. The case of *open space* is significant: the spaces are substituted by other invisible Unicode character. This technique is easily noticeable(even by the human eye) and not so much rubust. Similar is the *zero width* techniques which exploits the zero width characters present in the Unicode standard. Even more visible are the format, color and alignement alterations of *Format*. Much more interesting is the case of *Emoticons* which has found secure ground in the last period and which consist of assigning to each emojy a code(letter or word).

6.2.2 Linguistic

Much more stable are the algorithms which exploits linguistic characteristics in order to hide the presence of hidden bits. In the *Semantic* case the message is hidden inside abbreviations or achronyms. This method provides much more reliability and lower embedding capability than the previous one. Much worse and visible is the *Syntactic* approach which consists in changing symbols with others to represent some code.

6.2.3 Random and Statistic

These method start only from the SM and try to generate a CM. They are usually much more time and resources consuming. The *Compression* method consists in compressing the text of the SM using well known compression algorithms such as *Huffman Coding*. The so compressed text is then reordered to mimic the user-typed format or at least a plausible one. Not much more efficient is the *Random Cover* approach where an algorithm($AH4s$) is used to generate a long(and usually meaninglsess) text from the specified SM. The latter method is indeed very visible and also computationally expensive.

6.3 steganalysis

6.3.1 Visual steganalysis

This is a human powered technique which simply consists in reading the texts searching for anomalies in the syntax, impagination and type of characters used. This type of analysis can only be performed by trained users and in most of the scenarios simply detects the presence of hidden messagges without retreiving it. A common type of attack which could be performed by the user consciously(not necessarily) is manually changing the structure of the message. This may lead to the loss or irretrievability of the SM.

6.3.2 Statistical steganalysis

We have already treated this in the previous section, but now we will focus our attention on the particular case of text steganography. Since we don't want to treat the topic from a too mathematical perspective, we will try not to enter

into the mathematical technicalities. The basic principle beneath is the assumption that it is possible to describe the message with a probability function. Recalling some basic principles of probability, if $x_1, x_2, x_3 \dots x_n$ are independent, then $p(x_1, x_2, x_3, ...x_n) = p(x_1)p(x_2) \dots p(x_n)$. Instead when they are not then

$$p(x_1, x_2, x_3, ...x_n) = p(x_1)p(x_2|x_1)p(x_3|x_1, x_2) \dots p(x_n|x_1, x_2, \dots, x_{n-1})$$

Starting by the assumption that written text follows a logic schema and thus that words are interdependently related, then by computing the probability function of the text and comparing it to the one of the *stego-message*(assumed to be perturbed by steganography) we can detect the presence of steganography in the text. This tells us that in theory is possible to detect whether a sequence of characters follows a specific pattern or not, and it is in theory also possible to retrieve the message from such prediction. In [11] the experiment presented shows that it is possible to use a neural network to recognize patterns into text messages which are proper of *stego-messages*.

7 TCP/IP

7.1 Introduction

Before treating such topic we must briefly discuss the behaviour of the TCP/IP (**Internet protocol suit**) communications.

IP (Internet Protocol) is at the basis of internet communication. The protocol exploits the principle of encapsulation, sending packets composed by a *header* which contains information such as the **destination address** and **source address** and a *payload* which represents the actual data to be transmitted. Since physical channels usually have a limited MTU[2], then the data is usually fragmented in smaller chunks, wrapped into an header and only then transmitted.

TCP (Transmission Control protocol) is a protocol used for reliable (little information loss), ordered, error-checked data transmission between a machine hosting the data (**Server**) and another requiring such data (**Client**). It is performed previous a three-way handshake which estabilishes a connection between server and client, thus preparing a reliable communication channel.

UDP (User Datagram Protocol) , contrary to TCP, is less reliable but faster. It broadcasts the data in an unordered and uncontrolled way to the receiver. There is no need to estabilishing a connection in order to implement such protocol.

Figure 7: Structure of TCP packet

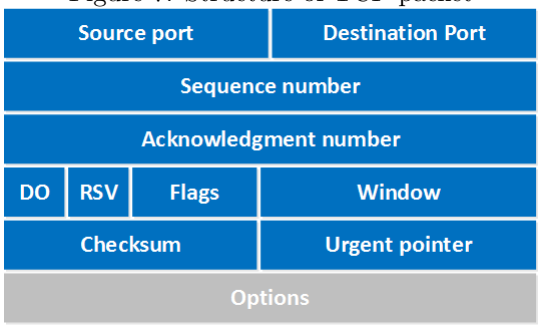
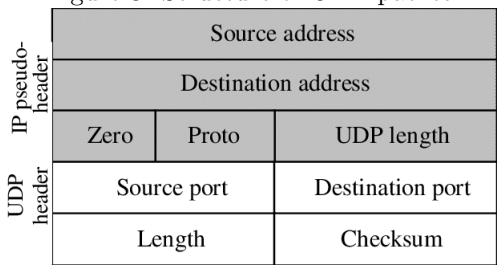


Figure 8: Structure of UDP packet



[2]Maximum Transmission Unit

7.2 Exploits and protection tools

As you could notice from the previous figures, the first part of the header is the same. This is because it is part of the IP protocol itself. In the second part of each header we find different types of metadata which are specific for each protocol. Generally the metadat contained in the header is redundant for the transmission of the message itself and this redundancy may become a target for a *stego-algorithm*[3] which starting from a *cover-network packet sequence*[4] and a *covert message*, can generate a sequence of packets(each one embedding a portion of the covered message) which will be sent over the network.

This procedure is not a *risk-free* approach for the attacker who wishes to send the *cover-network packet sequence*, since it is possible that the data will be currupted during transmission or there could be losses using non-reliable transport protocols(UDP). Other criticalities of such method stay in the fact that the sequence of packets will most likely traverse multiple nodes in the network before reaching the target, and the message may be detected by these nodes.

The defense against Steganography in TCP/IP communication consists in series of standards which are implemented by the devices on the internet and that we will illustrate through some examples.

Tof(Type of service) bits are a field in the TCP header which are nowdays rarely used. This could open doors to a steganographic attack if modern operating systems did not set them to zero by default. A warden monitoring the channel could immediately signal an error.

IP ID is a field in the Internet Protocol which is used to assist the receiver in reassemblying the fragmented packets. This field consist of randomly unique numbers representing a packet. It is possible to insert other types of information in this field by simply conform to the uniqueness constraint. Since in many cases the numbers used for the IP ID are not random, by knowing the charachteristics of the sender it is possible to detect an infiltration.

IP Fragment Offset is an offset which is present in the IP header which helps the receiver to reconstruct the sequence of bits from the fragmented sequence. Modulating the size of the fragments changes the offset field in the header and thus a message could be sent. The protection against this method is simply checking the size of the packets relative to the MTU and so even in this case a warden can easily detect an error.

TCP sequence number is a field in the TCP header which stores the randomly chosen position(for security reasons) of the first byte to be transmitted through the channel. The steganographic method consists in replacing this field with the data to be sent. Being random it is more difficult to spot a breach in the channel. In this case the usage of a SVM[5], a machine learning tool able to identify patterns inside the data transmitted could come into hand. However an error could be detected even simply by checking the presence of repetitions in the stream(not admitted by design).

Timestamp modulation is another technique of steganography which operate by modifing the *LSB* of the timestamp of a TCP packet in order to represent a '1'. The covert message is thus embedded into the data stream. Since the TCP Timestamp support is not universal, machines not supporting such feature may detect the hidden message.

7.3 Detection of TCP/IP steganography

Each operating system exhibits well defined characteristics in generated TCP/IP fields. These can be used to identify any anomalies that may indicate the use of steganography. For this purpose, a suite of tests which may be applied to *network traces*[6] are defined and they are used to identify whether the results are consistent with the operating systems believed to be installed on the source host. Diffreent methods of covert channel detection are used, employing IP ID characteristics, TCP ISN characteristics and explicit steganography detection.

7.3.1 IP ID characteristics

IP ID characteristics are the features identifying the IP address, a unique address that identifies a device on the internet or local network. They are employed by the following methods. *Sequential Global IP ID* implies the usage of a global counter for the IP ID. To detect this strategy one has to look if connections to different hosts have sequentially increasing IP IDs. *Sequential Per-host IP ID* is characterized by the usage of a per-host counter for packets. If it apperas to be fragmented, the warden can test whether connections to different hosts use apparently unrelated IP IDs; however connections to the same host have a sequentially increasing IP ID. *IP ID MSB Toggle* represents the case where the operating system system toggles the most significant bit of the IP ID every rekey interval, so that the warden can examine the MSB to check if it matches this pattern. *IP ID Permutation* strategy presence can be discarded by the warden if there are duplicates, since within a rekey interval the IP ID is non-repeating.

[3] an algorithm used for steganography
[4] a sequence of packets which will be transmitted over the network acting as a cover for the hidden messace
[5] Support Vector Machine
[6] function that performs network analysis on a geometric network

7.3.2 Explicit steganography detection

Explicit steganography detection can be employed by several methods. *Nushu Criptography* is a strategy applied by Nushu, which encrypts data before including it in the ISN field, resulting in a distribution which differs form the one that is normally generated by Linux; therefore, it can be detected. *TCP Timestamp* strategy involves the execution of a randomness test. In particular, if a low bandwidth TCP connection is being used to leak information, this test can be applied to the LSBs of the timestamps in the TCP packets. If an excessive presence of randomness is detected in the LSBs, it can be deduced that a steganographic covert channel is in use. There are also other features which may indicate the usage of steganography: *unsual flags*, *excessive fragmentation*, use of *IP options*, *unexpected TCP options* and *excessive re-ordering*.

8 Conclusions

Up to now we discussed what are steganography and steganalysis and how the latter is performed. The reason why steganalysis is important is that nowadays almost everyone uses a computer or a digital device, and the security of informations is a primary object of attention. This attention led to a developlment of studies on signal processing jointly with information security services. Steganography is not the only way one can hide informations, there are multiple options, each one of them with a specific target:

- encryption: confidentiality
- watermarking: copyright protection
- steganography: privacy that can also prevent traffic analysis

We can also make an example to clarify the difference between encryption and steganography: *the prisoners' problem* [12], which considers that two accomplices in a crime have been arrested and are in two different rooms. The warden decides to let them communicate by exchanging written messages at the condition of reading all of them, hoping to find some information and because he fears that they could share an escape plan. Now, if the two prisoners encrypted their messages the warden would have been able to notice that they are communicating something "strange" and probably he will not deliver the message to the other criminal; in the case in which the two prisoners steganographed the message, the warden would not have been able to find that there were hidden information.

Given this example, we can also clarify what *steganalysis* is: it can be seen as the process that the warden should do in order to find that in the "normal" message of the prisoners there were hidden information.

At this point we can easily understand that the steganography method is "*broken*" simply when steganalysis is able to detect that in the cover type there is a hidden message. In general we can also distinguish between

- *passive steganalysis* which simply detects the message without knowing anything else
- *active steganalysis* which detects the message with some extra information such as the length of the message and/or its location

Moreover, when steganalysis is performed successfully, we can also update the steganography method which has been broken by the steganalysis. This continuous research in steganography and steganalysis is useful when it comes to protect data. [9]

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