Masaryk University
Faculty of Informatics

Security and cryptography in GO

Bachelor's Thesis

Lenka Svetlovská

Brno, Spring 2017

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Declaration

Hereby I declare that this paper is my original authorial work, which I have worked out on my own. All sources, references, and literature used or excerpted during elaboration of this work are properly cited and listed in complete reference to the due source.

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Acknowledgement

This is the acknowledgement for my thesis, which can span multiple paragraphs.

Abstract

This is the abstract of my thesis, which can span multiple paragraphs.

Keywords

keyword1, keyword2, …

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1 Introduction

2 Basic Terms

In this section, I define the basic terms which are necessary to an understanding of the text presented in the following chapters. First I explain the symmetric and asymmetric cryptography, X.509 certificates, protocols SSL and TLS. Finally, I describe TLS_PSK, which is indispensable for working with .....

2.1 Cryptography

Cryptography is the study of mathematical techniques related to aspects of information security such as confidentiality, data integrity, entity authentication, and data origin authentication [1]. Today we talk about computer security which consists in the fact that the attacker does not have enough computational strength and time to decode the cipher. We can divide cryptography base on the type of keys into three parts. They are symmetric cryptography, asymmetric cryptography, and other primitives [1].

2.1.1 Symmetric Cryptography

Symmetric encryption, as the name suggests, means that the encryption and decryption of plaintext are based on sharing a together secret - keys. The secret key could be a number, a word or just string of random letters.

Symmetric ciphers could be divided into block and stream. Stream ciphers encrypt each character of plaintext separately, usually one bit. Block ciphers encrypt plaintext into blocks with fixed bit length n.

The main disadvantage of symmetric cryptography is the necessity of a large number of keys and need of their distribution. For example, for together communication n operators need to have

$$\frac{n * (n-1)}{2}$$

keys. It means that for the encrypted communications of mid-size company with 50 employees, it would need to share 1225 different keys.

On the other hand, the advantage is the low computational complexity of symmetric ciphers. Their using is also useful in cases where the encrypted data are not sent anywhere, for example, to protect files on a personal computer.

2.1.2 Asymmetric Cryptography

Asymmetric cryptography allows data encryption and particularly the implementation of the digital signature. Each entity has two keys. The first is the private key that is used to decrypt a message or create a digital signature. It must be kept secret. The second key is public which is used for encryption and authentication of the digital signature. Of course, there is impossible to derive the private key from the public key [2].

The main advantages of asymmetric cryptography are mainly a smaller number of keys than symmetric cryptography. If each entity has one public and one private key, it means that for n entities are needed $2n$ keys. In the same situation as in the previous example, a company of 50 employees would need to ensure the safety of 100 keys, which is substantially less than 1225.

The biggest disadvantage of asymmetric cryptography is its slowness compared with symmetric cryptography. Therefore, they are most often used together, while the text is encrypted with a random symmetric encryption key. The key is encrypted using asymmetric ciphers. In the case of a digital signature, the first is created the fixed length hash of the message and then it is signed using asymmetric cryptography.

2.1.3 Hash Function

Hash functions are one of the basic elements of modern cryptography, often called one-way hash function.

Hash functions are effectively designed display binary strings unlimited length to binary strings a fixed length, called hash value. For a perfect hash function that has n-bit hash value, there is a chance that a randomly selected string will be displayed on specific hash value 2^{-n}. The basic idea of hash functions is that the hash value should serve as a representative of the input string. Hash function suitable

for use in cryptography is usually chosen so that it is computationally very difficult find two different input strings that have the same hash value. If it succeeds in these two find strings, we say that we found a collision. Likewise, it should be computationally very difficult to find for a hash value corresponding to the input string. Using hash functions are used frequently to check the integrity of data and for digital signing of data [3].

ITEMIZE

2.2 Certificate

Certificate is digitally signed data structure whose foundation includes a public key of certificate owner. There are some standards of structure the certificate (X.509, EDI, WAP, etc.). The Internet is based on standard X.509 version 3, which issued the ITU. For the needs of the Internet, there is created an Internet profile of X.509 in the relevant RFC. Current Internet profile certificate is standard RFC-5280 [2].

2.2.1 Standard X.509

Standard X.509 was originally designed as an authentication framework for X.500 directories [4]. They have a hierarchical structure and the individual attributes can be assigned to individual computers of companies or individual printers. That is, each entity can be clearly identified, and each can have its private and public key. The proposal envisages the hierarchical structure of certificate authorities. Certificate X.509, see Figure 2.1.

The first version of the X.509 standard was already appeared in 1988 as the first proposal for PKI [4]. The first version was very simple and today is already inadequate. It contained only 7 fields:

- certificate version;
- certificate series number;
- algorithm which signed certificate;
- name of certification authority which certificate released;
- identity of certificate owner;
- public key of certificate owner;

- certificate validity.

The second version was introduced five years later in 1993 and brought only minimal changes. The second version did not solve the problems associated with the first version. Fields which was needed in this version, still missing [4]. It contained only two new fields:

- unique identifier of the certificate owner;
- unique identifier of the certification authority.

The third version was introduced in 1996. Its biggest and most important benefit is to support the expansion. It is defined a syntax that allows you to create custom certificate extension. It eliminates the major shortcomings of the two previous versions, but then appears some incompatibility.

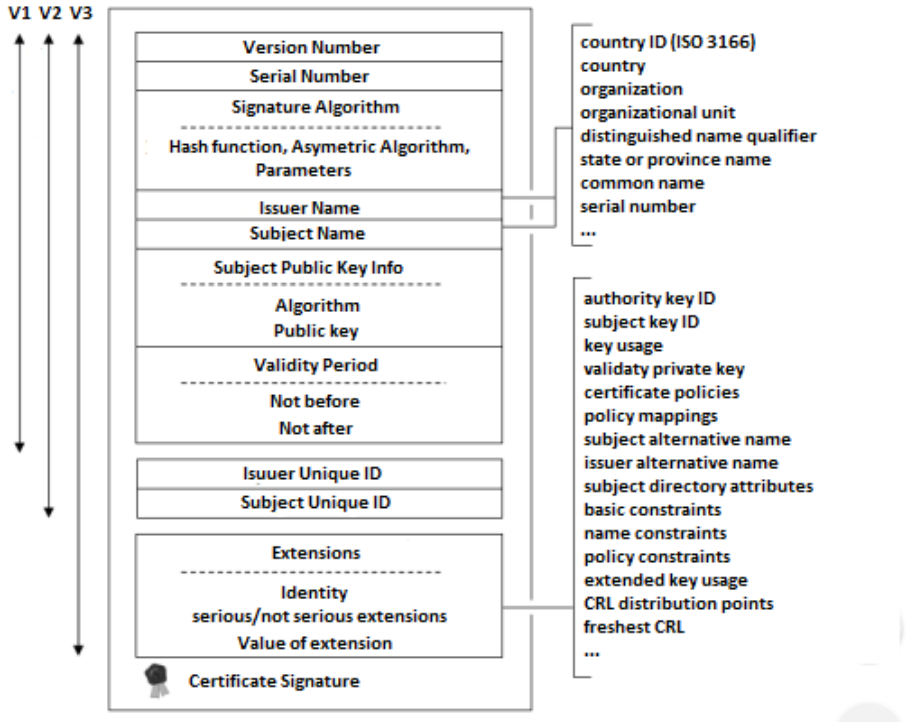


Figure 2.1: Structure X.509 Certificate

2.2.2 Certificate Authority

Certification Authority (CA) is an independent third party that issues certificates.

In other words, the CA is an institution which inspects the certificate request and issues certificates whose validity is verifiable using the responsive public key. The CA also takes care of archiving and distribution of certificates checks their validity and ensures their revocation. To the CA is truly credible, it must be impartial and, if it is possible, it should be subordinate any higher CA. Subordination means that it identifies using a certificate signed by the certification authority higher level [2].

Root CA, certification authorities at the highest level, uses the certificate signed by themselves (self-signed certificate).

2.2.3 Self-signed Certificate

The self-signed certificate is a certificate which the applicant gives by itself. The self-signed certificate has the same data structure as a certificate issues by CA. This certificate is recognized according to identical item Subject and item Issuer.

Creating self-signed certificate is not easy. To create certificate request we need to fill same items, which we do not know. For example, serial number, certificate validity, etc.

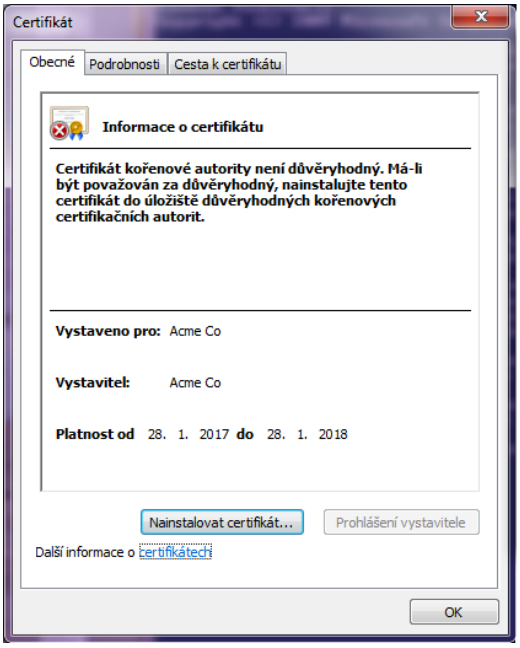
As proof of the private key possession by the user, the self-signed certificate uses a digital signature certificate which was made by the private key belonging to the public key in the certificate. Verification of the signature is carried out through a public key in the actual certificate [2].

Self-signed certificate is used by software internally. While the applicant generates CSR to be issued by the CA, the public key must be kept by the applicants. In this case, the public key is often maintained like a self-signed certificate. Subsequently it is rewritten by the certificate.

2.2.4 Formats PEM and DER

The PEM (Privacy Enhanced Mail) is a Base64 encoded DER certificate. It is designed to be safe for inclusion in ASCII or even rich-text

documents. This means that we can simple copy and paste the content of a pem file to another document and back. Following is a sample PEM file containing a private key and a certificate 2.2.




```
-----BEGIN RSA PRIVATE KEY-----
MIIEpAIBAAKCAQEAz2DH3nJePLkL84mVCAgtO8I
MI5cI3e2JKRr/cDpYa/sm7I5WRxeOqtNIN+VU6m
A .... MANY LINES LIKE THAT ..........
sXeRvIEx3lQnC1HFKuJN/8dDcD/tQi2URl41gpV
8Pl2o5bit+nzU2fvJIKOoGLF1NyX18ImApWL8kj
kgL3iXR5t9lbHRsD85zzy3OYBKZBXE/T5cbW4uW
-----END RSA PRIVATE KEY-----

-----BEGIN CERTIFICATE-----
MIIC9jCCAd6gAwIBAgIRAOzV53Pr8ldSJfEtCYN
ODAwWjATMREwDwYDVQQKDAhMZW5rYSA8MzCCASI
A .... MANY LINES LIKE THAT ..........
vZk8K04FuGSxpY7mtPLfeHni9RpxQAoU187/DwU
vpJyk/+8o7e0U3Lil/O7iZjXr3jDSYENc/fj0Hx
r+uQEnxgWgeGyhaB6f15zo6mGY0r+Czkov2gdJH
-----END CERTIFICATE-----
```

Figure 2.2: A sample example of DER and PEM file

A certificate or key must start with header and the number of dashes is meaningful, and must be correct. A single PEM file can contain a number of certificates and a key, for example, a single file with public certificate, intermediate certificate, root certificate or private key [5].

The DER (Distinguished Encoding Rules) is a binary form of ASCII PEM format certificate. All types of certificates and private keys can be encoded in DER format, its information is stored in the binary DER for ASN.1 and applications providing RSA, SSL and TLS should handle DER encoding to read in the information [6].

2.2.5 Certificate Signing Request

The certificate authority must fill individual items of the certificate duly before it signs the result digitally. The certificate applicant can

apply in two ways: submit a data structure called a certificate request or not so [2].

The certificate request should include:

- Applicant ID
- The public key
- Evidence of the possession of the private key
- Other information that the user wishes to insert certificate
- May contain evidence of the generation of paired data
- Data necessary for billing (in case issuance of certificates is paid)
- Passwords for communication with CA:
  - One-time password for issuing the certificate
  - One-time password for certificate revocation
  - Permanent password for personal (non-electronic) communication between user and CA
  - Phrase (in case losing every passwords)

2.2.6 PROCESY - podpisovanie a cert. exchange

2.3 Protocols SSL and TLS

Protocols SSL and TLS are used for secure communications between client and server. They create a framework for the use of encryption and hash functions.

SSL was developed by Netscape Communications which published three versions. The first version was only a test, the second has been used in practice. However, it still contained security vulnerabilities, the most important was susceptibility to attack *man in the middle*. The third version was introduced in 1996 and its specification could be found in the document *The SSL Protocol Version 3.0* [7]. Of this version was created TLS protocol which is currently the most widespread and supported [8]. There are three versions which have only minimal differences.

Protocol SSL/TLS provides authentication of the two communicating parties by using asymmetric encryption, message integrity by using MAC and confidentiality by encrypting all communications by selected symmetric cipher.

Protocol SSL/TLS is located between the application and the transport layer reference ISO/OSI model and consists of two main parts. They are *The Record Layer Protocol* (RLP) and *Handshake Protocol* (HP).

Record Layer Protocol processes application data, performs fragmentation, compression and data encryption. On the other hand, it decrypts the data again and verifies the checksums. RLP protocol does not care about the type of encryption algorithm or encryption key setting. This information is from HP.

Handshake Protocol is activated immediately after establishment the connection and provides identification of communicating parties, provision of cryptographic algorithms, compression algorithms and other attributes. Then it creates *a master secret* from which are derived encryption keys, initiation vectors and the MAC. The process of the protocol is:

1. The client wants to connect to the server and sends *ClientHello*, which contains the highest number of version supported by SSL/TLS, the number of session (it is empty if it is a new session), the list of supported ciphers and compression methods and a random number.

2. The client waits for a response in the form of a report *ServerHello*, which will contain the highest number of versions of SSL/TLS, which is supported by server and client. It will also contain encryption and compression method, which are selected from the list received in step one, a random number and its public key certificate (the server can also request authentication client).

3. The client verifies the server certificate, if all ciphers are satisfied. Next, he sends a request to server to exchange keys. At the end the server and client share a common 48 bits *premaster secret*. *The master secret* is derived from it. Then of the master secret and random numbers *ClientHello ServerHello* are derived two session keys to encrypt messages and two MAC initiation vectors for use symmetric cipher in CBC mode.

4. The client sends a confirmation selected ciphers. From this moment, the communication has been encrypted and the client sends a message that ends with this phase. In case the server

required the client authentication, it has been carried out in this step. Finally, the server sends a confirmation used ciphers and message about the completion of this phase, thereby HP ends.

The used algorithms:

- key exchange: RSA, Diffie-Hellman, ECDH;
- stream symmetric ciphers: RC4 with key length of 40-120 bits;
- block symmetric ciphers: DES, DES40, 3DES, IDEA;
- hashing algorithms: MD5, SHA.

TLS uses public key certificates for authentication. To establish a TLS connection are used symmetric keys (later called pre-shared keys or PSKs), shared in advance among the communicating parties [9].

2.3.1 PSK Key Exchange Algorithm

The cipher suites with PSK key exchange algorithm, use only symmetric key algorithms and are thus especially suitable for performance-constrained environments where both ends of the connection can be controlled. The cipher suites are intended for a rather limited set of applications, usually involving only a very small number of clients and servers.

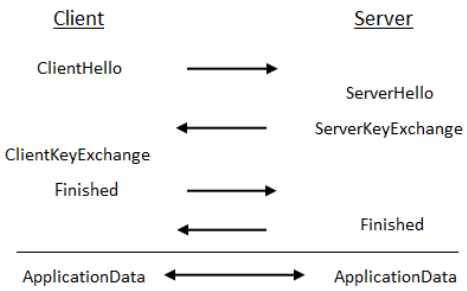


Figure 2.3: TLS PSK

The client indicates its willingness to use pre-shared key authentication by including one or more PSK ciphersuites in *the ClientHello message*. If the TLS server also wants to use pre-shared keys, it selects one of the PSK ciphersuites, places the selected ciphersuite in *the ServerHello message*, and can includes *ServerKeyExchange message*. If *ServerKeyExchange message* is included depends on the server provides to help the client in selecting which identity to use. The server can provide a "PSK identity hint" in *the ServerKeyExchange message*. The client indicates which key to use by including a "PSK identity" in *the ClientKeyExchange message*. If no hint is provided, *the ServerKeyExchange message* is omitted. Both clients and servers may

have pre-shared keys with several different parties. The Certificate and CertificateRequest payloads are omitted from the response.

The TLS handshake is authenticated using *the Finished messages* as usual. If the server does not recognize the PSK identity, it may respond with an *unknown_psk_identity alert message*. Alternatively, if the server wishes to hide the fact that the PSK identity was not known, it may continue the protocol as if the PSK identity existed but the key was incorrect: that is, respond with *a decrypt_error alert* [9].

3 Language GO

Go is a programming language developed at *Google* in year 2007 and announced in November 2009. Many companies have started using Go because of its performance, simplicity, ease of use and powerful tooling. Go programming language is a statically-typed language with advanced features and a clean syntax [10]. It combines the performance and security benefits associated with using a compiled language like *C++* with the speed of a dynamic language like *Python*. It provides:

- garbage collector - memory is cleaned up automatically when nothing refers to it anymore,
- fast compilation time - through effective work with addictions individual parts of the program and simple grammar,
- light-weight processes (via go-routines), channels,
- a rich standard library,
- easy testing - incorporated directly into the core language,
- one of the best documentation - a clear and full of examples.

Go excluded some features intentionally to keep language simple and concise. There is no support for type inheritance, method or operator overloading, circular dependencies among packages, pointer arithmetic, assertions nor for generic programming.

3.1 Packages

In Go, source files are organized into system directories called packages. To develop software applications, writing maintainable and reusable pieces of code is very important. Go provides the modularity and code reusability through it's package system. Go encourages programmers to write small pieces of software components through packages, and compose their applications with these small packages.

The packages from the standard library are available at the "pkg" subdirectory of the GOROOT directory. When we install Go, an environment variable GOROOT will be automatically added to our system for specifying the Go installer directory. The Go developer community is very enthusiastic for developing third-party Go packages. When

you develop Go applications, you can leverage these third-party Go packages [11].

When programmers develop executable programs, they will use the package "main" for making the package as an executable program. The package "main" tells the Go compiler that the package should compile as an executable program instead of a shared library. When programmers build shared libraries, they will not have any main package and main function in the package.

To download third-party Go packages is used command:

```
go get example/exampleLib
```

After installing the exampleLib, put the import statement in programs for reusing the code, as shown below:

```
package db
import (
  "example/exampleLib"
  "example/exampleLib/sub"
)
func init {
  // initialization code here
}
```

To install third-party Go packages is used command:

```
go install
```

The go install command will build the package "sub" which will be available at the pkg subdirectory of GOPATH.

```
package main
import (
  "fmt"
  "example/exampleLib/sub"
)
func main() {
    sub.Add("dr","Dart")
    fmt.Println(sub.Get("dr"))
    // code here
}
```

3.1.1 Crypto

Package crypto collects common cryptographic constants.

3.1.2 Encoding

Package encoding defines interfaces shared by other packages that convert data to and from byte-level and textual representations.

3.1.3 Hash

Package hash provides interfaces for hash functions.

Crypto	Description
aes	implements AES encryption (formerly Rijndael), as defined in U.S. Federal Information Processing Standards Publication 197.
cipher	implements standard block cipher modes that can be wrapped around low-level block cipher implementations.
des	implements the Data Encryption Standard (DES) and the Triple Data Encryption Algorithm (TDEA) as defined in U.S. Federal Information Processing Standards Publication 46-3.
dsa	implements the Digital Signature Algorithm, as defined in FIPS 186-3.implements the Elliptic Curve Digital Signature Algorithm, as defined in FIPS 186-3.
esdsa	implements the Elliptic Curve Digital Signature Algorithm, as defined in FIPS 186-3.
elliptic	implements several standard elliptic curves over prime fields.
hmac	implements the Keyed-Hash Message Authentication Code (HMAC) as defined in U.S. Federal Information Processing Standards Publication 198.
md5	implements the MD5 hash algorithm as defined in RFC 1321.
rand	implements a cryptographically secure pseudorandom number generator.
rc4	implements RC4 encryption, as defined in Bruce Schneier's Applied Cryptography.
rsa	implements RSA encryption as specified in PKCS#1.
sha1	implements the SHA1 hash algorithm as defined in RFC 3174.
sha256	implements the SHA224 and SHA256 hash algorithms as defined in FIPS 180-4.
sha512	implements the SHA-384, SHA-512, SHA-512/224, and SHA-512/256 hash algorithms as defined in FIPS 180-4.
subtle	implements functions that are often useful in cryptographic code but require careful thought to use correctly.
tls	partially implements TLS 1.2, as specified in RFC 5246.
x509	parses X.509-encoded keys and certificates. It contains package pkix which contains shared, low level structures used for ASN.1 parsing and serialization of X.509 certificates, CRL and OCSP.

Table 3.1: Table of crypto package created by golang

Encoding	Description
ascii85	implements the ascii85 data encoding as used in the btoa tool and Adobe's PostScript and PDF document formats.
asn1	implements parsing of DER-encoded ASN.1 data structures, as defined in ITU-T Rec X.690.
base32	implements base32 encoding as specified by RFC 4648.
base64	implements base64 encoding as specified by RFC 4648.
biary	implements simple translation between numbers and byte sequences and encoding and decoding of variants.
csv	reads and writes comma-separated values (CSV) files.
gob	manages streams of gobs - binary values exchanged between an Encoder (transmitter) and a Decoder (receiver).
hex	implements hexadecimal encoding and decoding.
json	implements encoding and decoding of JSON as defined in RFC 4627.
pem	implements the PEM data encoding, which originated in Privacy Enhanced Mail.
xml	implements a simple XML 1.0 parser that understands XML name spaces.

Table 3.2: Table of encoding package created by golang

Hash	Desription
adler32	implements the Adler-32 checksum.
crc32	implements the 32-bit cyclic redundancy check, or CRC-32, checksum.
crc64	implements the 64-bit cyclic redundancy check, or CRC-64, checksum.
fnv	implements FNV-1 and FNV-1a, non-cryptographic hash functions created by Glenn Fowler, Landon Curt Noll, and Phong Vo.

Table 3.3: Table of hash package created by golang

4 Analysis

It was necessary to examine features of language GO related safety and cryptography, analyze libraries which GO contains and also search for available third-party libraries. This chapter contains the overview, evaluate and compare existing cryptographic liberates base on their measures and next base on expansion measures important for implementation.

Table 4.1 shows analyzed Go package Crypto created by Golang and other Go packages created by third-parties. Individually items mean:

- Name - name of founder and package.
- Cryptographic functions - support cryptographic functions, such as symmetric encryption, asymmetric encryption and hash functions (all/sym/asym/hash/unknown).
- Start of project - a year of creating project.
- Is still opened - contributors still work on the project (Yes/No).
- Issue tracker system - support of solving bugs, feature requests, tracking todos, and more (Yes/No).
- Documentation accessibility - assessed on a scale of 0-5 (5 is the highest).
- Downloads - number of downloads. In case the package is saved on *https://github.com/*, the information about downloads presents value of Fork. Downloads of package Crypto created by Golang is unknown, this package is automatically installed with installing program Go.
- License - availability of licenses for free (Yes/Payment). The payment indicates the amount of payment per some period. This case did not occur.

Table 4.1: Table of cryptographic libraries in Go

Name	Crypto. functions	Start of project	Is still opened	Issue tracker system	Doc. accessability	Downloads	License
golang/crypto	all	2009	Y	Y	5	-	Y
ory-am/fosite	asym, hash	2015	Y	Y	4	39	Y
square/go-jose	asym, sym	2014	Y	Y	4	70	Y
Shopify/ejson	hash	2014	Y	Y	3	22	Y
mitchellh/go-mruby	asym	2014	Y	Y	4	19	Y
Sermo Digital/jose	all	2015	Y	Y	4	28	Y
mozilla/tls-observatory	hash	2014	Y	Y	4	31	Y
square/certigo	hash	2016	Y	Y	3	12	Y
docker/libtrust	all	2014	N	Y	4	26	Y
dedis/crypto	sym, hash	2010	Y	Y	4	17	Y
dchest/blake2b	hash	2012	N	Y	4	6	Y
enceve/crypto	hash	2016	N	Y	4	1	Y
go-libp2p-crypto	all	2015	Y	Y	4	5	Y

Continued on next page

Table 4.1 – continued from previous page

Name	Crypto. functions	Start of project	Is still opened	Issue tracker system	Doc. accessability	Downloads	License
dchest/blake2s	hash	2012	N	N	3	3	Y
benburkert/openpgp	sym, hash	2012	N	N	3	0	Y
minio/sha256-simd	hash	2016	Y	Y	3	14	Y
avelino/awesome-go	unknown	2014	Y	Y	2	2287	Y
ethereum/go-ethereum	all	2013	Y	Y	4	1028	Y
chain/chain	hash	2015	Y	Y	4	113	Y
lightningnetwork/lnd	sym, hash	2015	Y	Y	4	50	Y
square/go-jose	asym, hash	2014	Y	Y	4	70	Y
dgrijalva/jwt-go	asym, hash	2012	Y	Y	4	226	Y
golang/oauth2	asym, hash	2014	Y	Y	4	279	Y

The table 4.1 was created on the base of information available on following websites [12] [13] [14] [15]. The table does not contain packages which do not support any cryptographic functions. Also, the table does not contain information from untrusted sources. During the analysis, I discovered sources which are not actual or supported [16].

The next step of analysis was select the libraries which fulfill the requirements. The important parameters were the support of all cryptographic functions, the topicality of project, the approach to solving problems and no payment license. In the table 4.2, there are shown four libraries and compared to the base of the other measures:

- Crypto. key - possibilities for generation of cryptographic keys (Yes/No),
- X.509 Certificates - work with X.509 certificates (generation of self-signed certificates, support for certificate signing requests, support for different formats and extensions) (Yes/No),
- SSL/TLS - support of higher level protocols such as SSL/TLS (Yes/No),
- Use go lang crypto - dependence on Crypto package created by Golang (Yes/No/-).

Name	Crypto. func-tions	Start of project	Is still opened	Issue tracker system	Doc. access-ability	Down-loads	License	Crypto. keys	X.509 Certifi-cates	SSL/ TLS	Use Golang Crypto
crypto	all	2009	Y	Y	5	-	Y	Y	Y	Y	-
SermoDigital/ jose	all	2015	Y	Y	4	28	Y	Y	Y	N	Y
go-libp2p-crypto	all	2015	Y	Y	4	5	Y	Y	Y	N	Y
ethereum/go-ethereum	all	2013	Y	Y	4	1028	Y	Y	Y	N	Y

Table 4.2: Filtered table of cryptographic libraries in Go

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