



# **Hardware-Secured System for Secure Communications and Message Exchange**

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Thesis to obtain the Master of Science Degree in  
**Information Systems and Computer Engineering**

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# Acknowledgments

I would like to thank my parents for their friendship, encouragement and caring over all these years, for always being there for me through thick and thin and without whom this project would not be possible. I would also like to thank my grandparents, aunts, uncles and cousins for their understanding and support throughout all these years.

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I would also like to acknowledge my dissertation supervisors Prof. Some Name and Prof. Some Other Name for their insight, support and sharing of knowledge that has made this Thesis possible.

Last but not least, to all my friends and colleagues that helped me grow as a person and were always there for me during the good and bad times in my life. Thank you.

To each and every one of you – Thank you.



# Abstract

Individuals with high responsibility jobs such as government officials, top level company executives and diplomats are high profile targets to digital attacks, since they manage very sensitive information. Thus, attacks can have very damaging consequences for them and organizations. To maximize security, it is in their best interest to avoid storing cryptographic keys, passwords and perform critical cryptographic operations in their personal computers. This thesis proposes a cheap, relatively efficient but highly secure physical personal system, in a client-server mode, which enables individuals to securely exchange messages and sensitive documents. The proposed system secures communication by providing confidentiality and authentication to messages. This system will be responsible for performing every cryptography operation, store and manage cryptographic keys. All operations are performed inside the device and keys are never exposed to the outside, in order to not jeopardize the security of the communications.

## Keywords

Communication Security; Secure Physical Device; Confidentiality; Authentication.



# Resumo

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## Palavras Chave

Colaborativo; Codificação; Conteúdo Multimídia; Comunicação;





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# Acronyms

**UI**      User Interface



# 1

## Introduction

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In the modern world, most people have access to a computer, involved in many everyday tasks, such as, web browsing, communications, social networks, news, entertainment, among many others. There is no limit to what you can achieve with the Internet, using just a computer. For this reason, computers have a wide range of attacks potentially exploitable by hackers, by taking advantage of software vulnerabilities or user mistakes. This is of great concern to people with high responsibilities from their jobs, who deal with sensitive information, such as, government officials, top level company executives and diplomats. Suffering an attack to a personal computer can be highly damaging as it can carry severe consequences for companies and countries. In addition, high profile officials who deal with sensitive information are more likely to be targeted by attackers.

## **1.1 Problem**

New attacks, targeting computers, are discovered daily. They can come from zero-day vulnerabilities, phishing scams and many others, the opportunities are endless. It is impossible to predict and protect against all. Communications security, depends on the cryptography keys and passwords used. These are usually stored, along with other sensitive information, in the user's computer. Instead of storing the data in the user's computer, a more optimal solution, meaning, harder to compromise the security of communications, is to separate the platform used by the user for communications (the user's computer), and the device responsible for managing, securing communications and storing sensitive data. The goal is to add another layer of security, to make it difficult to compromise security even if the user's computer is compromised. A secure and independent solution is needed to establish secure channels of communication, store keys and perform critical operations, even if the computer might be compromised. A possible approach is the utilization of a personal physical device that is responsible for storing digital keys and perform critical operations. These devices need to be highly secure and independent from the user's personal computer.

## **1.2 Requirements**

In order to address the problem and using the discussed approach, the implemented solution must comply with the following requirements:

- The box must be tamper-resistant, secure and personal;
- The system must allow secure interaction between different entities;
- All the user's secrets, such as keys and passwords must be stored in the device;
- The user's secrets must never be exposed to the outside;

- All critical operations must be performed in the device;
- The system must authenticate the user before performing operations. The system does not need to authenticate itself to the user;
- The system must be easy to use to the regular non-savvy user;
- The system should perform the operations in a reasonable time to minimize the user's wait;
- It should be relatively low cost.

# 2

## Architecture

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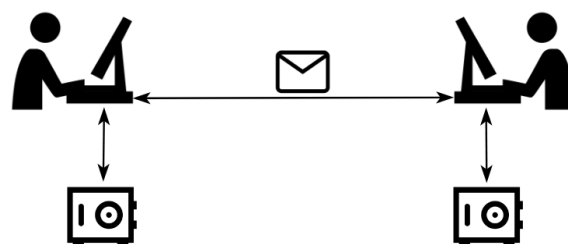
The objective of the system was to develop a device in a box format to enable users to establish safe channels of communication. This is achieved with a safe and secure device which is personal to each individual. In order to secure the communications between users, the device saves the user's sensitive data, such as keys, and performs all security critical operations. The system is designed so that each user has it's own physical box.

## 2.1 Services

The solution will provide several services, wich fullfill the requirements defined in 1.2.

- Secure Storage to save the user's sensitive cryptographic keys, passwords, documents or any data;
- Key management, generation, revocation and importation of keys when the users deem necessary;
- Confidentiality to keep the contents of the communications secret, except from authorized entities;
- Integrity to safeguard communications from unauthorized modifications;
- Authentication to ascertain the identity of the data sender;
- Non-repudiation to prevent an entity from denying authorship of a piece of information.

## 2.2 Components



**Figure 2.1:** Client and device

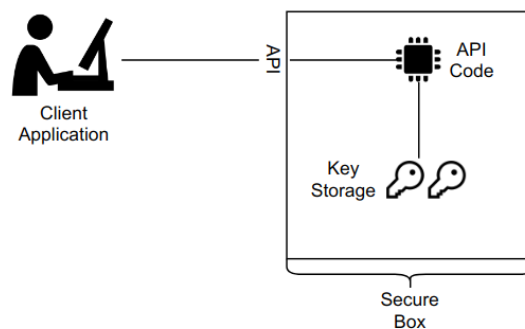
The solution is composed of two main components, as shown in figure 2.1:

- The physical box which responsible for securing communications;
- The client application on the user's computer which provides an interface for the user to execute operations on the box.

By separating these components, the security of the system is isolated and solely of total responsibility of the box. It is not dependent on the user's personal computer.

Both components are connected through a common interface, such as USB, in order to be more easily accessible to the end users.

Figure 2.2 depicts the client application, interacting with the secure device through the application programming interface (API), the implementation of operations inside the device and secure storage where all the keys are stored.



**Figure 2.2:** Client application and secure device

Figure 2.2 depicts the client application, interacting with the secure device through the application programming interface (API), the implementation of operations inside the device and secure storage where all the keys are stored.

## 2.3 Operations

The system operations will ensure the system requirements and services are fulfilled. For the user to be able to execute them, he first must authenticate himself to the device. This is done with a PIN or password, which identifies the user. Once authenticated, the operations will be available to the user to be executed in the box.

The operations are split in three types:

- The administration operations manage the authentication and communication configuration;
- The data exchange operations secure the user's communication;
- The key exchange operations manage the keys stored inside the device, which will be used to secure communications.

### **2.3.1 Administration Operations**

The administration operations will allow the user to manage the authentication related parameters. The only operations of this type is to change the authentication PIN. The device will be initialized from fabric with a default PIN which must be supplied to the user. Before performing any operation the user should change his PIN to begin secure communications.

### **2.3.2 Data Exchange Operations**

The main operations will be responsible to secure the communications between users. These operations will fulfill the confidentiality, authentication and non-repudiation services.

- Secure data exchange with confidentiality and authentication. The objective of this operation is to send and receive data to and from the device. Plaintext data will be returned to the user encrypted and authenticated with their key stored inside the device. In the case of encrypted and authenticated messages, an error will be returned if the decryption was unsuccessful, otherwise, the user will receive the plaintext data;
- Digital Signature operation will provide non-repudiation to a piece of data. The user will send the information to the box, and the subsequent signature will be returned, which can be used to verify the data's authorship. To verify a signature, the user sends it to the device, and receives either success or failure to verify.

### **2.3.3 Key Exchange Operations**

These operations will handle key exchange when new keys need to be generated and exchanged between users, to enable further communications, and to import other user's public keys. This will serve the secure storage and key management services.

The first operations will enable the user to ask for a new key, generated inside the box, in order to securely send it to another user. The user receiving the new key, generated by another user, will receive and store the key inside the box. The final operation will provide a way to import other user's public keys, as well as export their personal public key, to be shared with another user.



# 3

## Solution Protocol

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Symmetric keys will be used to encrypt and authenticate messages. They have better performance with larger messages compared to asymmetric keys. Each user can have stored in their box, several symmetric keys. This enables the user to establish secure communications with multiple different people or groups. The non-repudiation property of asymmetric keys will be used to create digital signatures of documents. The other use, will be to share symmetric keys between user who wish to communicate. The box stores the private and public key pair of the user, and the public keys of people the user wishes to trade secrets with.

### **3.1 Initial State**

The users will receive the device with a pair of private and public keys, generated inside the device from fabric. Each device will have the user's public keys, whom he wishes to communicate. The user can request whose public keys he wants, before the device is initialized in fabric. This allows the users to trade symmetric keys between them, which they can use to begin trading messages securely. In addition, the device can also come with a symmetric key stored in each the user's device.

For each user or group a user wants to communicate with, he has a symmetric key stored in the device.

When a new user wants to establish secure communications with an existing user or a group, he must share his public key with the user, ideally physically to ensure there are no mistakes or attacks. After this they can securely share symmetric keys to enable efficient and secure messaging.

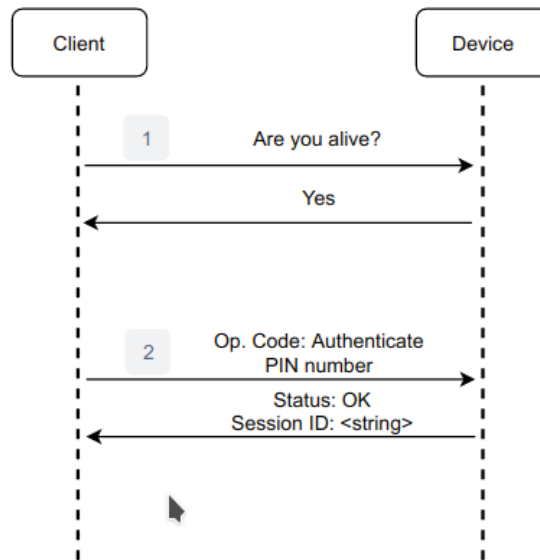
### **3.2 Protocol**

A protocol was devised for every operations with different phases and data for each operation.

#### **3.2.1 Authentication Protocol**

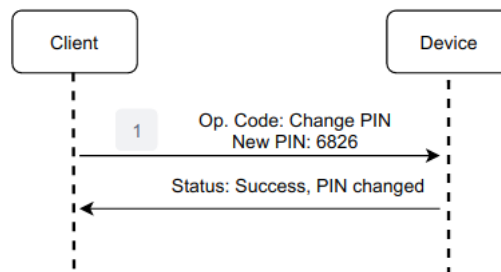
Before executing any operation the user must authenticate himself to the device.

1. The first phase is initiated by the user by sending a message to check if the box is alive and connected to the computer.
2. The operation will move to the second phase when the user receives an affirmative response. He will then send the operation code, which indicates he wants to authenticate himself, and the authentication PIN. The device will respond with a status parameter indicating failure or success. When successful the box will also return a session ID string, which the user will need for further operations, to prove he has authenticated himself.



**Figure 3.1:** Authentication Protocol

### 3.2.2 Administration Protocol



**Figure 3.2:** Change Authentication PIN protocol

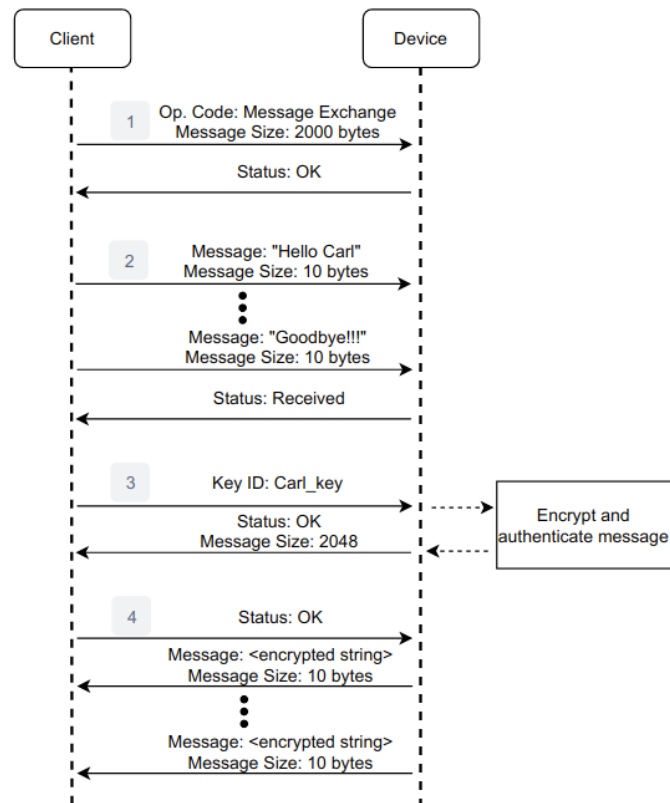
As explained before, there is only one administration operation, changing the authentication PIN, pictured in figure 3.2.

The user initiates by sending the operation code, identifying the operation, the new PIN number and the session ID acquired previously. The device verifies the session ID and send a response, indicating the success or failure of the operation.

### 3.2.3 Message Exchange Protocol

Protocol to encrypt and authenticate messages:





**Figure 3.3:** Message Exchange Protocol

1. The user sends the operation code, signaling he wants to send a message, and the message size;
2. The box will respond with an OK message that the user can begin transmitting the message. The message will be transmitted a maximum of X bytes per "packet". Each packet contains the message information and the size of the message information for that packet. When the transmission ends, the device will confirm the reception;
3. The user subsequently will respond with the symmetric key ID, which he wants to encrypt and authenticate the message with. The box will handle the cryptographic operations and return a status message and the encrypted message size.
4. After the client confirms, the encrypted message with the additional MAC and IV parameters appended, will be returned in the same manner it was sent.

Protocol to decrypt and verify message authentication:

1. The operation code is sent, as well as the encrypted message size;

2. The box will respond with an OK message that the user can begin transmitting the message, one packet at a time;
3. When the message transmission ends, the device will confirm its reception, and the user will subsequently respond with the symmetric key ID, which can decrypt and verify the message authentication;
4. After performing the decryption and authentication operations, the device will return a message indicating its success or failure. In case of a successful operations, it will return, in the same manner it was sent, the plaintext message.

In the case of digital signatures, the user's must have each others public keys, if they do not already have them. Protocol for generating a digital signature:

1. The user initiates with the code operation and the plaintext message size;
2. When the box responds with an OK message, the user transmits the message one packet at a time;
3. In possession of the message, the device will generate the digital signature using the user's private key. When finished the signature is sent back.

Protocol for verifying digital signatures:

1. The user initiates with the code operation;
2. When the box responds with an OK message, the user transmits the message one packet at a time;
3. When done, the user also sends the signature and the name of the signer, so the device knows what public key to use to verify the signature;
4. Then, the device will verify the digital signature using the signer's public key, message and signature. The result will be sent back to the user.

### **3.2.4 Key Exchange Protocol**

Protocol to import public keys:

1. The user send a message with the operation code, indicating he wants to send someone's public key;
2. After the device responds with an OK signal, the user sends the public key, and the name of the owner of the public key;

3. The device then informs the user of the operation's success or failure.

Just like digital signatures, for users to be able to share symmetric keys between each other, they must possess each others public keys in their device. If not, they must physically meet to share them, and import them to their respective devices, with the available operation.

Protocol to send new symmetric key:

1. The user sends a message with the operation code;
2. After the device responds with an OK signal, the user sends the key ID, the name the key will be saved as, and the name of the user he wants to share the key with, so the device knows which public key to use to secure the key;
3. A new symmetric key will be generated and saved in the device's secure storage, with the key ID sent by the user. The box will encrypt and sign the key with public-key cryptography, and send it to the user, which he can securely share with the other user.

Protocol to save new symmetric key, received from another user:

1. The user sends a message with the operation code;
2. After the device responds with an OK signal, the user sends the key ID, the name of the key sender, and the encrypted and signed key;
3. The device will then verify the signature with the sender's public key and decrypt the key, subsequently saving it in the device's secure storage along with other keys already present.



# 4

## This is the Fourth Chapter

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## 4.1 Development Process

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- Technology Research and Related Works
- Requirements Gathering and Study
- Design of the Architecture
- Implementation Process
- Testing and Functional Validation

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## 4.2 Development Environment

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**Algorithm 4.1: Time Control Strategy**

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```
begin
  nextBitrate  $\leftarrow$  nextDownloadLevel
  nextBitrate  $\leftarrow$  GetNextBitrate()
  cpuLoad  $\leftarrow$  GetCpuLoad()
  bitrateDelta  $\leftarrow$  getBitrateDelta(currentBitrate, nextBitrate)
  if bitrateDelta > maxThreshold then
    | SetBitrate(nextBitrate)
  if minThreshold < bitrateDelta < maxThreshold and numAttempts < 2 then
    | numAttempts  $\leftarrow$  numAttempts + 1
  else if minThreshold < bitrateDelta < maxThreshold and numAttempts = 2 then
    | numAttempts  $\leftarrow$  0
  else
    | SetBitrate(nextBitrate)
  if 0 < bitrateDelta < minThreshold and numAttempts < 3 then
    | numAttempts  $\leftarrow$  numAttempts + 1
  else if 0 < bitrateDelta < minThreshold and numAttempts = 3 then
    | SetBitrate(nextBitrate)
```

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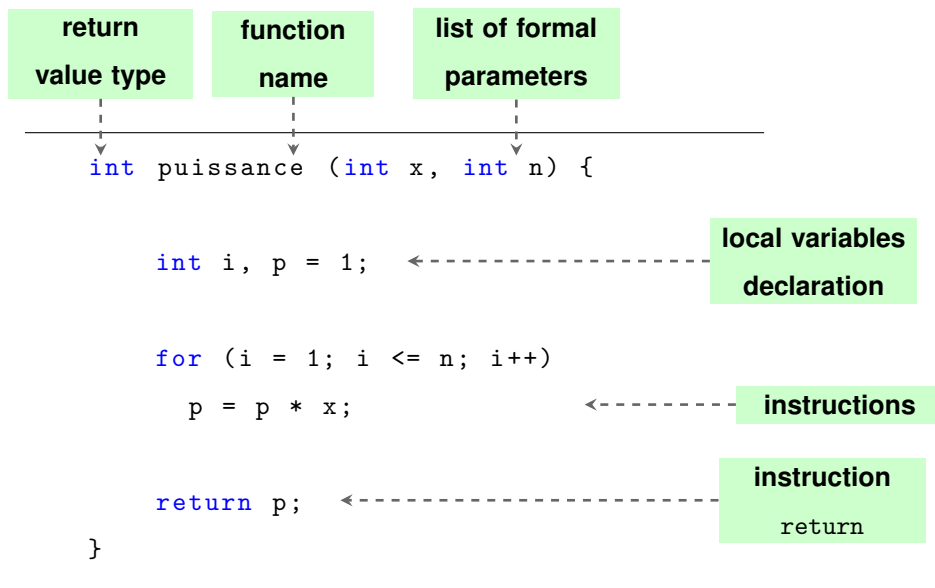
## 4.3 Client Application

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Quisque lacus. Donec ipsum. Nullam vitae sem at nunc pharetra ultricies. Cras vehicula varius turpis.





**Listagem 4.1:** A listing with a Tikz picture overlayed

And here another method (Listing 4.1) for mixing (overlay) a picture with a listing of code.

### 4.3.1 User Interface

Donec semper turpis sed diam. Sed consequat ligula nec tortor. Integer eget sem. Ut vitae enim eu est vehicula gravida. Morbi ipsum ipsum, porta nec, tempor id, auctor vitae, purus. Pellentesque neque. Nulla luctus erat vitae libero. Integer nec enim. Phasellus aliquam enim et tortor. Quisque aliquet, quam elementum condimentum feugiat, tellus odio consectetur wisi, vel nonummy sem neque in elit. Curabitur eleifend wisi iaculis ipsum. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. In non velit non ligula laoreet ultrices. Praesent ultricies facilisis nisl. Vivamus luctus elit sit amet mi. Phasellus pellentesque, erat eget elementum volutpat, dolor nisl porta neque, vitae sodales ipsum nibh in ligula. Maecenas mattis pulvinar diam. Curabitur sed leo..

Cras eu mauris. Quisque lacus. Donec ipsum. Nullam vitae sem at nunc pharetra ultricies. Vivamus elit eros, ullamcorper a, adipiscing sit amet, porttitor ut, nibh. Maecenas adipiscing mollis massa. Nunc ut dui eget nulla venenatis aliquet. Sed luctus posuere justo. Cras vehicula varius turpis.

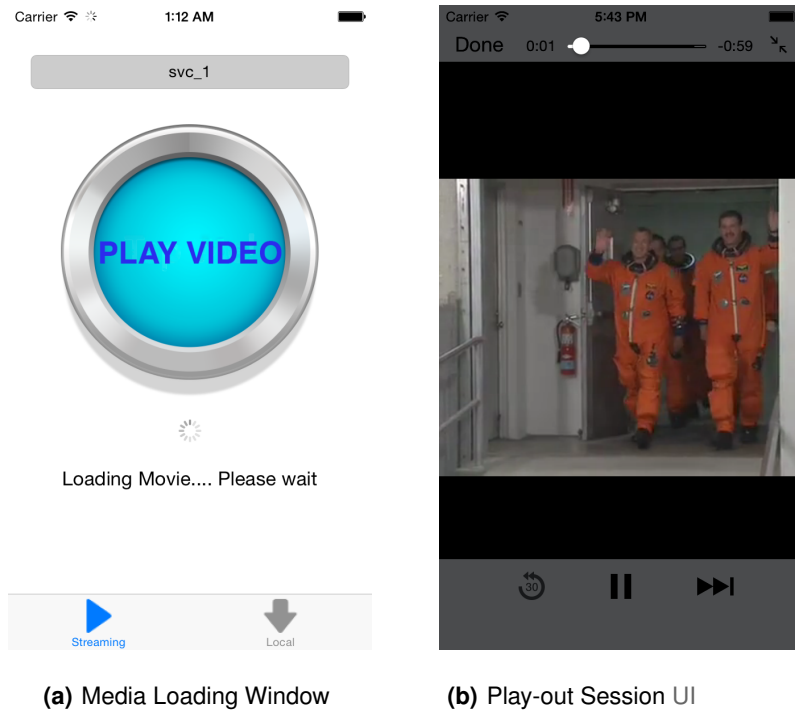
### 4.3.2 Vivamus luctus elit sit amet mi

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urna nibh ut arcu. Aliquam in lacus.

Figures 4.1(a) and 4.1(b) proin at eros non eros adipiscing mollis.



**Figure 4.1:** Complete User Interface

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# 5

## This is the Fifth Chapter

### Contents

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5.1	Maecenas vitae nulla consequat . . . . .	27
5.2	Proin ornare dignissim lacus . . . . .	28

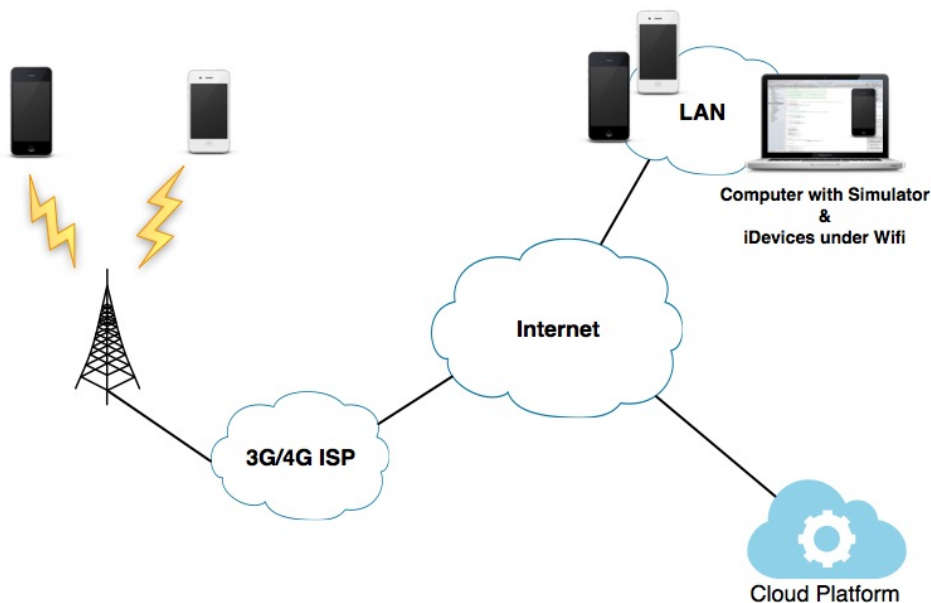
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## 5.1 Maecenas vitae nulla consequat

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**Figure 5.1:** Test Environment

Aliquam aliquet, est a ullamcorper condimentum, tellus nulla fringilla elit, a iaculis nulla turpis sed wisi. Fusce volutpat. Etiam sodales ante id nunc. Proin ornare dignissim lacus. Nunc porttitor nunc a sem. Sed sollicitudin velit eu magna. Aliquam erat volutpat. Vivamus egestas. Nunc tempor diam vehicula mauris. Nullam sapien eros, facilisis vel, eleifend non, auctor dapibus, pede Table 5.1 used in the tests. The Network Link Conditioner allows to force/simulate fluctuations in fixed network segments.

**Table 5.1:** Network Link Conditioner Profiles

Network Profile	Bandwidth	Packets Dropped	Delay
Wifi	40 mbps	0%	1 ms
3G	780 kbps	0%	100 ms
Edge	240 kbps	0%	400 ms

Aliquam aliquet, est a ullamcorper condimentum, tellus nulla fringilla elit, a iaculis nulla turpis sed wisi. Fusce volutpat. Etiam sodales ante id nunc. Proin ornare dignissim lacus. Nunc porttitor nunc a sem. Sed sollicitudin velit eu magna. Aliquam erat volutpat. Vivamus ornare est non wisi. Proin vel quam. Vivamus egestas. Nunc tempor diam vehicula mauris. Nullam sapien eros, facilisis vel, eleifend non, auctor dapibus, pede.

## 5.2 Proin ornare dignissim lacus

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Et “optimistic” nulla dui purus, eleifend vel, consequat non, dictum porta, nulla. Duis ante mi, laoreet ut, commodo eleifend, cursus nec, lorem. Aenean eu est. Etiam imperdiet turpis. Praesent nec augue. Curabitur ligula quam, rutrum id, tempor sed, consequat ac, dui  $G_j$ , nec ligula et lorem consequat ullamcorper  $p$  ut mauris eu mi mollis luctus  $j$ , porttitor ut, Equation (5.1), uctus posuere justo:

$N_j$  Is the number of times peer  $j$  has been optimistically unchoked.

$n_j$  Among the  $N_j$  unchokes, the number of times that peer  $j$  responded with unchoke or supplied segments to peer  $p$ .

$C_{r[j]}$  The cooperation ratio of peer  $j$ . If peer  $j$  never supplied peer  $p$ , the information of  $C_{r[j]}$  may not be available.

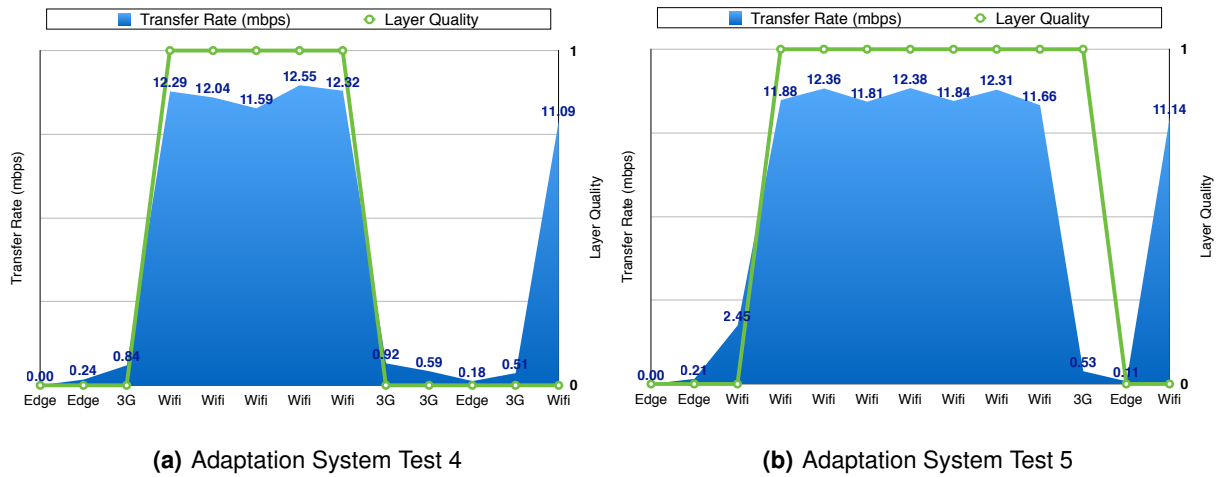
$C_{r(max)}$  The maximum cooperation ratio of peer  $p$ 's neighbors, i.e.,  $C_{r(max)} = \max(C_r)$ .

$$G_j = \begin{cases} \frac{n_j C_{r[j]}}{N_j} & \text{if } n_j > 0 \\ \frac{C_{r(max)}}{N_j + 1} & \text{if } n_j = 0 \end{cases} \quad (5.1)$$

Cursus  $C_{r(max)}$  conubia nostra, per inceptos hymenaeos  $j$  gadipiscing mollis massa  $N_j = 0$ , unc ut dui eget nulla venenatis aliquet  $G_j = C_{r(max)}$ .

Vestibulum accumsan eros nec magna. Vestibulum vitae dui. Vestibulum nec ligula et lorem consequat ullamcorper. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Phasellus eget nisl ut elit porta ullamcorper. Maecenas tincidunt velit quis orci. Sed in dui. Nullam ut mauris eu mi mollis luctus. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Sed cursus cursus velit. Sed a massa.

Both Figures 5.2(a) and 5.2(b) Phasellus eget nisl ut elit porta “perfect” tincidunt. Class aptent taciti sociosqu ad litora torquent per conubia nostra.



**Figure 5.2:** Adaptation System Behavior Test

Cras sed ante. Phasellus in massa. Curabitur dolor eros, gravida et, hendrerit ac, cursus non, massa. Aliquam lorem. In hac habitasse platea dictumst. Cras eu mauris. Quisque lacus. Donec ipsum. Nullam vitae sem at nunc pharetra ultricies. Vivamus elit eros, ullamcorper a, adipiscing sit amet, porttitor ut, nibh. Maecenas adipiscing mollis massa. Nunc ut dui eget nulla venenatis aliquet. Sed luctus posuere justo. Cras vehicula varius turpis. Vivamus eros metus, tristique sit amet, molestie dignissim, malesuada et, urna.





# 6

## Conclusion

### Contents

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6.2	System Limitations and Future Work . . . . .	34

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Pellentesque vel dui sed orci faucibus iaculis. Suspendisse dictum magna id purus tincidunt rutrum. Nulla congue. Vivamus sit amet lorem posuere dui vulputate ornare. Phasellus mattis sollicitudin ligula. Duis dignissim felis et urna. Integer adipiscing congue metus.

## 6.1 Conclusions

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## **6.2 System Limitations and Future Work**

Aliquam aliquet, est a ullamcorper condimentum, tellus nulla fringilla elit, a iaculis nulla turpis sed wisi. Fusce volutpat. Etiam sodales ante id nunc. Proin ornare dignissim lacus. Nunc porttitor nunc a sem. Sed sollicitudin velit eu magna. Aliquam erat volutpat. Vivamus ornare est non wisi. Proin vel quam. Vivamus egestas. Nunc tempor diam vehicula mauris. Nullam sapien eros, facilisis vel, eleifend non, auctor dapibus, pede.



## Code of Project

Nulla dui purus, eleifend vel, consequat non, dictum porta, nulla. Duis ante mi, laoreet ut, commodo eleifend, cursus nec, lorem. Aenean eu est. Etiam imperdiet turpis. Praesent nec augue. Curabitur ligula quam, rutrum id, tempor sed, consequat ac, dui. Vestibulum accumsan eros nec magna. Vestibulum vitae dui. Vestibulum nec ligula et lorem consequat ullamcorper.

**Listagem A.1:** Example of a XML file.

```
1 <?xml version="1.0" encoding="UTF-8"?>
2 <StreamInfo version="2.0">
3   <Clip duration="PT01M0.00S">
4     <BaseURL>videos/</BaseURL>
5     <Description>svc_1</Description>
6     <Representation mimeType="video/SVC" codecs="svc" frameRate="30.00" bandwidth="401.90"
7       width="176" height="144" id="L0">
8       <BaseURL>svc_1</BaseURL>
9       <SegmentInfo from="0" to="11" duration="PT5.00S">
```

```

10         <BaseURL>svc_1-L0-</BaseURL>
11     </SegmentInfo>
12 </Representation>
13 <Representation mimeType="video/SVC" codecs="svc" frameRate="30.00" bandwidth="1322.60"
14     width="352" height="288" id="L1">
15     <BaseURL>svc_1/</BaseURL>
16     <SegmentInfo from="0" to="11" duration="PT5.00S">
17         <BaseURL>svc_1-L1-</BaseURL>
18     </SegmentInfo>
19 </Representation>
20 </Clip>
21 </StreamInfo>

```

Etiam imperdiet turpis. Praesent nec augue. Curabitur ligula quam, rutrum id, tempor sed, consequat ac, dui. Maecenas tincidunt velit quis orci. Sed in dui. Nullam ut mauris eu mi mollis luctus. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Sed cursus cursus velit. Sed a massa. Duis dignissim euismod quam.

#### Listagem A.2: Assembler Main Code.

```

1  ; *****
2  ; * Constantes
3  ; *****
4
5  ON      EQU 1 ; contagem ligada
6  OFF     EQU 0 ; contagem desligada
7  INPUT   EQU 8000H ; endereço do porto de entrada
8          ;(bit 0 = RTC; bit 1 = botão)
9  OUTPUT  EQU 8000H ; endereço do porto de saída.
10
11
12 ; *****
13 ; * Stack
14 ; *****
15
16 PLACE   1000H
17 pilha:   TABLE 100H ; espaço reservado para a pilha
18 fim_pilha:
19
20 ; *****
21
22 PLACE   2000H
23
24 ; Tabela de vectores de interrupção
25
26 tab:     WORD    rot0
27
28 ; *****
29 ; * Programa Principal
30 ; *****
31
32 PLACE   0
33
34 inicio:
35     MOV BTE, tab ; incializa BTE
36     MOV R9, INPUT ; endereço do porto de entrada
37     MOV R10, OUTPUT ; endereço do porto de saída
38     MOV SP, fim_pilha
39     MOV R5, 1 ; inicializa estado do processo P1
40     MOV R6, 1 ; inicializa estado do processo P2
41     MOV R4, OFF ; inicializa controle de RTC
42     MOV R8, 0 ; inicializa contador
43     MOV R7, OFF ; inicialmente não permite contagem
44     EIO ; permite interrupções tipo 0

```

```

45     EI                ; activa interrupções
46
47 ciclo:
48     CALL P1           ; invoca processo P1
49     CALL P2           ; invoca processo P2
50     JMP  ciclo        ; repete ciclo
51
52 ; *****
53 ;* ROTINAS
54 ; *****
55
56 P1:
57     CMP R5, 1         ; se estado = 1
58     JZ  P1_1          ; se estado = 1
59     CMP R5, 2         ; se estado = 2
60     JZ  P1_2          ; se estado = 2
61 sai_P1:
62     RET              ; sai do processo.
63
64
65 P1_1:
66     MOVB R0, [R9]     ; lê porto de entrada
67     BIT R0, 1
68     JZ  sai_P1        ; se botão não carregado, sai do processo
69     MOV R7, ON        ; permite contagem do display
70     MOV R5, 2         ; passa ao estado 2 do P1
71     JMP sai_P1
72
73 P1_2:
74     MOVB R0, [R9]     ; lê porto de entrada
75     BIT R0, 1
76     JNZ sai_P1        ; se botão continua carregado, sai do processo
77     MOV R7, OFF       ; caso contrário, desliga contagem do display
78     MOV R5, 1         ; passa ao estado 1 do P1
79     JMP sai_P1

```

Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Phasellus eget nisl ut elit porta ullamcorper. Maecenas tincidunt velit quis orci. Sed in dui. Nullam ut mauris eu mi mollis luctus. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos.

This inline MATLAB code `for i=1:3, disp('cool'); end;` uses the `\mcode{}` command.<sup>1</sup>

Nullam ut mauris eu mi mollis luctus. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Sed cursus cursus velit. Sed a massa. Duis dignissim euismod quam. Nullam euismod metus ut orci.

### Listagem A.3: Matlab Function

```

1 for i = 1:3
2     if i >= 5 && a ~= b           % literate programming replacement
3         disp('cool');             % comment with some  $\pi x^2$ 
4     end
5     [i,ind] = max(vec);
6     x_last = x(1,end) - 1;
7     v(end);
8     ylabel('Voltage ( $\mu V$ )');
9 end

```

<sup>1</sup>MATLAB Works also in footnotes: `for i=1:3, disp('cool'); end;`

Nullam ut mauris eu mi mollis luctus. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Sed cursus cursus velit. Sed a massa. Duis dignissim euismod quam. Nullam euismod metus ut orci.

**Listagem A.4:** function.m

```
1 % Copyright 2010 The MathWorks, Inc.
2 function ObjTrack(position)
3 % #codegen
4 % First, setup the figure
5 numPts = 300;           % Process and plot 300 samples
6 figure;hold;grid;       % Prepare plot window
7 % Main loop
8 for idx = 1: numPts
9     z = position(:,idx); % Get the input data
10    y = kalmanfilter(z);  % Call Kalman filter to estimate the position
11    plot_trajectory(z,y); % Plot the results
12 end
13 hold;
14 end % of the function
```

Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Phasellus eget nisl ut elit porta ullamcorper. Maecenas tincidunt velit quis orci. Sed in dui. Nullam ut mauris eu mi mollis luctus. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Sed cursus cursus velit. Sed a massa. Duis dignissim euismod quam. Nullam euismod metus ut orci. Vestibulum erat libero, scelerisque et, porttitor et, varius a, leo.

**Listagem A.5:** HTML with CSS Code

```
1 <!DOCTYPE html>
2 <html>
3   <head>
4     <title>Listings Style Test</title>
5     <meta charset="UTF-8">
6     <style>
7       /* CSS Test */
8       * {
9         padding: 0;
10        border: 0;
```



```

11     margin: 0;
12 }
13 </style>
14 <link rel="stylesheet" href="css/style.css" />
15 </head>
16 <header> hey </header>
17 <article> this is a article </article>
18 <body>
19     <!-- Paragraphs are fine -->
20     <div id="box">
21         <p>
22             Hello World
23         </p>
24         <p>Hello World</p>
25         <p id="test">Hello World</p>
26         <p></p>
27     </div>
28     <div>Test</div>
29     <!-- HTML script is not consistent -->
30     <script src="js/benchmark.js"></script>
31     <script>
32         function createSquare(x, y) {
33             // This is a comment.
34             var square = document.createElement('div');
35             square.style.width = square.style.height = '50px';
36             square.style.backgroundColor = 'blue';
37
38             /*
39              * This is another comment.
40              */
41             square.style.position = 'absolute';
42             square.style.left = x + 'px';
43             square.style.top = y + 'px';
44
45             var body = document.getElementsByTagName('body')[0];
46             body.appendChild(square);
47         };
48

```

```

49     // Please take a look at +=
50     window.addEventListener('mousedown', function(event) {
51         // German umlaut test: Berührungspunkt ermitteln
52         var x = event.touches[0].pageX;
53         var y = event.touches[0].pageY;
54         var lookAtThis += 1;
55     });
56     </script>
57 </body>
58 </html>

```

Nulla dui purus, eleifend vel, consequat non, dictum porta, nulla. Duis ante mi, laoreet ut, commodo eleifend, cursus nec, lorem. Aenean eu est. Etiam imperdiet turpis. Praesent nec augue. Curabitur ligula quam, rutrum id, tempor sed, consequat ac, dui. Vestibulum accumsan eros nec magna. Vestibulum vitae dui. Vestibulum nec ligula et lorem consequat ullamcorper.

#### Listagem A.6: HTML CSS Javascript Code

```

1
2 @media only screen and (min-width: 768px) and (max-width: 991px) {
3
4     #main {
5         width: 712px;
6         padding: 100px 28px 120px;
7     }
8
9     /* .mono {
10         font-size: 90%;
11     } */
12
13     .cssbtn a {
14         margin-top: 10px;
15         margin-bottom: 10px;
16         width: 60px;
17         height: 60px;
18         font-size: 28px;
19         line-height: 62px;
20     }

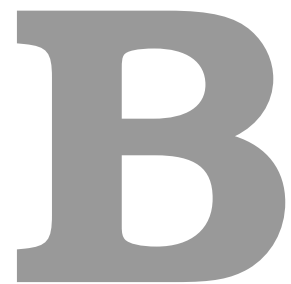
```

Nulla dui purus, eleifend vel, consequat non, dictum porta, nulla. Duis ante mi, laoreet ut, commodo eleifend, cursus nec, lorem. Aenean eu est. Etiam imperdiet turpis. Praesent nec augue. Curabitur ligula quam, rutrum id, tempor sed, consequat ac, dui. Vestibulum accumsan eros nec magna. Vestibulum vitae dui. Vestibulum nec ligula et lorem consequat ullamcorper.

#### Listagem A.7: PYTHON Code

```
1 class TelegramRequestHandler(object):
2     def handle(self):
3         addr = self.client_address[0]          # Client IP-address
4         telgram = self.request.recv(1024)      # Recieve telgram
5         print "From: %s, Received: %s" % (addr, telgram)
6         return
```





## A Large Table

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**Table B.1:** Example table

Benchmark: ANN	#Layers (1)	#Nets (2)	#Nodes* (3) = 8 · (1) · (2)	Critical path (4) = 4 · (1)	Latency ( $T_{iter}$ ) (5)
A1	<b>3–1501</b>	1	<b>24–12008</b>	<b>12–6004</b>	4
A2	501	1	4008	2004	<b>2–2000</b>
A3	10	<b>2–1024</b>	<b>160–81920</b>	40	60 <sup>†</sup>
A4	10	50	4000	40	<b>80–1200</b>
Benchmark: FFT	FFT size <sup>‡</sup> (1)	#Inputs (2) = 2 <sup>(1)</sup>	#Nodes* (3) = 10 · (1) · (2)	Critical path (4) = 4 · (1)	Latency ( $T_{iter}$ ) (5)
F1	<b>1–10</b>	2–1024	<b>20–102400</b>	4–40	6–60 <sup>†</sup>
F2	<b>5</b>	32	1600	20	<b>40 – 1500</b>
Benchmark: Random networks	#Types (1)	#Nodes (2)	#Networks (3)	Critical path (4)	Latency ( $T_{iter}$ ) (5)
R1	3	10–2000	500	variable	(4)
R2	3	50	500	variable	(4) × [1; ⋯ ; 20]

\* Excluding constant nodes.

<sup>†</sup> Value kept proportional to the critical path: (5) = (4) · 1.5.

<sup>‡</sup> A size of  $x$  corresponds to a  $2^x$  point FFT.

Values in bold indicate the parameter being varied.

As Table B.1 shows, the data can be inserted from a file, in the case of a somehow complex structure. Notice the Table footnotes.

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And now an example (Table B.2) of a table that extends to more than one page. Notice the repetition of the Caption (with indication that is continued) and of the Header, as well as the continuation text at the bottom.

**Table B.2:** Example of a very long table spreading in several pages

Time (s)	Triple chosen	Other feasible triples
0	(1, 11, 13725)	(1, 12, 10980), (1, 13, 8235), (2, 2, 0), (3, 1, 0)
2745	(1, 12, 10980)	(1, 13, 8235), (2, 2, 0), (2, 3, 0), (3, 1, 0)
5490	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
8235	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
10980	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
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**Table B.2 – continued from previous page**

<b>Time (s)</b>	<b>Triple chosen</b>	<b>Other feasible triples</b>
13725	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
16470	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
19215	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
21960	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
24705	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
27450	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
30195	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
32940	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
35685	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
38430	(1, 13, 10980)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
41175	(1, 12, 13725)	(1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
43920	(1, 13, 10980)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
46665	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
49410	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
52155	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
54900	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
57645	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
60390	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
63135	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
65880	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
68625	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
71370	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
74115	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
76860	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
79605	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
82350	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
85095	(1, 12, 13725)	(1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
87840	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
90585	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
93330	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
96075	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
98820	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
101565	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
104310	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
107055	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
109800	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
112545	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
115290	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
118035	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
120780	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
123525	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
126270	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
129015	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
131760	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
134505	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
137250	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
139995	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
142740	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
145485	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
148230	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)

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**Table B.2 – continued from previous page**

<b>Time (s)</b>	<b>Triple chosen</b>	<b>Other feasible triples</b>
150975	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
153720	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
156465	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
159210	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
161955	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
164700	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)