Preliminary Report for Project

‘Cross-Layer Optimisation for 4G Broadband Wireless Communication Networks’

Author: Yang Zhao (201220049)

Project Supervisor: Dr Xu Zhu (Judy)

Project Assessor: Unassigned

Declaration of academic integrity

The standard University of Liverpool statement of academic integrity [1] should go here as follows:

I confirm that I have read and understood the University’s Academic Integrity Policy.

I confirm that I have acted honestly, ethically and professionally in conduct leading to assessment for the programme of study.

I confirm that I have not copied material from another source nor committed plagiarism nor fabricated, falsified or embellished data when completing the attached piece of work. I confirm that I have not copied material from another source, nor colluded with any other student in the preparation and production of this work.

SIGNATURE…………………………………Yang Zhao………...............................................……………

DATE…………………………………..............9th Oct. 2017..........................................................................

Abstract

In conventional communication model, layers are designed independently for the convenience of improvement in each stage, which do not employ the spectrum effectively. This project intends to optimise the wireless communication systems with heterogeneous downlink traffic from users, by creating adaptive cross-layer design across the physical (PHY) layer and the medium access control (MAC) layer and maximizing the weighted sum capacity (WSC) of clients. Weight, which is associated with the delay, packet size and quality of service (QoS) priority, will be employed to allocate subcarrier and power controller. The transmission order is determined by packet dependent (PD) scheduling in the MAC layer. To reduce the overall complexity, the WSC of users rather than those of queues are considered in the algorithm, while the weighted sum of selected packets is calculated instead of all packets. To explore the advantages and disadvantages of the design, various resource allocation and packet scheduling schemes will be simulated and compared. The simulation result is expected to reveal that our model is more advanced in terms of QoS information and system throughput with MWSC based strategy, and the PD scheduling should increase the system throughput along with shortening the package delay on average. The overall complexity should be decreased as well. If possible, the fairness problem would be considered based on the amount of data for each user. MATLAB will be employed to examine the performance and complexity of the adaptive cross-layer model.

1. Introduction

This preliminary report aims to provide an overall sketch of the project “Cross-Layer Optimisation for 4G Broadband Wireless Communication Networks”, which includes the project description, methodology, plan, motivation, industrial relevance, literature review and results so far. In traditional communication systems, layers are constructed independently then cooperate through protocols and services. Although easy to maintain and enhance, this sort of object-oriented structure cannot utilise the bandwidth and power efficiently. Consequently, the probability of cross-layer design has been explored in the previous research, which focused mainly on traffic queue based algorithms to reduce the consumed power, decrease the average packet delay and maximise the sum capacity (SC). This project utilises weight to denote the importance and urgency of the packets and calculate WSC based on clients to achieve higher capacity and shorter delay with less complicated sum calculation method.

1. Project Description and Methodology

Focusing on the PHY Layer and MAC Layer, this project is intended to build an adaptive cross-layer model for 4G wireless communication systems. It is assumed that the multiuser system to be enhanced is based on orthogonal frequency-division multiplexing (OFDM) technology, and heterogeneous downlink traffic from each client is to be optimized. To indicate the importance and urgency of the packets, the concept of weight is introduced in the design, associated with the delay, packet size and QoS priority. In the PHY layer, the subcarrier and power controller will be allocated to maximize the WSC for users, while the transmission order of the packets is to be determined by the weight of selected packets in the MAC layer. The user-based algorithm rather than queue-based one is employed to reduce the complexity and improve the efficiency since the number of users is smaller than that of queues in most cases. In addition, the WSC of selected packets is calculated instead of all packets to simplify the problem. By choosing packets properly, the algorithm can perform as expected. In addition, various resource allocation schemes like maximum capacity (MC) and proportional fairness (PF) based will be examined, while packet scheduling schemes as largest weighted delay first (LWDF) and packet dependent (PD) scheduling will be tested and compared to reveal the pros and cons of our design.

1. Project Plan

The plan is explained by the specification from in Appendix 1, and the relevant Gantt chart is attached in Appendix 2.

1. Project Rationale and Industrial Relevance (this section must be included)

After studying the fundamental theory of the OSI model, it was found that the concepts of layer, protocol and service extraordinary since they divide the whole network into parts, which appeal independent but cooperate mutually. Nevertheless, this kind of object-oriented scheme restricts the efficiency of the whole communication system to some extent, especially for the resource allocation and data scheduling in the PHY and MAC layer. Therefore, a cross-layer design is demanded to optimize the current model. Previous works have covered the traffic queue based data scheduling, and some of them also calculate the MWSC for all packets [4]. Nevertheless, the algorithms are complicated due to a large number of queues and packets. In this project, the user-based WSC is considered for selected packets, to estimate the total WSC in a simpler approach. It is estimated that the strategy can utilize the power and bandwidth more effectively, hence enlarge the system throughput and shorten the average delay. In addition, reducing the complexity can be another advantage of the design. If realised properly, the scheme can be employed by the ISP servers to provide clients with better wireless communication performance, which can be helpful for the companies to win a bigger share of the market. A similar project has been researched by the supervisor [2], and several significant discoveries and achievements have been derived at an earlier stage. This project aims to create an advanced adaptive model based on the previous one, by allocating weight through a more comprehensive scheme, exploring more efficient algorithm, and comparing diverse resource allocation strategies.

1. Literature Review

Previous works have made some progress for resource allocation and data scheduling. In [3], overall transmit power was minimized with adaptive subcarrier power allocation. Article [4] derived a joint subcarrier and power allocation to achieve MWC for systems with constant power and delay. [5] proposed a modified largest weighted delay first (M-LWDF) data scheduling strategy to optimize the packet with larger head-of-line delay, higher instantaneous data rate and higher demand for the outage probability.

In [2], [6] and [7], user-based MWSC+PD based design managed to enlarge the system throughput with a short average delay for packets.

With the assistance of the relevant work, this project aims to achieve higher capacity and shorter delay with less complicated sum calculation method by assigning the weight based on more potential factors and optimizing the algorithm for selected packets.

1. Results

The background knowledge of wireless communication, such as additive white Gaussian noise (AWGN), signal-to-noise ratio (SNR) per bit (Eb/N0), multipath channel, Rayleigh fading and optimal receiver have been understood. In addition, Q-function, bipolar and unipolar NRZ AWGN signals have been simulated with MATLAB to compare the bit error rate (BER) in AWGN channel for analytical and numerical cases. Finally, the relevant articles [1] [2] [3] have been read.

For bipolar NRZ AWGN signal, the code is attached below.

%BipolarNRZ\_AWGN.m Simulate the performance of Bipolar NRZ in AWGN channels

clear all;

close all;

%Eb/N0 in dB

Eb\_N0\_dB=0:1:10;

%Convert Eb/N0 into the linear scale

Eb\_N0=10.^(Eb\_N0\_dB/10);

%Fix the bit energy to be 1

Eb=1;

%Fix the bit duration to be 1

T=1;

%Calculate the signal amplitude

A=sqrt(2\*Eb/T);

%Energy of bit 0

E0=(A^2\*T);

%Energy of bit 1

E1=A^2\*T;

%Optimal threshold

Thr=(E1-E0)/2;

%Matched filter impulse response--constant with amplitude A over one bit

%duration.

h=A;

%Calculate the correspnding noise power spectral density

N0=Eb./Eb\_N0;

%Number of different SNRs--------------?

len\_EbN0=length(Eb\_N0);

%Total number of bits per block

N\_bit=10000;

%Maximum number of blocks to simulate

N\_block=1000;

%Eb/N0 index pointer

EbN0\_pointer=1;

temp\_EbN0\_pointer=EbN0\_pointer;

%Number of errors counted for each Eb/N0

errs=zeros(1,len\_EbN0);

%Number of blocks simulated for each Eb/N0

block\_count=zeros(1,len\_EbN0);

%While the Eb/N0 index pointer has not reached the last value, and the

%number of blocks has not exceeded the maximum number, N\_block,

%do the iterations

while (EbN0\_pointer <= len\_EbN0) && (block\_count(len\_EbN0) < N\_block)

%Generate a binary bit sequence

D=round(rand(1,N\_bit));

D\_inv=1-D;

%Transmitted signal after bipolar NRZ line coding.

%1 is mapped to amptitude A; 0 is mapped to amptitude -A.---------

Tx\_data = A\*D+(-A)\*D\_inv;

%AWGN with normalised power 1

Noise=randn(1, N\_bit);

%Simulate different Eb/N0 values

for n = EbN0\_pointer : len\_EbN0

%Standard deviation of AWGN

sigma\_AWGN=sqrt(N0(n)/2);

%Received signal. The noise power is N0(n).

Rx\_data = Tx\_data + sigma\_AWGN\*Noise;

%Matched filter output signal

V=h\*Rx\_data;

%Recover the transmit data from the received data.

%When the MF output is V>Th, output 1; otherwise output 0.

Recov\_data = zeros (1,N\_bit);

Recov\_data (V>Thr)=1;

%Count the number of errors-----------------------?

errs(n)= errs(n)+sum(abs(Recov\_data-D).^2);

%If more than 500 errors have been counted, move the Eb/N0

%index pointer to the next Eb/N0

if errs(n)>=500

temp\_EbN0\_pointer = temp\_EbN0\_pointer+1;

end

%Update the nubmer of blocks simulated

block\_count(n)=block\_count(n)+1;

end

%Update Eb/N0 pointer

EbN0\_pointer=temp\_EbN0\_pointer;

block\_count

end

%Calculate the numerical BERs for different Eb/N0's. Each block has N\_bit bits.

Num\_BER = errs./(N\_bit\*block\_count);

%Calculate the analytical BERs for different Eb/N0's--------------------

Ana\_BER=Q(sqrt(2\*Eb\_N0));

figure;

semilogy(Eb\_N0\_dB, Num\_BER, '-s');

hold on;

semilogy(Eb\_N0\_dB, Ana\_BER, 'r-\*');

grid on;

legend('Numerical BER', 'Analytical BER');

title('Bipolar NRZ in AWGN Channels');

xlabel('Eb/N0 (dB)');

ylabel('BER');

%Q function

function y=Q(x)

x=real(x);

y=erfc(x)/2;

end

The result is shown in Figure 1.

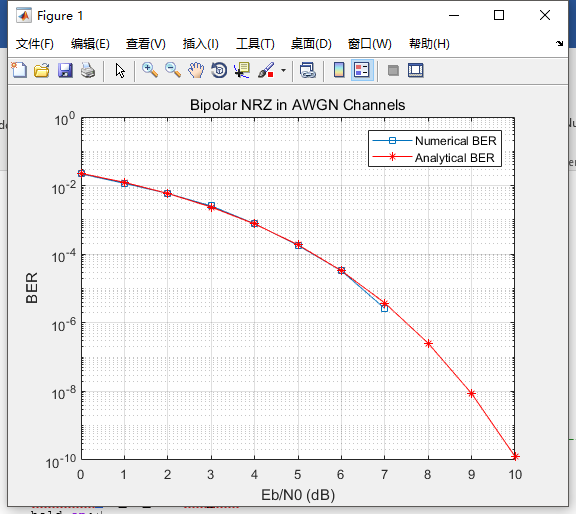


Figure 1 BER comparison for bipolar NRZ signal in AWGN channels

For unipolar NRZ AWGN signal, the code is attached below.

%UnipolarNRZ\_AWGN.m Simulate the performance of Unipolar NRZ in AWGN channels

clear all;

close all;

%Eb/N0 in dB

Eb\_N0\_dB=0:1:10;

%Convert Eb/N0 into the linear scale

Eb\_N0=10.^(Eb\_N0\_dB/10);

%Fix the bit energy to be 1

Eb=1;

%Fix the bit duration to be 1

T=1;

%Calculate the signal amplitude

A=sqrt(2\*Eb/T);

%Energy of bit 0

E0=0;

%Energy of bit 1

E1=A^2\*T;

%Optimal threshold

Thr=(E1-E0)/2;

%Matched filter impulse response--constant with amplitude A over one bit

%duration.

h=A;

%Calculate the correspnding noise power spectral density

N0=Eb./Eb\_N0;

%Number of different SNRs--------------?

len\_EbN0=length(Eb\_N0);

%Total number of bits per block

N\_bit=10000;

%Maximum number of blocks to simulate

N\_block=1000;

%Eb/N0 index pointer

EbN0\_pointer=1;

temp\_EbN0\_pointer=EbN0\_pointer;

%Number of errors counted for each Eb/N0

errs=zeros(1,len\_EbN0);

%Number of blocks simulated for each Eb/N0-----------?

block\_count=zeros(1,len\_EbN0);

%While the Eb/N0 index pointer has not reached the last value, and the

%number of blocks has not exceeded the maximum number, N\_block,

%do the iterations

while (EbN0\_pointer <= len\_EbN0) && (block\_count(len\_EbN0) < N\_block)

%Generate a binary bit sequence

D=round(rand(1,N\_bit));

%Transmitted signal after unipolar NRZ line coding.

%1 is mapped to amptitude A; 0 is mapped to amptitude 0.

Tx\_data = A\*D;

%AWGN with normalised power 1

Noise=randn(1, N\_bit);

%Simulate different Eb/N0 values

for n = EbN0\_pointer : len\_EbN0

%Standard deviation of AWGN

sigma\_AWGN=sqrt(N0(n)/2);

%Received signal. The noise power is N0(n).

Rx\_data = Tx\_data + sigma\_AWGN\*Noise;

%Matched filter output signal

V=h\*Rx\_data;

%Recover the transmit data from the received data.

%When the MF output is V>Th, output 1; otherwise output 0.

Recov\_data = zeros (1,N\_bit);

Recov\_data (V>Thr)=1;

%Count the number of errors-----------------------?

errs(n)= errs(n)+sum(abs(Recov\_data-D).^2);

%If more than 500 errors have been counted, move the Eb/N0

%index pointer to the next Eb/N0

if errs(n)>=500

temp\_EbN0\_pointer = temp\_EbN0\_pointer+1;

end;

%Update the nubmer of blocks simulated

block\_count(n)=block\_count(n)+1;

end;

%Update Eb/N0 pointer

EbN0\_pointer=temp\_EbN0\_pointer;

block\_count;

end;

%Calculate the numerical BERs for different Eb/N0's. Each block has N\_bit bits.

Num\_BER = errs./(N\_bit\*block\_count);

%Calculate the analytical BERs for different Eb/N0's

Ana\_BER=Q(sqrt(Eb\_N0));

figure;

semilogy(Eb\_N0\_dB, Num\_BER, '-s');

hold on;

semilogy(Eb\_N0\_dB, Ana\_BER, 'r-\*');

grid on;

legend('Numerical BER', 'Analytical BER');

title('Unipolar NRZ in AWGN Channels');

xlabel('Eb/N0 (dB)');

ylabel('BER');

%Q function

function y=Q(x)

x=real(x);

y=erfc(x/sqrt(2))/2;

end

The result is indicated in Figure 2.

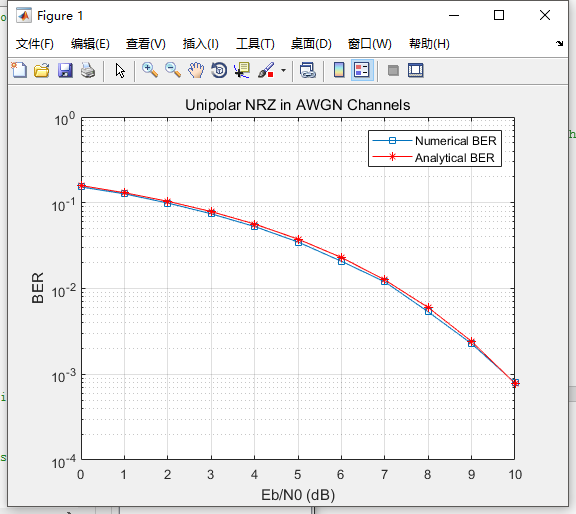


Figure 2 BER comparison for unipolar NRZ signal in AWGN channels

1. Conclusion

To sum up, this project will develop an adaptive cross-layer design for the downlink multiuser OFDM system across the PHY and MAC layer. User-based MWSC scheme for selected packets is to be employed for resource allocation, while PD strategy will be utilised for data scheduling. The system complexity would be reduced by targeting at clients and choosing typical packets to sum the weight. Other algorithms will be simulated and compared with the proposed one to check the pros and cons of our design. It is estimated that the scenario can utilize the power and bandwidth more effectively, hence enlarge the system throughput and shorten the average delay.

Reference List (include section headings)

Books

1. The University of Liverpool. (2015/16) *CoPA appendix L: Academic Integrity Policy* [online]. Available: [https://www.liv.ac.uk/media/livacuk/tqsd/code-of-practice-on- assessment/appendix\_L\_cop\_assess.pdf](https://www.liv.ac.uk/media/livacuk/tqsd/code-of-practice-on-assessment/appendix_L_cop_assess.pdf) (accessed 26th September 2016)

Periodicals and academic journals articles

1. N. Zhou, X. Zhu, Y. Huang. & H. Lin, “Low complexity cross-layer design with packet dependent scheduling for heterogeneous traffic in multiuser OFDM systems”, *IEEE Transactions on Wireless Communications.* vol. 9, no. 6, pp. 1912-1923, Jun. 2010.
2. C. Y. Wong, R. S. Cheng, K. B. Letaief, and R. D. Murch, “Multiuser OFDM with adaptive subcarrier, bit and power allocation,” *IEEE JSAC*, vol. 17, pp. 1747–1758, Oct. 1999.
3. D. S. W. Hui, V. K. N. Lau, and W. H. Lam, “Cross-layer design for OFDMA wireless systems with heterogeneous delay requirements,” *IEEE Trans. Wireless Commun.*, vol. 6, pp. 2872–2880, Aug. 2007.
4. M. Andrews, K. Kumaran, K. Ramanan, A. Stolyar, P. Whiting, and R. Vijayakumar, “Providing quality of service over a shared wireless link,” *IEEE Commun. Mag.*, vol. 2, pp. 150–154, Feb. 2001.
5. K. B. Johnsson and D. C. Cox, “An adaptive cross-layer scheduler for improved QoS support of multiclass data services on wireless systems,” *IEEE J. Sel. Areas Commun.,* vol. 23, pp. 334–343, Feb. 2005.

Patents, Standards, Theses, Unpublished (if any)

1. Y. Qi, “Cross-layer optimization for high speed wireless communication networks”, MSc dissertation, Dept. Electronic & Elec. Eng., Univ. of Liverpool, Liverpool, UK, 2011.
2. R. Dai, “Cross-layer optimization for 4G broadband wireless communication networks”, Undergraduate dissertation, Dept. Electronic & Elec. Eng., Univ. of Liverpool, Liverpool, UK, 2014.

Appendix 1. The specification report form.



***Department of Electrical Engineering and Electronics***

***Project Specification Form 2017-2018***

***Final Year BEng (*ELEC340*) and Year 3 MEng (*ELEC440*)***

Student Name: Yang Zhao Module: ELEC340

Supervisor: Dr Xu Zhu Student ID No: 201220049

Project Title: Cross-Layer Optimisation for 4G Broadband Wireless Communication Networks

**Project Specification**

**A. Project Description and Methodology:**

(Overall view of the project with proposed route to realization i.e. what are the project aims and objectives and how you are going to do it?)

Focusing on the physical (PHY) Layer and the medium access control (MAC) Layer, this project is intended to build an adaptive cross-layer model for 4G wireless communication systems. It is assumed that the multiuser system to be enhanced is based on orthogonal frequency-division multiplexing (OFDM) technology, and heterogeneous downlink traffic from each client is to be optimized. To indicate the importance and urgency of the packets, the concept of weight is introduced in the design, associated with the delay, packet size and quality of service (QoS) priority. In the PHY layer, the subcarrier and power controller will be allocated to maximize the weighted sum capacity (WSC)for users, while the transmission order of the packets is to be determined by the weight of selected packets in the MAC layer. The user-based algorithm rather than queue-based one is employed to reduce the complexity and improve the efficiency, since the number of users is smaller than that of queues in most cases. In addition, the WSC of selected packets is calculated instead of all packets, to simplify the problem. By choosing packets properly, the algorithm can perform as expected. In addition, various resource allocation schemes like maximum capacity (MC) and proportional fairness (PF) based will be examined, while packet scheduling schemes as largest weighted delay first (LWDF) and packet dependent (PD) scheduling will be tested and compared to reveal the pros and cons of our design. A similar project has been researched by the supervisor, and several significant discoveries and achievements have been derived in the early stage. This project aims to create advanced adaptive model based on the previous one, by allocating weight through a more comprehensive scheme, exploring more efficient algorithm, and comparing diverse resource allocation strategies.

**B. Project Tasks and Milestones:** (indicate the tasks and milestones that should be achieved and their expected dates e.g. understanding of theory, designs of circuits, construction of circuits, software specifications, working demonstrations etc.)

**Tasks:** (a task is a package of work that should be completed during a particular time period)

1 Learning basic knowledge about communication systems (Weeks 1-2)

2 Studying AWGN channel and fading channel models (Week 3)

3 Researching OFDM system (Week 4)

4 Problem formulation (Week 5)

5 Resource allocation (MSC, PF and MWSC) plus MATLAB simulation (Weeks 6-8)

6 Data scheduling (LWDF and PD) plus MATLAB simulation (Weeks 9-11)

7 Scheme and algorithm improvement (Weeks 12-13)

8 Complexity and performance analysis (Weeks 14-15)

9 Result explanation (Weeks 16-17)

10 Thesis writing (Weeks 12-20)

**Milestones:** (an objective that should be achieved by a particular date e.g. the completion of a task)

1 Understanding of fundamental communication model and essential knowledge (Week 3)

2 Review of article in relevant fields (Week 4)

3 Creation of the basic structure of the adaptive cross-layer model with problem formulation (Week 5)

4 Resource allocation in the PHY layer with MATLAB simulation (Week 8)

5 Data scheduling in the MAC layer with MATLAB simulation (Week 11)

6 Performance improvement and complexity reduction (Week 13)

7 Complexity and performance analysis (Week 15)

8 Report writing (Week 20)

**C. Project Deliverables:** (Indicate what should be completed at the end of the project e.g. this list should indicate what will be presented / demonstrated at the final bench inspections)

1 Advanced adaptive cross-layer design for 4G broadband wireless networks

2 MATLAB simulation for resource allocation (MSC, PF and MWSC)

3 MATLAB simulation for data scheduling (LWDF and PD)

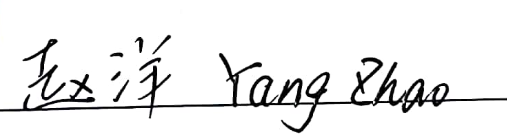
4 Comparison for various resource allocation and data scheduling strategies

5 Explanation about the performance and complexity of the design

6 Comparison about the pros and cons of proposed model with the traditional one

7 Report explaining the theory, method, procedure, algorithm and outcome

**D.** A sectionon Project Rationale and Industrial Relevance must be included in the preliminary report (deadline midnight Friday 14th October 2016). This should explain how and why the project was devised, e.g. it may be a project sponsored by a company or linked to a research project.

Student Signature:  Date: \_\_\_\_\_\_\_\_\_10/10/2017\_\_\_\_\_\_\_\_\_\_

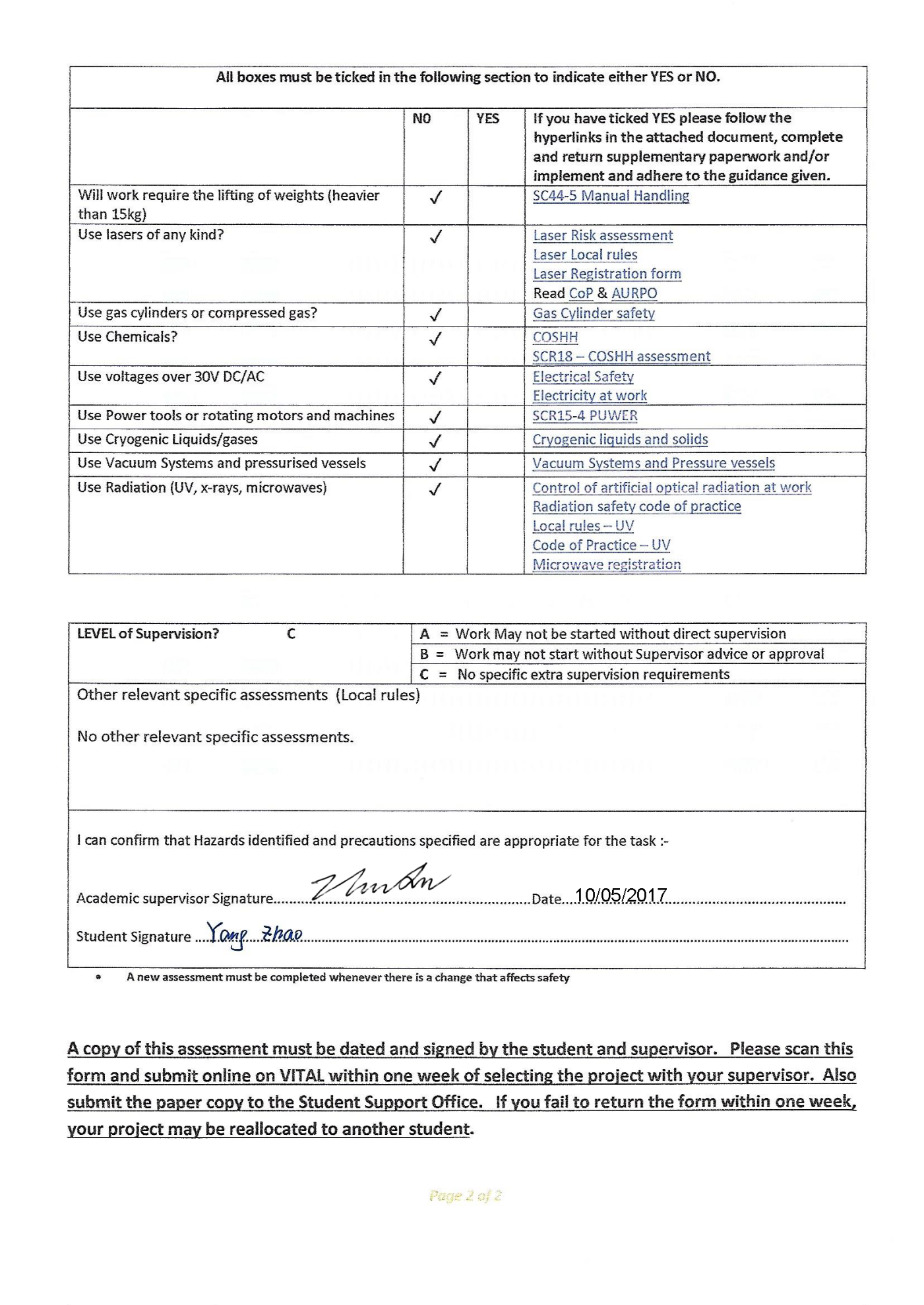
Supervisor’s Signature:  Date: \_\_\_\_\_\_\_\_\_10/10/2017\_\_\_\_\_\_\_\_\_\_

By signing this form, the supervisor and student are confirming that the project is of a sufficiently demanding nature that it is suitable for the individual project component of an accredited engineering degree and that a student, who is capable of producing a first class performance, will be able to demonstrate his/her capabilities in this project.

Appendix 2. A Gantt chart preferable produced by MS Excel or MS Project.

Appendix 3. The risk assessment form.





Appendix 4. Ethical approval questionnaire.

