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Electrocardiogram data collection under network attacks on the MAC platform

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ELECTROCARDIOGRAM DATA COLLECTION UNDER NETWORK ATTACKS ON THE MAC PLATFORM

A Thesis

by

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ELECTROCARDIOGRAM DATA COLLECTION UNDER NETWORK ATTACKS ON THE MAC PLATFORM

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ABSTRACT

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Increasing heart disease among human beings needs more precise treatment, which requires monitoring of electrocardiogram (ECG). In many cases, real time monitoring of ECG is needed via wireless or wireline networks. Use of network-connected computers for monitoring proposes can raise security issues, which can be created by viruses, worms, or external agents such as DoS attack traffic. Any alteration of this biomedical signal can lead to wrong diagnosis and wrong treatment. Furthermore, in healthcare industry, HIPAA rules require health information to be kept secure by providing confidentiality, integrity, and availability. This thesis investigates how integrity and availability of remotely monitored ECG signals can be affected silently due to adverse network conditions, hence raising false alarms. In this thesis, components of monitored ECG signals under adverse network conditions are measured and compared against normal ECG signals for detection of different heart diseases.

DEDICATION

I dedicate this research to my family, who encouraged me in every step. Your efforts and supports made me strong to follow up a higher education. Your patience and love made this research possible. Thank you for your indeterminable love.

ACKNOWLEDGMENTS

I would like to acknowledge and a special thanks to Dr. Sanjeev Kumar, my committee chairman for his valuable guidance, encouragement, and patience in the entire work. Also I would like to acknowledge and thank my committee members: Dr.Jun Peng, and Dr. Yoonsu Paul Choi, for serving on the committee.

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CHAPTER I

INTRODUCTION

Heart is one the most crucial organs in every existent. This organ is responsible to spread blood through the whole body and blood carries all the vital materials to other organs. Since heart's function is very important, scientists study heart's performance in different situations. They have tried to invent different equipment to capture heartbeat in order to study it and find out heart problems. If just one single part of the heart does not work properly, it can be shown in the electrocardiogram (ECG). Therefore, for understanding the heart problem first we should learn the fundamental information that is shown by the ECG.

1.1 Motivation

This research was done to observe the effect of Cyber-attacks on ECG signal, subsequently the C.I.A components which are lost under attacks, also to investigate how HIPAA make a secure environment for healthcare industry. The performances of four operating systems for ECG monitoring have been investigated under this research to reach an advance ECG monitoring and prevent false interpretations.

1.2 Heart Function

The heart is an organ that is made by muscle, and it is responsible to pump the clean blood (oxygen-rich blood) through the whole body. Each heart has two similar sides as the left side and the right side; these two sides circulate blood at the same time but in different directions, so heart pumps the blood in a rhythmic manner. Each side consists of two chambers, the Atrium and the Ventricle. The atrium is the chamber where the blood enters and the ventricle is the chamber where the blood is pumped to the further circulation. Figure 1.1 shows the blood circulation in the heart.

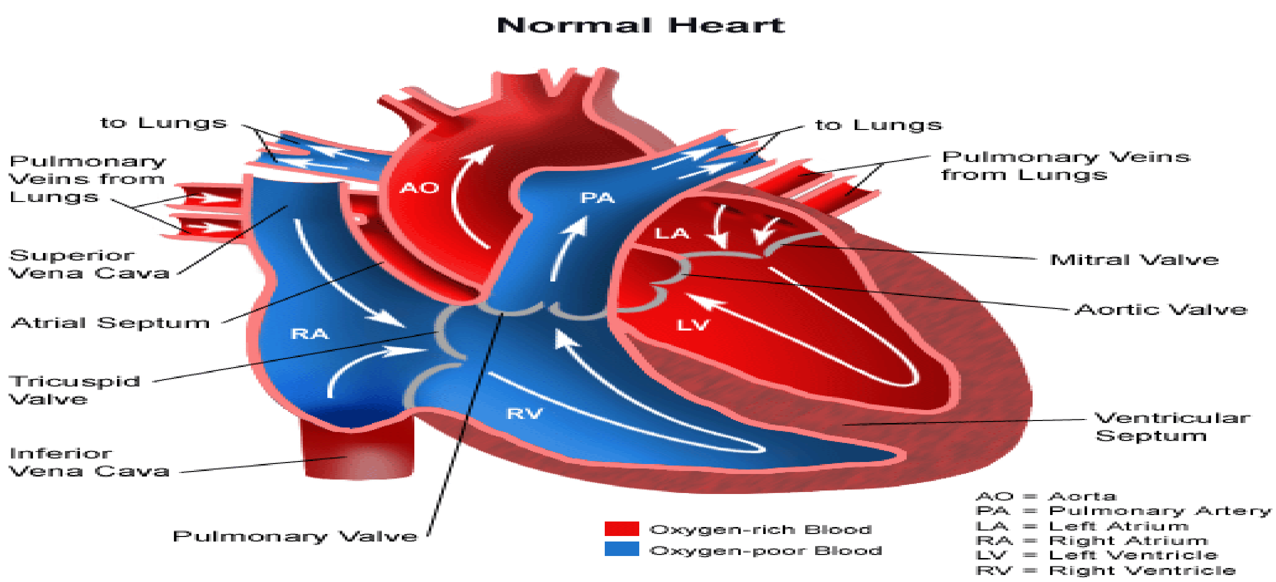


Figure 1.1 Illustration of the heart's circulation (the arrows indicate the direction of the blood flow in to and out of the heart) [20]

The left and the right side of the heart are divided by a muscular wall called septum. There are four different valves in the heart that control the direction of blood flow. Atrioventricular valves is located between atria, ventricles, and Pulmonary and aortic valves are located between ventricles and the arteries.

Myocardium is the muscular wall of the heart, which produces mechanical force during heart contraction. Muscle cells of the myocardium allow an electrical impulse to rapidly propagate throughout the heart. Mechanical force is triggered by electrical impulse and these electrical impulses precede heart contraction.

A cardiac cycle starts from the right atrium. In the right atrium blood comes to heart from all body veins except lungs veins. After right atrium is triggered, it forces blood in to the right ventricle. When the right ventricle has been filled with blood, it contracts and pushes the blood to lungs then the extra carbon dioxide is exchanged by oxygen. Then the clean blood (oxygenated blood) goes to the left atrium and then blood goes to the left ventricle. The left ventricle pushes blood to all body organs and tissues (except the lungs). This blood cycle is known as cardiac cycle.

Each cardiac cycle consists of two phases depolarization and repolarization, in mechanical terms they are known as contraction and relaxation. Rapid change in the cell's membrane potential is depolarization (from -90 to 20mV in nearly 1ms). By a rapid change in voltage membrane neighboring cells to depolarize and then an electrical impulse propagates from one cell to another cell of the heart. Each depolarization is flowed by a repolarization. During repolarization cardiac cells membrane potential return to their resting state or primary state. [1]

1.3 Electrical Activity of the Heart

Cardiac cycle starts in a vast number of pacemaker cells, these cells propagate electrical impulse at the same time and are known as SA (sinoatrial) node. SA node is located in the upper part of the right atrium. The electrical impulse spreads through the conduction system therefore the atrial and ventricular depolarization and repolarization take place as shown in figure 1. 2. After electrical activation of the right and left atria, the impulse before going to the ventricles is delayed at the AV (atrioventricular). This delay helps the atrial ventricular or AV node to increase the volume of the blood in the ventricle before ventricular contraction happens. It occurs because of the muscle tissue in the AV node area this muscle generates a slower impulse.

The impulse goes to the wall between the two ventricle at the His bundle. His bundle is the only electrical connection between the atria and the AV node and ventricles. Then His bundle is divided in to two pathway right bundle and left bundle, these branches go to the left and right ventricles and then extend to the specialized conduction fibers that are known as Purkinje fibers. As it is mentioned before, there is a delay in AV node so the velocity in AV node is 0.05 m/s whereas the velocity of the Purkinje fibers is 4 m/s.

SA node in the heart performs as a natural pacemaker that generates the heart beat rate. As the SA node' cells have the fastest pacemaker rate and all other cells follow in synchrony, this property of beating on its own is called automaticity. The maximum heart beat rate decreases as the age goes up in humans.

SA node in the normal heart always has the fastest pacemaker cells; only in ectopic focus some other pacemaker cells take precedence over the SA node. Ectopic focus can be located in the atria or in the ventricle and during this problem discharge rate of the SA node falls below a certain level. The normal SA node rate is about 50-60 times per minute and the ventricular cells discharge at a rate between 20-40 times per minute. [1]

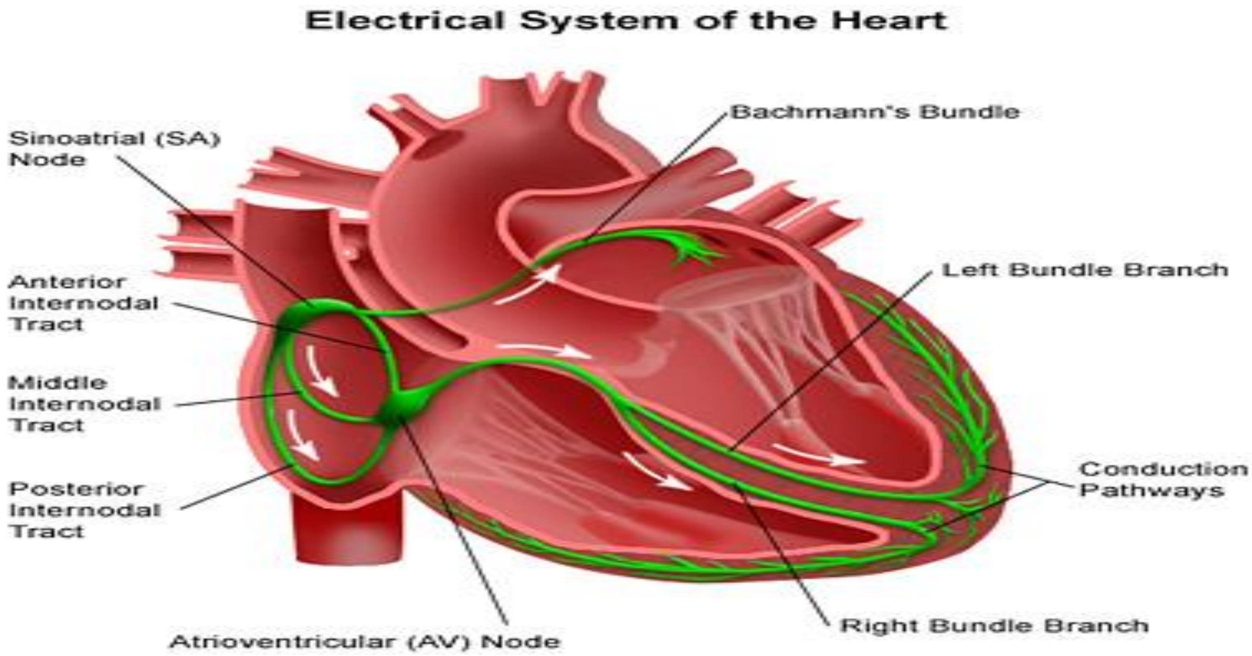


Figure 1.2 Illustration of the heart electrical Activity [21]

1.4 History of the Electrocardiogram

In the 1880s first electrocardiogram was recorded by Augustus Waller. In 20th century further improvement in ECG recordings was developed by Willem Einthoven who was a Dutch physiologist. He used a string galvanometer to develop the device, that device was more sensitive to record electrical potentials only on legs than the last one. That device could record the electrical potentials on the body surface. Willem Einthoven also defined the places of the recording electrodes on the body (on the arms and legs). In the 1924 he were rewarded the Nobel Prize in medicine. After that recording, the electrical signal of the heart by ECG developed dramatically and it was used as a clinical tool. Today the ECG is recorded in different way and reliable and useful information can be extracted from it. Depend on the place of the electrode on the body surface ECG can show different type of information. For collecting heart rhythm, only a few electrodes are enough whereas for information on waveform morphology ten electrodes are required. In a new technique that is known as body surface potential mapping an array of 100-200 electrodes is used to capture the information from heart signaling. The result of this method is a sequence of potential distribution over the body surface and it can be shown as an electrical image. [1]

1.5 ECG Background

1.5.1 Depolarization and Repolarization. Heartbeat is started by SA node before that all the cardiac cells are at rest and this position is shown by isoelectric line or horizontal line in the ECG. Dominant vector is a vector that helps to understand the different waves of the ECG and realize how they are generated. At atrial depolarization, the dominant vector is directed to the AV node so its direction is downward. Therefor a positive polarity is generated in the ECG according the atrial depolarization. As the muscle cells of the atria are small, the wave's amplitude of this action is very low.

After the atrial depolarization ECG recording goes back to the baseline or isoelectric line and it stays on that position until ventricular depolarization. Depolarization of the AV node and His bundle are not visible in ECG recording because muscle masses are small, whereas ventricular depolarization waves are much larger than other depolarization and they are visible in ECG recording that is because of the muscle mass which is large enough to be visible. Ventricular depolarization starts at septum, which is a wall between ventricles. In this action direction of the dominant vector is away from the electrodes so is traced as negative wave in the ECG. The negative wave has a short duration because of its high conduction velocity. Ventricular depolarization continue until it changes the direction of the dominant vector the direction of the electrode, this action is shown as long positive polarity, it ends when the direction of the dominant vector goes away of the electrode again so it ends with the negative short polarity in the ECG. After ventricular depolarization finishes the ventricular repolarization begins. At ventricular repolarization, the sequence of the dominant vector direction is very similar to the ventricular depolarization vector direction so this action is traced by a positive wave in the ECG. Atrial repolarization merges with ventricular depolarization because ventricular depolarization has much larger amplitude than atrial repolarization.

It is very important to understand each action and the waves that are traced in ECG recording. All the waveforms are depended on the position of the electrodes so if the wave front is spreading perpendicularly to the electrode, this wave front will be absent in the ECG record. In addition, the amplitude of each wave is depending on the distance between the heart and the position of the electrode. [1]

1.5.2 ECG Recording Techniques. Scientists and doctors measure the electrical activity of the heart by placing electrodes on the body surface of the patient. These electrodes are positioned in different sites of the body in order to trace all the variation of the electrical activity of the heart. The ECG is recorded by unipolar or bipolar leads or both; actually the ECG recording is the difference in voltage between two leads. The unipolar leads measure the voltage difference between one lead and a reference electrode which stays at the almost constant position during the measurement, this reference lead usually is called as central terminal, whereas in bipolar lead voltage difference between two leads is measured for example between leads on the left arm and the left leg.

ECG signals magnitude ranges are from a few microvolts to nearly 1 V, so a differential amplifier with high gain is used. This amplifier is designed only for bioelectrical signals. Each wave has a maximum magnitude only a few millivolts but in ECG baseline according to the variation of the electrode impedance the magnitude may reach to 1 V.

Nowadays ECG is recorded in different ways; the two most important standard electrode positions are described. The most widely used standard that is used these days is standard 12-lead ECG, and the other technique is vectorcardiogram (VCG). It is very important to know that none of the techniques is better than others and the best technique is not the one that shows the maximized information. Heartbeat is recorded for different clinical and scientific issues, so each technique is used for special propose. [1]

1.5.2.1 Standard 12-Lead ECG. This technique is the most considerable technique. In this method three kind of leads configuration is used, this configurations are: the bipolar limb lead, the augmented unipolar limb leads, and the unipolar precordial leads. 10 electrodes are placed in twelve positions of the body surface, three bipolar limb leads measure the voltage difference between the left and right arm and left leg (Figure 1.3-A), these leads are labeled as I, II, III. The augmented unipolar limb leads (aVF, aVL and aVR) are used to fill 60˚ gaps in the direction of the bipolar limb leads (Figure 1.3-B). Augmented unipolar limb leads use the same electrodes as bipolar limb leads but the voltage value that is measured by these electrodes is the difference between one vertex of the triangle and the average of the remaining two vertices (Figure 1.3-B).

The precordial leads are placed on the front and left side of the patient's chest. These six leads provide better information than other leads also these leads are unipolar and related to central terminal. The value of the central terminal is equal to the average of the voltages of leads on the left and right arm and left leg. The voltages measured by these leads are labeled as V_1, V_2, V_3, V_4, V_5, V_6. Leads V_1 and V_2 record heart activity of the right ventricle. Leads V_3 and V_4 record heart activity of the left ventricle (anterior wall) while V_5 and V_6 show the activity of the lateral wall. Other leads than precordial leads have low amplitude and they are very similar to noise because they are far from the heart. [1]

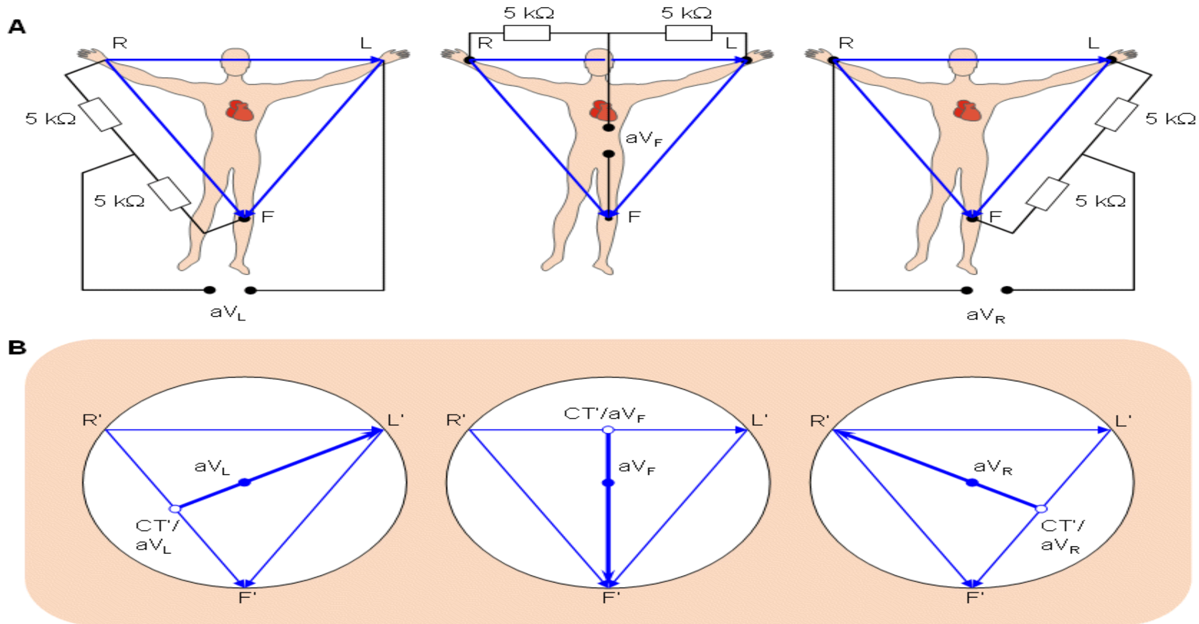


Figure 1.3 (A) Electrode position for the bipolar limb leads (B) augmented unipolar limb leads [22]

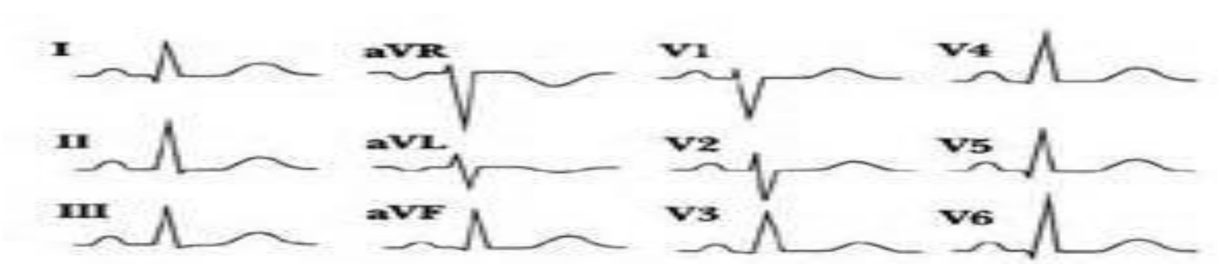


Figure 1.4 The standard 12 lead ECG with bipolar leads (I, II, III), augmented unipolar limb leads (aVF, aVL, and -aVR), and unipolar precordial leads (V_1, …,V_6) [23]

1.5.2.2 Orthogonal Leads (VCG). In this recording technique, the heart activity is measured in three directions X, Y, Z. This method is corrected by E. Frank so the corrected one is known as Frank lead system after his invention. This recording is based on seven leads that are positioned on the chest, back, neck and left foot. Leads X, Y, Z, trace the heart activity from left side, below and from the front and these leads are similar to V_5, aVF and V_2. Information that is recorded by 12-standard leads is more useful than VCG and it is preferred in clinical usage. [1]

1.5.3 ECG Waves and Time Intervals (QRS complex). The most important ECG characteristics are known as QRS complex. As each wave has a particular behavior during the cardiac cycle, it is very important to understand the meaning of them one by one.

The P wave represents the atrial depolarization of the cardiac heart and QRS complex reflect the ventricular depolarization and ventricular repolarization is reflected by T wave (Figure 1.5). Atrial repolarization cannot be extract by QRS complex, because atrial repolarization needs a larger QRS complex.

Two characteristics of ECG are considered to interpret it. These two characteristics are amplitude and time duration of the QRS complex. Amplitude is defined by isoelectric line or QRS complex, the time duration is defined when each wave deviate from the ECG baseline.

The sequential depolarization of the right and left atria is shown by P wave; it has positive polarity and mono phasic morphology. Its amplitude is less than 300 uV and its duration is less than 120 ms. Usually it is difficult to define the exact duration time of the P wave since it has a low amplitude and smooth morphology. Lack of P wave in the ECG signal means heart rhythm start in the ventricles and this shows ventricular ectopic focus. P wave has a low frequency spectrum below 10-15 Hz.

Depolarization of the right and left ventricles is shown by QRS complex; the time duration of the QRS complex for a normal heart is nearly 70-110 ms. Q wave is the first negative deflection in the QRS complex, R is the next deflection in the QRS complex which is positive and the subsequent negative deflection is defined as S wave (Figure 1.5). According to the location that the heartbeat originates from there, the QRS complex is variable; it may have less than three waves or more than three waves also the duration of it may increase to 250ms. The QRS complex has the largest amplitude in cardiac cycle waves, nearly 2-3 mV, so in any kind of computer-based analysis the QRS complex is the first wave, which is identified. The frequency of the QRS complex has the highest frequency in the ECG waves and it is concentrated in the interval 10-50 Hz.

The ST segment represents time duration that starts from the end of the S wave and finishes by the T wave (end of the S wave is known as J point); it does not show a wave form. The ST segment is related to the depolarization of ventricles. The ST segment changes represent various cardiac conditions such as more elevate, depressed or more steeply sloped.

The T wave represents repolarization of the ventricular and its time duration is nearly 300 ms after the QRS complex. According to rapid heartbeat the T wave becoming narrower and closer to the QRS complex. In normal condition, the T wave has a smooth, rounded morphology with the positive single peak.

The U wave is a slow wave that comes after the T wave. The origin of this wave is not clear but some scientists believe it originates after repolarization of the ventricles. As the heartbeat becomes faster, the T wave and the P wave merge with each other, so it becomes difficult to define the T wave and P wave from wave to baseline.

The RR interval shows the time duration between two successive R waves this interval indicates the length of a ventricular cardiac cycle and is known as ventricular rate. The RR interval is useful to determine the characters of different arrhythmias.

The PQ interval shows the depolarization of onset atria and depolarization of onset ventricles. The electrical impulse requires time duration to spread from SA node to the ventricles, but this interval is not dependent on heart beat rate.

The time duration from onset of ventricular depolarization to the complete ventricular repolarization is known as the QT interval. This interval changes with heart beat rate, it becomes shorter at more rapid rate. If the QT interval becomes longer, it can cause sudden death or other heart high-risk disorders. [1]

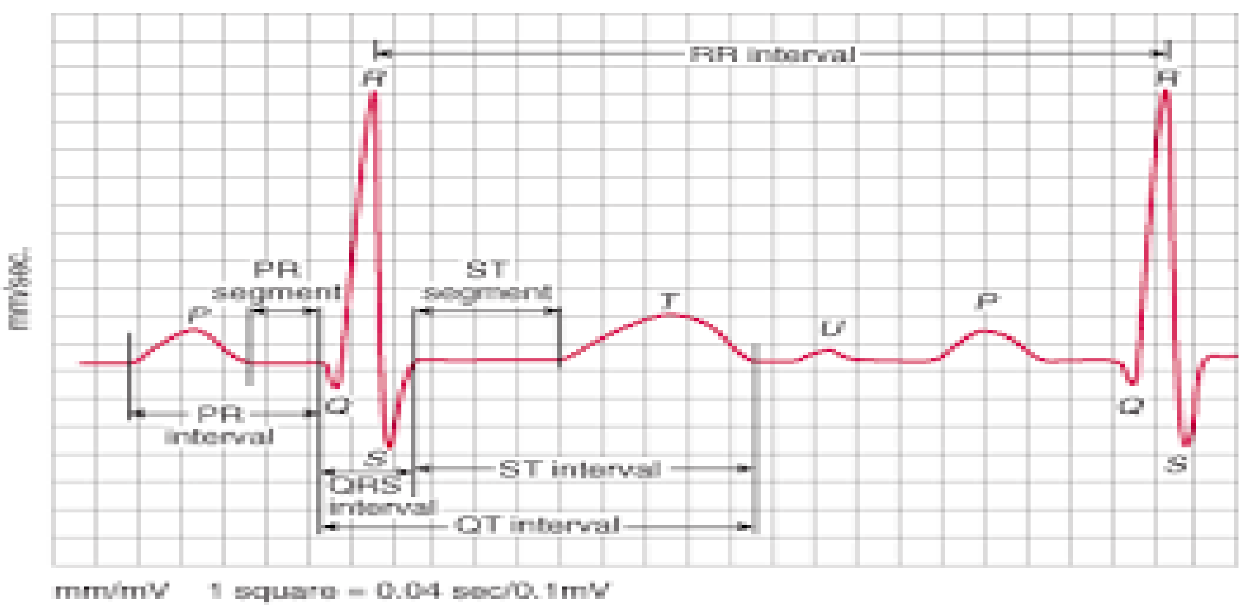


Figure 1.5 ECG waves and important time intervals [24]

Table 1.1 represents the values for all the components of the ECG signal in a normal heart condition.

Table 1.1 Feature value of normal ECG

Feature	Value
PR interval	0.12-0.20s
P-wave interval	0.00-0.12s
QRS	0.06-0.11s
RR interval	0.60-1.00s
R-wave amplitude	>0.50mv
QT interval	0.33-0.43s
T-wave amplitude	>0.05mv
P-wave amplitude	<0.25mv

CHAPTER II

ABNORMALITIES IN THE HEART RHYTHM

Monitoring unusual ECG not always means the patient has heart problem. Beside heart problems, a captured ECG can be different form baseline if artifact, interference, wandering baseline, faulty equipment, or network attacks effect on the captured signals.

2.1 Artifact

Waveform interference or in other words artifact is detected during excessive movement. As it is shown in figure 2.1 this problem ECG baseline signal becomes wavy, bumpy and tremulous. Another factor that causes waveform interference is dry electrodes, because of the poor connection to the body surface. [2]

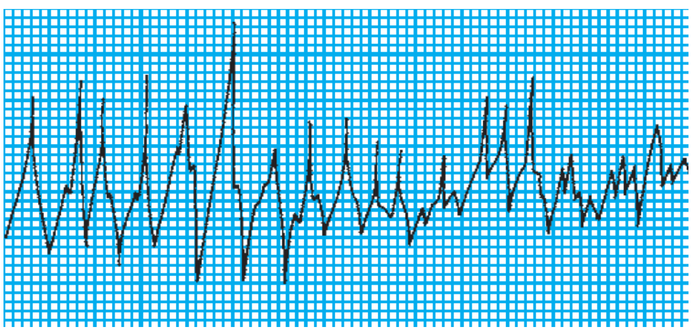


Figure 2.1 Artifact or wave interference [2]

2.2 Interference

Although one of the factors that produce electrical interference is electrical power leakage, electrical interference can happened by interference from other room equipment or the equipment, which are grounded improperly. This problem occurs because of the current pulses are lost at a rate of 60 cycles per second, so the ECG baseline becomes thick and unreadable. [2]

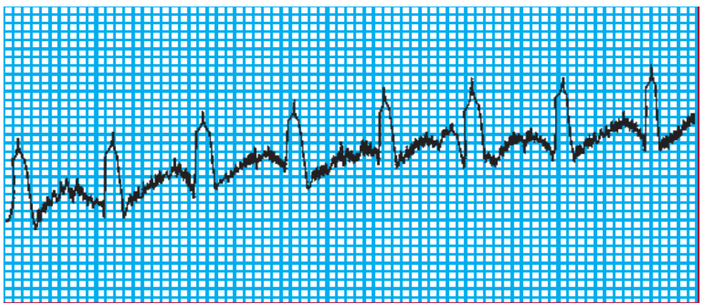


Figure 2.2 Electrical interference [2]

2.3 Wandering Baseline

Fluctuate baseline or wandering baseline is referred to the baseline, which is not stable, and fluctuates over the time. It is look like the movement of the chest wall at the time of respiration but also it can happen according to poor connection of electrodes or by placing electrodes in the wrong measuring point of the body surface. [2]

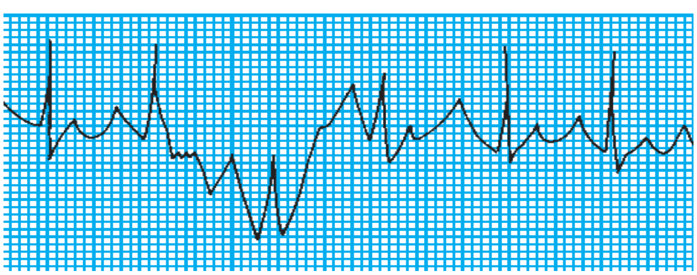


Figure 2.3 Wandering baseline [2]

2.4 Faulty Equipment

Broken lead wires, cable or electrode can cause different problems in the monitoring of ECG signals as it is shown in figure 2.4 the ECG signal becomes too weak. [2]

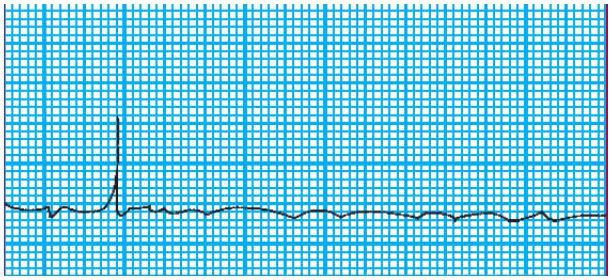


Figure 2.4 Weak ECG signal according to faulty equipment [2]

2.5 Sinus Node Arrhythmias

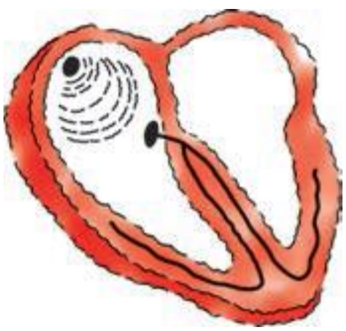


Figure 2.5 Sinus arrhythmia [2]

2.5.1 Sinus Arrhythmia. To understand the concept of sinus arrhythmias, it is important to know what is the sinus node and how it involve in the heart function. In a normal heart function, sinus node or sinoatrial node (SA) acts as a pacemaker. Function of the heart is started by this node so it is the primary pacemaker and other pacemakers start to work after sinus node. The range of firing rate of SA node for healthy adult is 50 to 60 times per minute. This node is located at the right upper side of the atria.

There are different kind of heart problem, which are called sinus arrhythmia, sinus bradycardia, sinus tachycardia, sinus arrest and sick sinus syndrome. These problems happened when the SA node (the pacemaker cells of the SA node) does not work properly. Although the heartbeat rate stays in the normal limitation, the rhythm of the heart is irregular. Difference between the shortest and longest P-P interval and the shortest and longest R-R intervals can show this irregular pattern. Arrhythmia usually happened in athletes and children, but it rarely happens to infant.

Beside the irregular respiration, several things produce sinus arrhythmia these factors are inferior wall myocardial infarction (MI), advance age, use some drugs such as digoxin (Lanoxin) or morphine, and some actions, which cause intracranial pressure increasing.

In the arrhythmia, which is related to the respiration, inspiration can increase the heart rate and the expiration can decrease the heart rate, so breathing can produces irregular pattern of heart beat rate that is called sinus arrhythmia. In the respiration the atrial and ventricular rates do not change and stay in the normal limits (50-60 beats per minute) the only thing that changes in respiration is the QT interval that may change slightly.

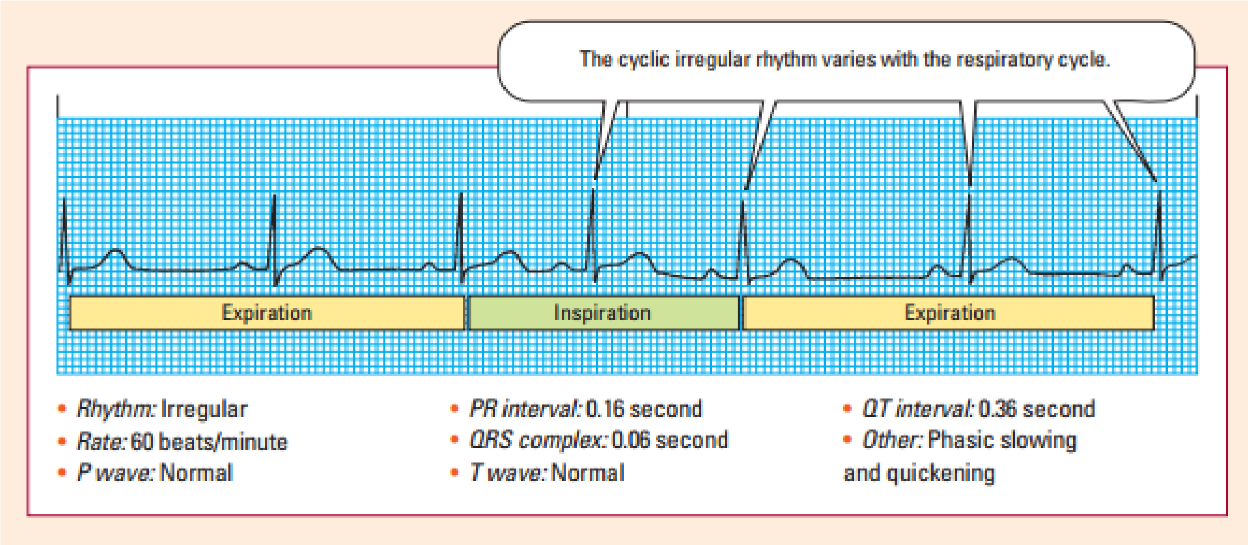


Figure 2.6 Identifying sinus arrhythmia [2]

Sinus arrhythmia is different from other abnormality such as atrial fibrillation, normal sinus rhythm with premature atrial contractions, sinoatrial block, or sinus pauses.

When the heart beat rate is, slow it is the best time for detecting the sinus arrhythmia, because if the heartbeat rate increases arrhythmia may disappear. [2]

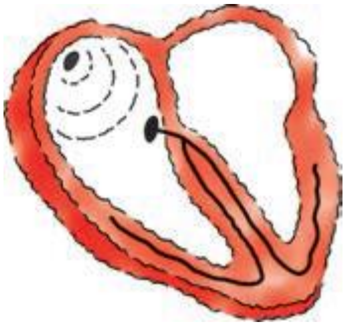


Figure 2.7 Sinus bradycardia [2]

2.5.2 Sinus Bradycardia. When the sinus rate is below 60 beats per minute and the ECG rhythm is regular, it is defined as Sinus bradycardia. During sleep as the metabolism decreases or in a person whose heart is working in a good conditioned such as athlete, as they do exercise regularly increasing the heart beat rate in them happen later than ordinary people do, so in normal condition their heart beat rate can be less than 60 beats per minute. The usage of certain drugs can cause sinus bradycardia . In general, sinus bradycardia occurs when metabolism needs less blood flow. In this condition, automaticity in the SA node will reduce, this happens because the vagal stimulation increase and sympathetic stimulation reduce at the same time.

Sinus bradycardia is generated from same point as sinus arrhythmia is generated this point is the right coronary artery which accumulate blood to the SA node.

Normally most of adults can endure a sinus bradycardia with heart beat rate of 45 to 59 beats per minute, but just a few people can endure it with a rate of below 45 beats per minute. Sinus bradycardia usually has no symptoms but it can be shown as a decreasing ECG signal in the cardiac output. In the case of no symptoms, there is no problem if this situation occurs but when sinus bradycardia generates symptoms such as very long R-R interval or signs of hypotension and dizziness it could be a critical heart issue and it needs quick diagnose and treatment. Sinus bradycardia can be a preliminary stage of some serious arrhythmia for instance ventricular tachycardia and ventricular fibrillation. Children are affected by sinus bradycardia less than adults are. In many cases, sinus bradycardia is not dangerous but in some cases, it can cause syncope or Stokes Adams attack.

As it is shown in figure 2.8 in sinus bradycardia has regular atrial and ventricular rhythms, but the rate of them is under 60 beats per minute, all other characteristics of the sinus bradycardia such as P wave, QRS complex, PR interval, T wave and QT interval are normal.

Some drugs like atropine, epinephrine or dopamine can be used as a treatment for sinus bradycardia. [2]

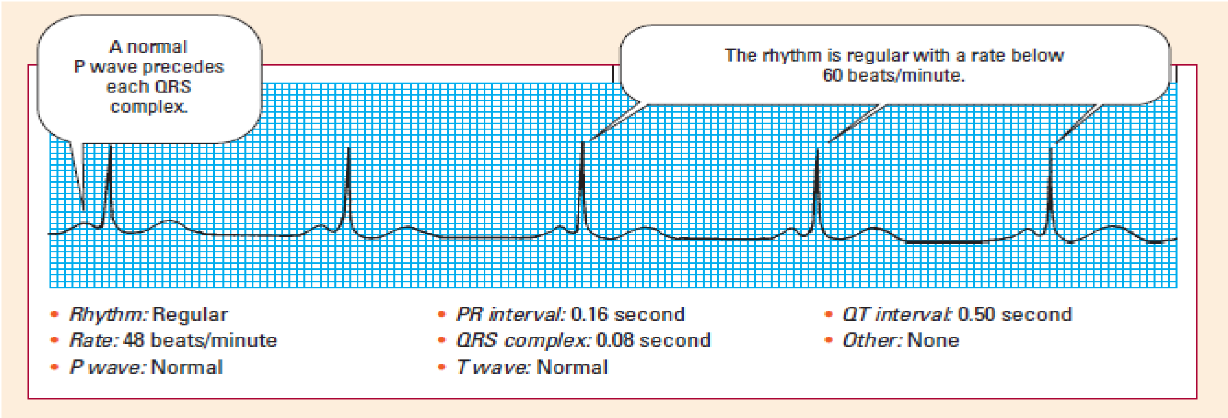


Figure 2.8 Identifying sinus bradycardia [2]

Figure 2.9 Sinus tachycardia [2]

2.5.3 Sinus Tachycardia. Sinus tachycardia is completely opposite of the sinus braycardia. In this case, the heart beat rate increase to more than 100 beats per minute. In normal person, this can happen after exercise or high emotional states or pain in these cases there is no clinical issue and if the stimulation of this arrhythmia is removed tachycardia will disappear.

During the myocardial activity, body needs more oxygen at the higher heart rate, so patients have chest pain according to tachycardia. These following heart problems can cause sinus tachycardia such as coronary artery disease, aortic stenosis and hypertrophic cardiomyopathy. This happens because the filling time of the ventricular decrease subsequently the amount of blood, which is pumped by the ventricles, will decrease in each contraction. The ventricular volume in diastole increase to 120 or even 130 ml in normal heart contraction, in this case it can cause the reduction volume of ventricular. As the volume of the ventricle decreases arterial pressure and peripheral perfusion decreases, so the hearts needs more oxygen for myocardial ischemia during the diastole.

Sinus tachycardia is usually followed by an intensive MI and very poor sign in the captured ECG according to the enormous damage to the heart, and continuing sinus tachycardia can cause heart failure and heart shock.

Atrial and ventricular rhythms in sinus tachycardia are regular as same as a normal ECG but their rate increase to 100 or even 160 beats per minute. In this case, P wave is in its normal size and shape but its amplitude starts to increase. By increasing the heart beat rate, the P wave merges with the T wave and it becomes difficult to distinguish them. In tachycardia the PR interval, QRS complex, and T wave are normal but QT interval is shorter than normal ECG signal as it is shown in figure 2.10. Although the sinus tachycardia rate is more than 100 beat per minute it has a regular rhythm. Usually patients with this problem have no symptom. Some patients with sinus tachycardia feel pain in their chest and feel nervous or anxious. By the continuation of the sinus tachycardia patient may hear extra heart beat sound with jugular vein swelling. [2]

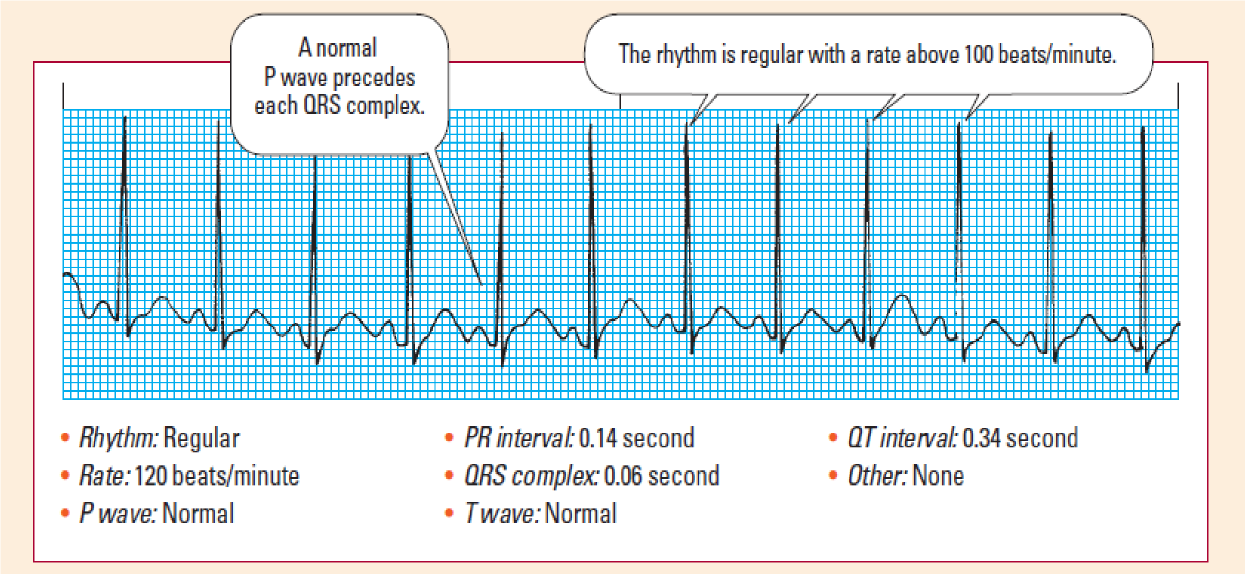


Figure 2.10 Identifying sinus tachycardia [2]

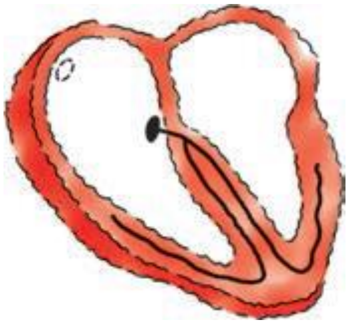


Figure 2.11 Sinus arrest [2]

2.5.4 Sinus Arrest. Sinus arrest or atrial standstill is a kind of heart problem, which involves impulse formation disorder. This problem occurs because of the lack of electrical activity in the atrium, as a result one complete PQRST complex will be disappear in the captured ECG signal. Beside this missing ECG other part of the ECG signal will be normal. In general, when there is only one or two atrial standstill in the ECG, it is called sinus pause and when three or more beats are missing it is called sinus arrest. Sinus arrest is also considered as third-degree SA block or exit block.

Sinus arrest happens when the SA node fails to generate an impulse. This problem has several reasons such as intensive infection, heart disease and vagal stimulation. Sinus arrest may also merge with sick sinus syndrome.

There are two most important groups of patients for this heart problem. One group is include patients who do not have continues pause or pauses, these are considered as asymptomatic and no treatment is require and the patient may not even feel the arrhythmia. These pauses usually happen in adult during sleep, vagal tone or hypersensitive carotid sinus disease. The duration of these, pauses are nearly 2 or 3 seconds. Second group includes patients with long and frequent sinus arrest they are considered as patient with symptom. This arrhythmia can cause syncope or one stage before syncope and tacks nearly 7 seconds to happen. When sinus arrest happens, it can cause acute injury because the patient may fall if the arrhythmia is long.

ECG signal in sinus arrest has atrial and ventricular rhythms, which are normal but there is a missing complex in the ECG signal. The rates of the atrial and ventricle are regular as well.

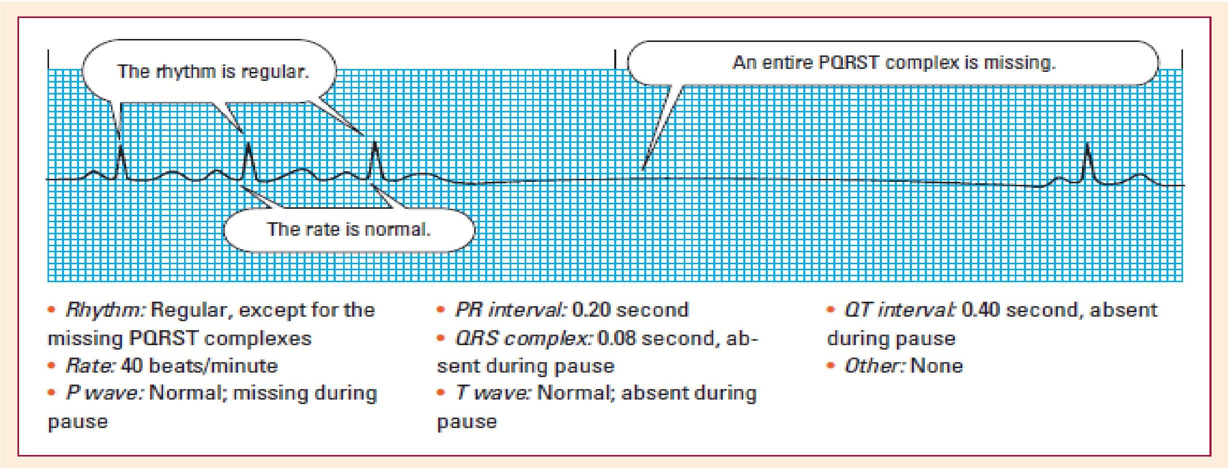


Figure 2.12 Identifying sinus arrest [2]

As it is shown in figure 2.12 in sinus arrest the P wave and QRS complex which follows the P wave are absent during the pause otherwise they are similar to the normal ECG signal. The PR interval is not measurable during the pause because it completely disappears when sinus arrest occurs. The T wave and the QT interval have the same situation as the P wave and the QRS complex they are normal unless a pause occurs. During the sinus arrest pulse and heart, sound cannot be diagnosed but repeated pauses can decrease the ECG signal it means the blood pressure becomes low with altered mental status and cool skin so the patient feels unclearly vision or dizziness. [2]

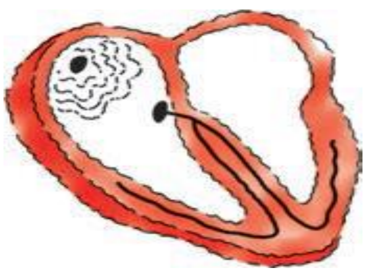


Figure 2.13 Sick sinus syndrome [2]

2.5.5 Sick Sinus Syndrome. Some of SA node abnormalities are called sinus nodal dysfunction or in another word sick sinus syndrome. These abnormalities occur when there is impulse failure, which is generated, or when impulses cannot go to the atrium. This problem is usually combined with bradycardia or sinus arrest or even SA node block and sometimes rapid atrial fibrillation. There is a condition in sick sinus syndrome, which is a combination of flutter, and atrial tachyarrhythmia it is called bradycardia-tachycardia or (brady-achy) syndrome. This problem usually happens in patients who have 60 years old or older, but as exception, it can happen to children who have had open-heart surgery with SA node failure.

Sick sinus syndrome occurs when SA node's automaticity works improperly or there are some abnormalities in the impulses, which are generated, form nodal region. In addition, there is a serious condition of this problem, which can affect the atrial wall this is surrounding the SA node and exits blocks can cause subsequent inflammation or damage the atrial tissue of the heat and finally sink sinus syndrome happens. Generally, it happens according to the age of the patient, if there are other kinds of diseases and the duration of the arrhythmia. Some times this problem combines with fibrillation or involves pauses, so syncope may happen. The duration of the syncope depends on the age of the patient but it usually lasts nearly 2 or 3 seconds.

As it is shown in figure 2.14 in this problem heart beat rate may become fast, slow or normal and the rhythm can be regular or irregular. However, there is a certain abnormality in the monitored ECG that can be fast or slow. This abnormality can be detected as decreasing heart beat rate during the exercise and all the sinus node arrhythmia may be detected in the ECG signal, so there is any set pattern for this problem.

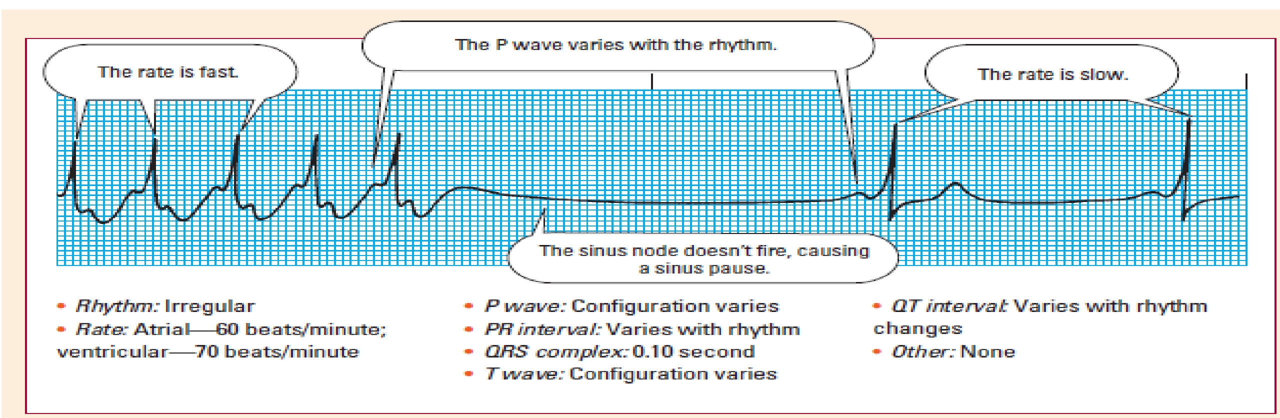


Figure 2.14 Identifying sick sinus syndrome [2]

In sick sinus syndrome both medication for bradycardia and tachycardia are used as this problem combines with both arrhythmia. [2]

2.6 Atrial Arrhythmias

Atrial arrhythmias are considered as the most important and common cardiac rhythm abnormality. In this case, impulses are originated from outside of the SA node, so ventricular contraction is effected by this problem and both ventricles do not fill completely.

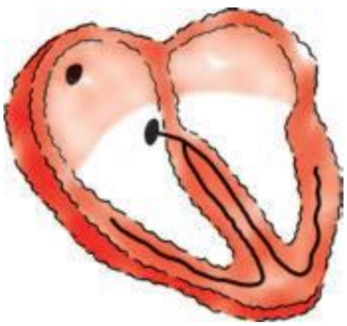


Figure 2.15 Atrial arrhythmias [2]

Three factors can cause all the atrial arrhythmias; They are defined as enhanced automaticity, reentry, and triggered activity.

In the enhance automaticity, the automaticity of the atrial fibers start to rise subsequently the automaticity which includes the extracellular factors such as hypoxia, acidosis, hypocalcaemia, and digoxin toxicity also it can change the condition of the SA node and SA node starts to trigger impulses faster.

In reentry, there is an impulse delay through the conduction pathway, but impulse is active enough to generate another impulse this happens in the myocardial repolarization. This problem is usually combined with coronary artery disease, cardiomyopathy, or myocardial infarction (MI).

When repolarization is not completed, it can be considered as a factor of atrial arrhythmias. Incomplete repolarization can cause ectopic firing frequently and repetitive so it is called triggered activity. The depolarization, which is generated by, triggered activity, is defined as after depolarization, it can happen with cell injury, digoxin toxicity and some other conditions. If after depolarization continues, it can cause atrial and ventricular tachycardia. [2]

2.6.1 Premature Atrial Contractions. Premature atrial contractions are also called as PACs.As it is shown in figure 2.16 they start from outside the SA node and usually happen in atrial after one impulse is generated by SA node, which is an ill-tempered focus and fires its own impulse before SA node generates another impulse. PACs may involve AV node performance and rest of the heart conduction system. In block PACs ECG no QRS complex can be detected.

Figure 2.16 Premature atrial contractions [2]

PACs usually occur in normal heart but they happen by using alcohol, nicotine, suffering from anxiety, fatigue, fever and some diseases. PACs are serious because they may correlate to other heart problem such as coronary or valvular heart disease, intensive respiratory failure, hypoxia, pulmonary disease and digoxin toxicity. Although they are serious for some patients, most patients who do not have a heart problem are considered as healthy person. Some symptoms for PACs are heart failure or an electrolyte imbalance pain and anxiety.

As it is shown in figure 2.17, the ECG signal for a PAC is involve with premature P wave, which is look like an abnormal P wave in contrast to sinus P wave. The QRS complex is similar to the normal condition of ECG signal but it proceeds by a pause. This happens because the SA node makes another impulse sooner than the normal ECG cycle. In the ECG, which is traced by PAC, heart failure has irregular atrial and ventricular rates but their rhythms are normal. As the P wave is abnormal and premature it can be merged with T wave and completely lost in the ECG signal. PR interval can be normal or abnormal. It can be shortened or prolonged these abnormalities correspond to the ectopic focus's origin. In the worst case, PACs can cause hypotention and syncope. [2]

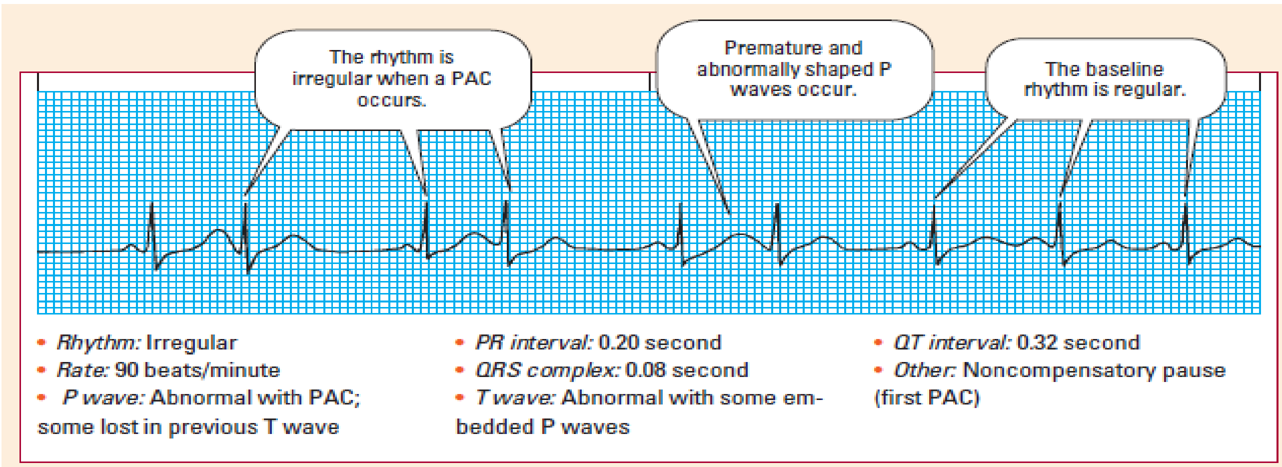


Figure 2.17 Identifying premature atrial contractions [2]

2.6.2 Atrial Tachycardia. In atrial tachycardia, impulses start above the ventricles so its rate is fast nearly 150 to 250 beats per minute. By decreasing the time for ventricular, to fill the ventricular retain atrial tachycardia starts to exceed subsequently decreasing in oxygen, which is needed for the body. The fast rate can cause diminish the atrial kick, decrease the cardiac output and coronary perfusion and some myocardial changes. There are three type of atrial tachycardia they are called: atrial tachycardia with block, multifocal atrial tachycardia, and paroxysmal atrial tachycardia (PAT).

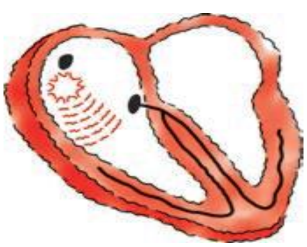


Figure 2.18 Atrial tachycardia [2]

A patient with atrial tachycardia has a normal heart condition. This case happens because of the usage of the caffeine or marijuana and physical stress. Atrial tachycardia in some patients is considered as a serious heart problem that can cause MI, cardiomyopathy, congenital anomalies, Wolff-Parkinson-White syndrome, and valvular heart disease that is also combined with sick sinus syndrome.

As it is shown in, figure 2.19 the ECG, which is captured from a patient with atrial tachycardia problem the QRS complex, is visible and as normal condition follows the P wave but P wave can be invisible if a block happens. In this arrhythmia, the ventricular and atrial rates are same. Both atrial and ventricular rhythms are regular but they are extremely faster than normal condition. The P wave may become invisible because of the rapid rate; it may merge with previous ST segment or the T wave. In the case, that the P wave becomes invisible PR interval cannot be detected on ECG signal. The QRS complex is normal in this arrhythmia. The QT interval is normal but can be shorter than normal condition because of the rapid heartbeat rate. If ischemia happens the T wave may invert otherwise it is normal. [2]

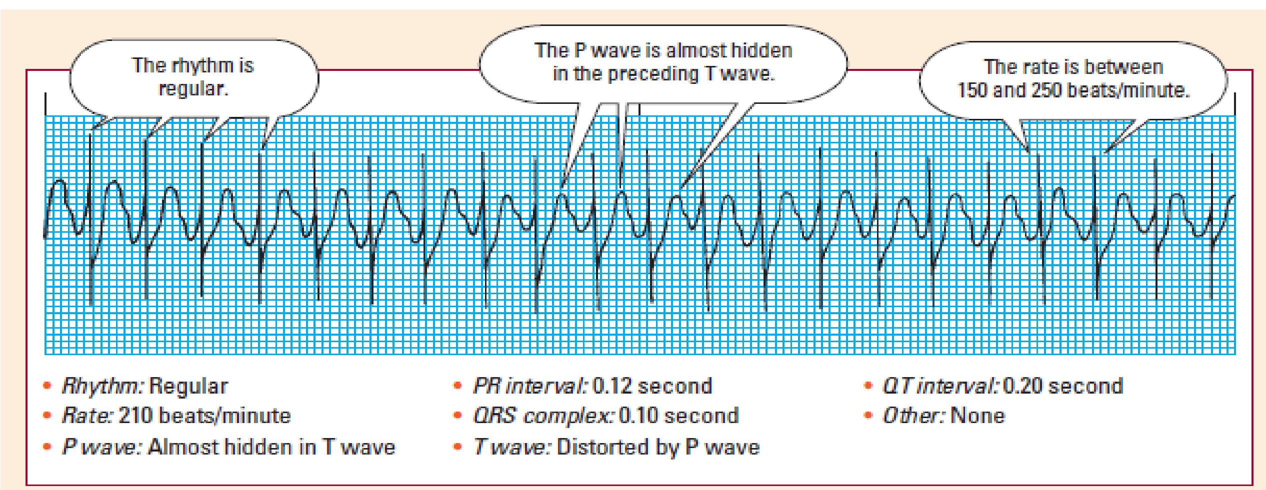


Figure 2.19 Identifying atrial tachycardia [2]

2.6.3 Atrial Flutter. Atrial flutter and atrial tachycardia both are in the same group; they are considered as supraventricular tachycardia. The atrial rate in atrial flutter is 250 to 350 beats per minute and usually defined as 300 beats per minute. This problem starts at one atrial, and it is related to the reentry, and enhanced automaticity. In atrial flutter's ECG the P wave disappear because it merges with other part of the ECG so the ECG becomes as a saw-toothed wave and are called flutter waves or f waves.

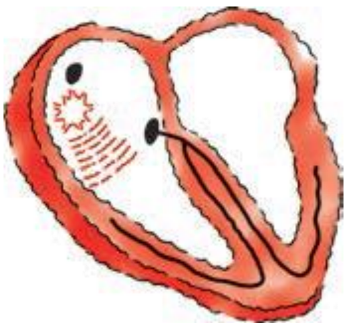


Figure 2.20 Atrial flutter [2]

In atrial flutter, the ventricular rate is slower than normal condition this happens because the AV node cannot allow heart conduction to the ventricles. Patients with mitral valve disease hyperthyroidism, pericardial disease, primary myocardial disease, atrial tissue problem and advance pressure usually face with this arrhythmia. If it happens in healthy people, it can show the intrinsic heart problem.

As it is shown in, figure 2.21 atrial flutter has abnormal P wave so it is look like a saw-tooth wave. The rate of the ventricular and atrial are not same here usually the ventricular rate is less than atrial rate in one-half or one-fourth of it. The QRS complex is normal but in some cases, it may combine with flutter waves so the T wave and the QT interval cannot be identified. The atrial rhythm is defined as atrial fibrillation and flutter because it may vary between these two arrhythmias. [2]

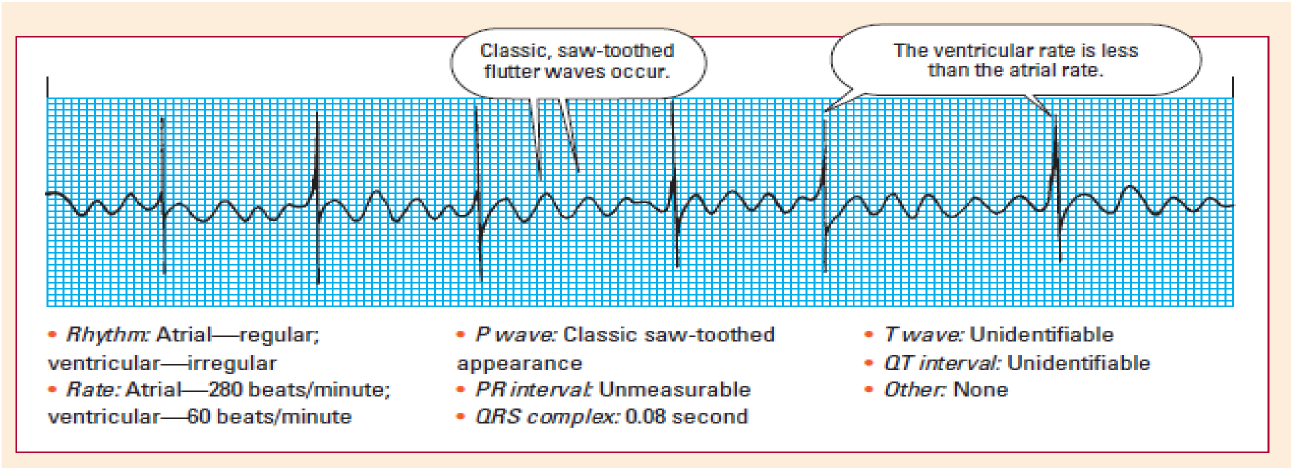


Figure 2.21 Identifying atrial flutter [2]

2.6.4 Atrial Fibrillation. Atrial fibrillation or A-fib is a kind arrhythmia, which is related to the asynchronous electrical activity of the heart. It is the most common arrhythmia among people in the United States. Impulses may trigger at the rate of 400 or even 600 beats per minute as a result in the arrhythmia (atrial fibrillation) a loss of atrial kick can happen very similar to atrial flutter. Only impulses that pass the AV node can be responded by ventricles, so on the ECG signal, which is captured for this heart problem there is no P wave and the rhythm can be normal or abnormal.

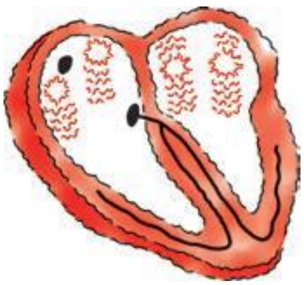


Figure 2.22 Atrial fibrillation [2]

Atrial fibrillation is more common than atrial flutter or atrial tachycardia. It can happen after an open heart surgery or other heart problem such as hypotension, pulmonary embolism, COPD, electrolyte imbalances, mitral insufficiency, mitral stenosis, hyperthyroidism, infection, coronary artery disease, intensive MI, pericarditis, hypoxia, and atrial septal. It can happen in healthy people by using extra coffee, alcohol, or nicotine and sometimes it happens in a person who is under stress or uses drugs such as aminophylline and digoxin.

In the atrial fibrillation as it is shown in figure 2.23, there is no P wave in the ECG and ventricular rhythm is irregular because by trigger many impulses in atria depolarization cannot propagate as a normal heart contraction. In the ECG signal P wave, become very similar to the f wave because different parts of the atria start to trigger individually. In this arrhythmia AV node acts as a filter, it prevents all the atrial impulses to pass through the ventricle actually the muscle tissue which is around the AV node prevents impulses from other part of the heart to pass through ventricle.

In atrial fibrillation, the rate of the atria is nearly 400 beats per minute and the ventricular rate is alternative from 100 to 150 beats per minute or even lower than that. Atrial fibrillation is consider as controlled if the ventricular is less than 100 beats per minute and considered as uncontrolled if the ventricular rate is increase more than 100 beats per minute. If instead of P waves, there are f waves atrial fibrillation is called coarse. [2]

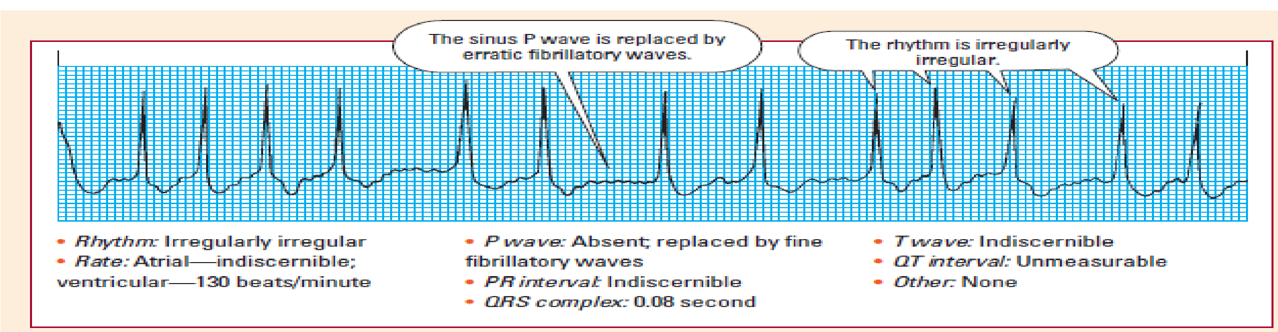


Figure 2.23 Identifying atrial fibrillation [2]

2.6.5 Wandering Pacemaker. If the impulses are generated from some other part of the heart which is above the ventricle area the rhythm becomes irregular and it is called wandering pacemaker. In this problem impulses are not originated from SA node and the originated point of impulses is changed beat to beat even sometimes it can generate from AV node. As the pacemaker site changes beat to beat, the P wave and PR interval are different.

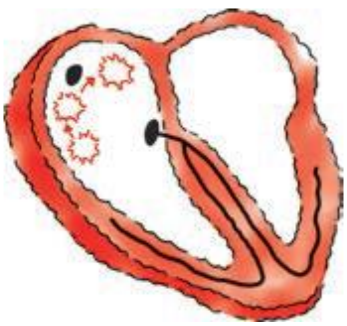


Figure 2.24 Wandering pacemaker [2]

There are some factors can cause the wandering pacemaker such as exceed vagal tone, digoxin toxicity and heart failure like rheumatic carditis. The arrhythmia can happen to young patient and athletes who have low heart beat rate but it is considered as a normal condition for these two groups because it is difficult to detect any abnormalities in these two groups' ECG signal. In general wandering pacemaker is not a serious heart problem.

As it is shown in, figure 2.25 the rhythm on the ECG of wandering pacemaker is irregular because of the different sites that impulses are originated from them so the shape of the P wave changes according to the alternative sites. The rate is normally 60 to 100 beats per minute as a normal heartbeat rate. Impulses can originate in SA node, atria, or AV junction. If it originates from AV junction the P wave may come before after or during the QRS complex. The PR interval also changes form one beat to another beat as the site of pacemaker changes but it will stay at 0.20 second or even less. This can make RR intervals with different duration but ventricular depolarization is normal subsequently the QRS complex, the T wave and QT interval are normal. [2]

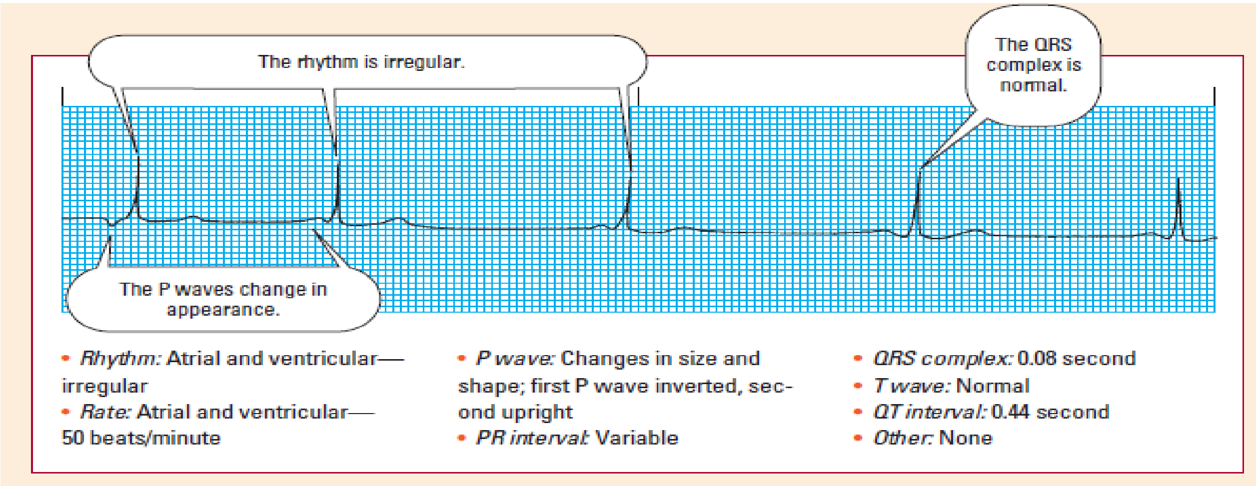


Figure 2.25 Identifying wandering pacemaker [2]

2.7 Junctional Arrhythmias

The area around the AV node and bundle His is called atrioventricular junction or AV junction. Junctional arrhythmias originate from this area. It happens when the SA node cannot generate the impulses, so they are generated by AV node. In normal heart condition, AV node is responsible to slow down the impulses from the atria to ventricles so the atria can have more time to pump more blood to the ventricles before the ventricles contract. Sometimes atrial arrhythmias are mistaken for junctional arrhythmias because both of them have atria slow rate and invert P wave but PR interval is different. In atrial arrhythmias, the PR intervals are normal however in junctional arrhythmias have a low PR interval usually less than 0.12 second. [2]

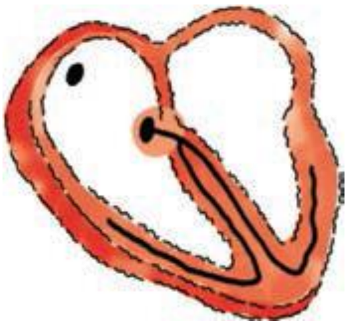


Figure 2.26 Junctional arrhythmias [2]

2.7.1 Premature Junctional Contraction. A premature junctional contraction is usually known as PJC, which happens before a normal beat so it produces an irregular rhythm. When an intensive impulse is originated from a site within the AV junction will produce a prematurely and out of sequence beat. In this arrhythmia atria are depolarized irregularly but ventricles are depolarized normally, so this can cause an inverted P wave.

PJCs can happen because of heart failure or exterior factors, these factors are: exceeding toxic level of digoxin, extra caffeine usage, inferior wall myocardial infarction (MI), rheumatic heart disease, valvular disease, hypoxia, heart failure, or inflammation of the AV junction after an open-heart surgery.

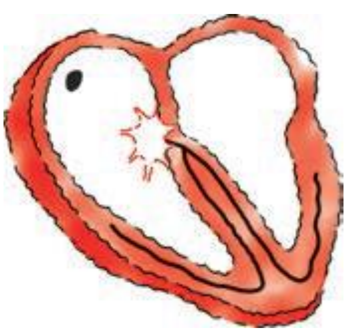


Figure 2.27 Premature junctional contraction (PJC) [2]

As it is shown in figure, 2.28 a PJC can cause an irregular rhythm but the rest of the ECG has a regular rhythm. The most abnormality in the PJC is P wave, which is inverted, according to the mistaken impulse it can come before; during or after the QRS complex, also it can be disappeared if it happens during the QRS complex. If it comes before the QRS complex, the PR interval becomes less than 0.12 second. In this abnormality the QRS complex, T wave and QT interval are usually normal. The PJC usually is not a serious heart problem only in some cases patients who have hypotension need treatment. [2]

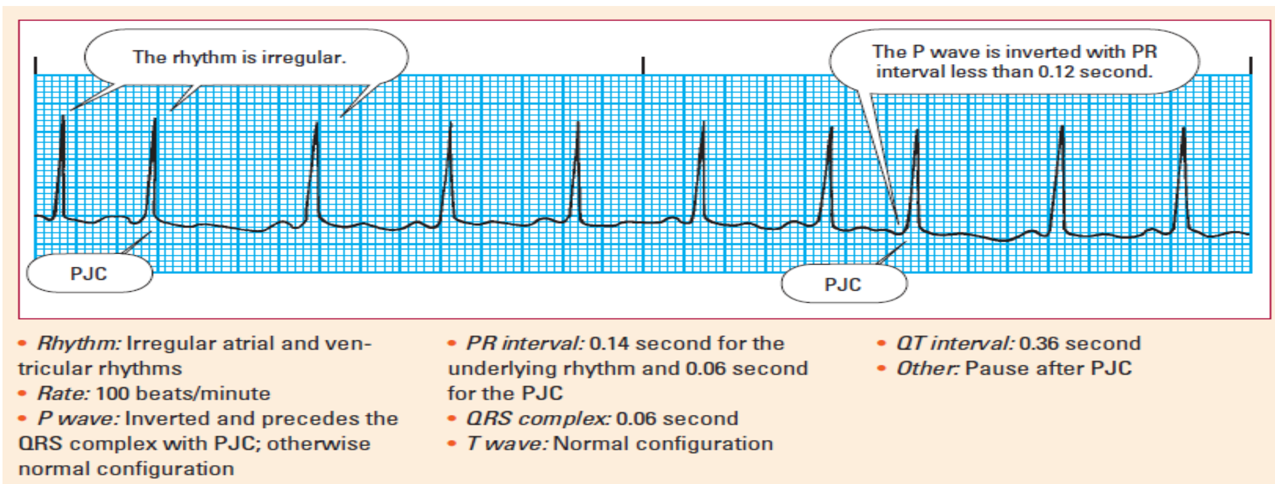


Figure 2.28 Identifying premature junctional contraction [2]

2.7.2 Junctional Escape Rhythm. Junctional escape rhythm happens after a heart conduction delay in the atria and produces a barrage of beats. In this arrhythmia AV junction acts as a heart's pacemaker that happens because higher pacemaker sites in atrial slow down or fail to trigger. These junctional beats prevent the ventricular stop so a string of beats passes ventricles.

Similar to other junctional arrhythmias, junctional escape rhythm has inverted P wave and normal impulse conduction which pass through the ventricle.

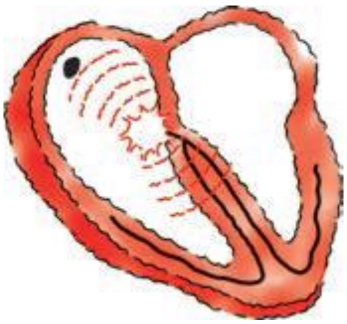


Figure 2.29 Junctional escape rhythm [2]

Any factor that interrupts the function of the SA node subsequently the AV junction leads function can cause junctional escape rhythm. The factors that cause arrhythmia include sick sinus syndrome, vagal stimulation, digoxin toxicity, inferior wall MI, and rheumatic heart disease.

Junctional escape rhythm has a regular heartbeat rate between 40 to 60 beats per minute and the P wave can comes before, after or during the QRS complex. If the P wave merges with the QRS complex, it disappears. If the P wave comes before the QRS complex, the PR interval is measureable and it will be less than 0.12 second. As it is shown in figure 2.30 the QRS complex, the T wave, and QT interval are normal. In addition, if the heart beat rate is less than 60 beats per minute it can cause hypotension, syncope, or decreased urine output. [2]

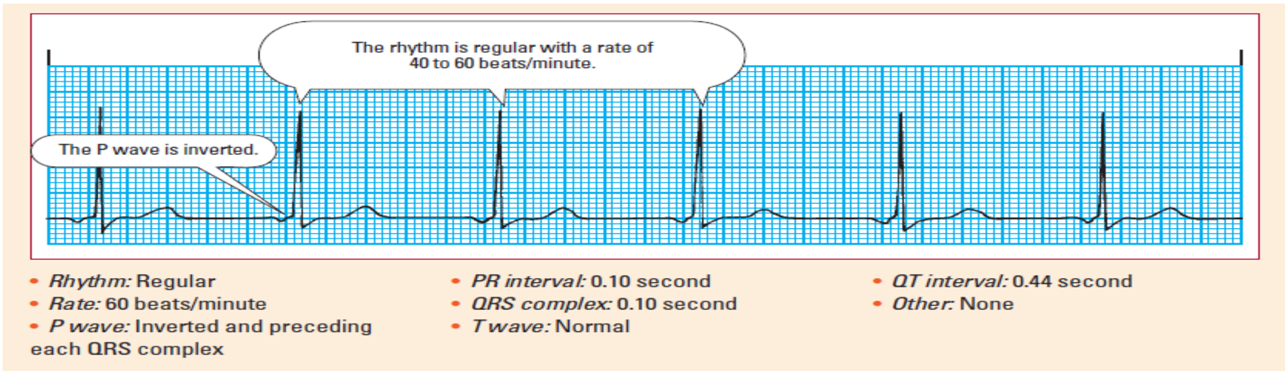


Figure 2.30 Identifying junctional escape rhythm [2]

2.7.3 Accelerated Junctional Rhythm. This arrhythmia happens when the impulses are generated from the AV junction instead of the SA node and usually they are faster than the SA impulses. Ventricular depolarization is normal but atrial depolarization at a backward conduction. The heart beat rate in this arrhythmia is between 60 to 100 beats per minute.

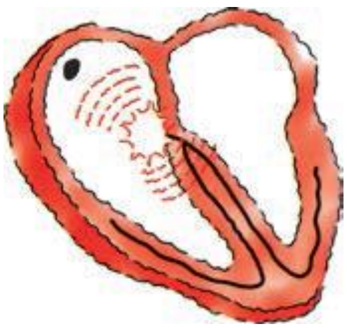


Figure 2.31 Accelerated junctional rhythm [2]

Several factors can cause accelerated junctional rhythm by affecting the SA node and the AV node such as digoxin toxicity, hypokalemia, inferior or posterior wall MI, rheumatic heart disease, valvular heart disease. This arrhythmia in the worst case can cause hypotension, syncope, decrease urine output by reduce the heart output. This happens because atria depolarization prevents blood from going to the ventricles.

As it is shown in, figure 2.32 atria are depolarized after the QRS complex. The rhythm of this heart problem is regular. It has a rate between 60 to 100 beats per minute. The P wave can be invisible but if it is present, it will be in an inverted shape. As same as other junctional arrhythmias the P wave can come before, after or during the QRS complex and if it happens during the QRS complex, it will be disappeared with the PR interval less than 0.12 second. The QRS complex, T wave and QT interval all are normal. A patient with this heart problem feels dizziness, hypotensive, and confused, it also has weak peripheral pulses. [2]

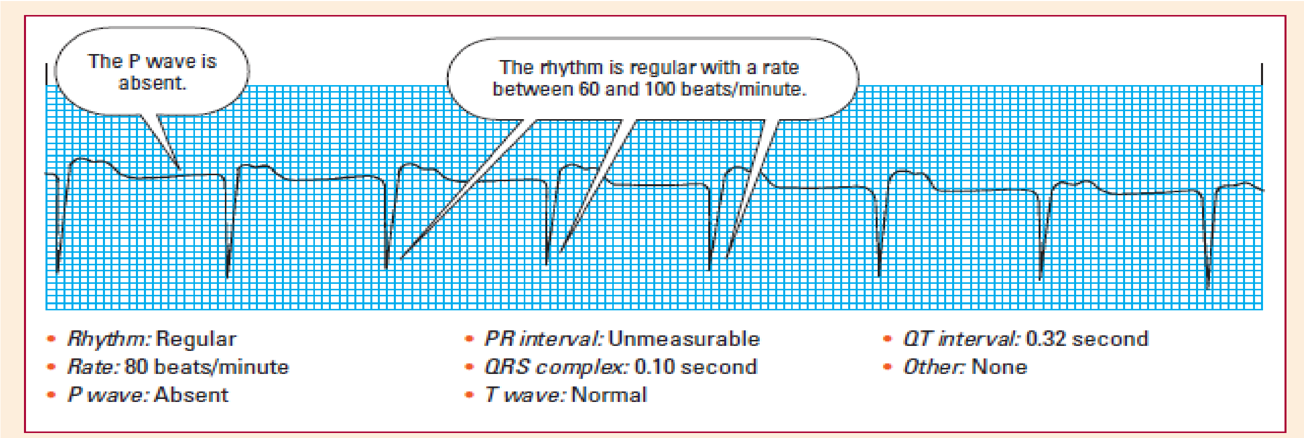


Figure 2.32 Identifying accelerated junctional rhythm [2]

2.7.4 Junctional Tachycardia. Junctional tachycardia happens when an intensive focus from the AV junction increase the automaticity, subsequently overtaking the SA node to acts as a heart's pacemaker. In this problem, three or more PJCs happen in a simple row. The heart rate here is normally 100 to 200 beats per minute and very similar to the accelerated junctional rhythm the atria are depolarized at the backward conduction and the ventricular conduction is normal.

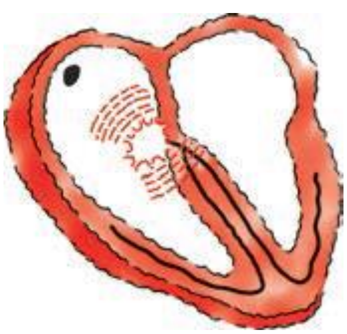


Figure 2.33 Junctional tachycardia [2]

Some causes of the junctional tachycardia are such as digoxin toxicity which, is considered as the most important cause of this arrhythmia and in the worst case it combine with hypokalemia, inferior or posterior wall MI or ischemia, congenital heart disease in children, and inflammation of the AV junction after open heart surgery.

As it is shown in figure 2.34 it is different from other kind of arrhythmias according to its rate, during this problem the amount of blood that fills ventricle is reduced. Heartbeat rate in junctionla tachycardia is between 100 to 200 beats per minute. The P wave in the ECG is inverted as same as other junctionla arrhythmia and can happen before after or during the QRS complex. The one that occurs in the QRS complex will be disappear. The PR interval measurement is depends on the P wave location. If the P wave comes before QRS complex, it will be less than 0.12 second. The QRS complex is normal but the T wave can be normal or abnormal. Sometimes the P wave combines with the T wave or if the heart beat rate becomes too fast, the T wave will disappear. The patients with this arrhythmia feel dizziness and have low blood pressure. [2]

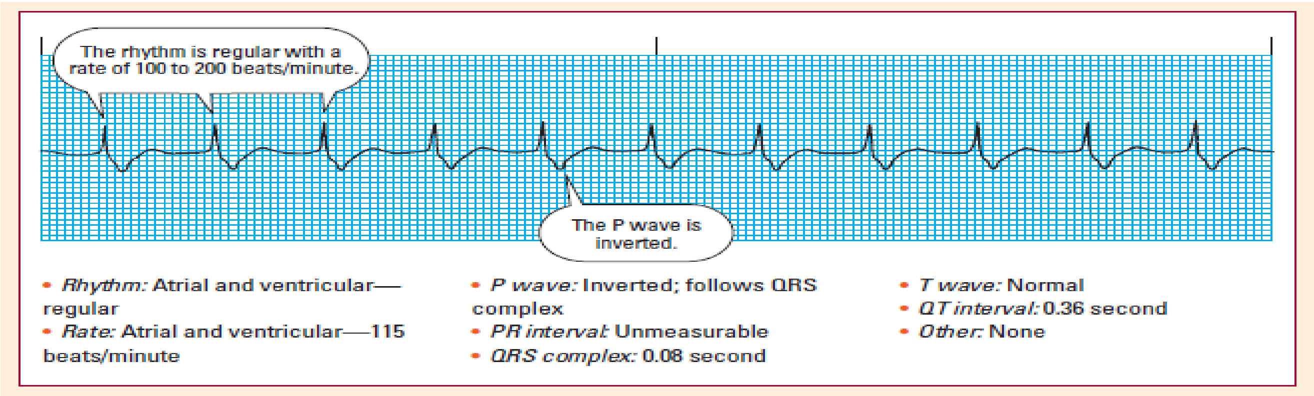


Figure 2.34 Identifying junctional tachycardia [2]

2.8 Ventricular Arrhythmias

According to the figure 2.35 ventricular arrhythmias is related to the ventricles below the bundle of His. It happens during the depolarization when impulses propagate in the wrong way. In these arrhythmias, conduction is longer than normal heart conduction so the QRS complex is wider than normal one. The P wave is invisible because atrial depolarization does not happen and the T wave and the QRS complex are not in the normal direction because of the abnormal repolarization and depolarization. As in these arrhythmias impulses are originated from ventricles instead of atria, there is no atria kick on the ECG. [2]

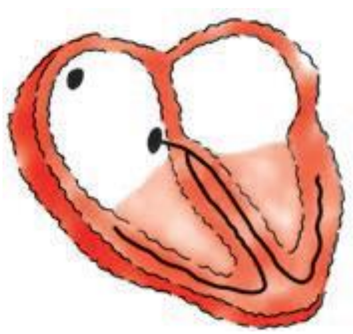


Figure 2.35 Ventricular arrhythmias [2]

2.8.1 Premature Ventricular Contraction. Premature ventricular contraction is also called PVC is a kind of heart problem which usually happens in normal people. It can also happen in patients with some heart problem such as threatening lethal ventricular arrhythmias. The ECG for this problem can show the bigeminy or trigeminy. PVC happens by an electrical heart problem in the ventricular conduction or any heart muscle tissue. It can occur during the repolarization or depolarization. Several factors cause this heart abnormality such as some kinds of electrolyte abnormal distributed, metabolic acidosis, ventricular chambers failure (dilatation of cambers); factors that cause increase the stimulation (like caffeine, alcohol or tobacco).

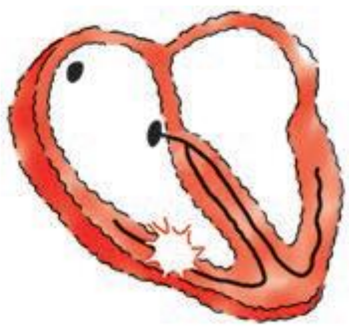


Figure 2.36 Premature ventricular contraction [2]

PVCs are important because they may cause some other serious heart problem such as ventricular tachycardia or ventricular fibrillation and in the worst case, it can damage heart. As it is shown in the figure, 2.37 PVCs reduce the cardiac output it happens because the time for filling the ventricle is decreased. The ECG for this heart problem is wide and extravagant it does not follow a regular rhythm for atria and ventricles. According to this arrhythmia, the P wave is invisible and the ST segment becomes wavy. The PR interval and the QT interval are not measurable because of the abnormal beats. The QRS complex happens sooner than usual case but its shape is normal and has duration more than 0.12 second. The T wave appears in the opposite of the QRS complex. PVCs happens between two normal sinus beats because the ventricle cannot response the P wave that is overtaking in the sinus node. [2]

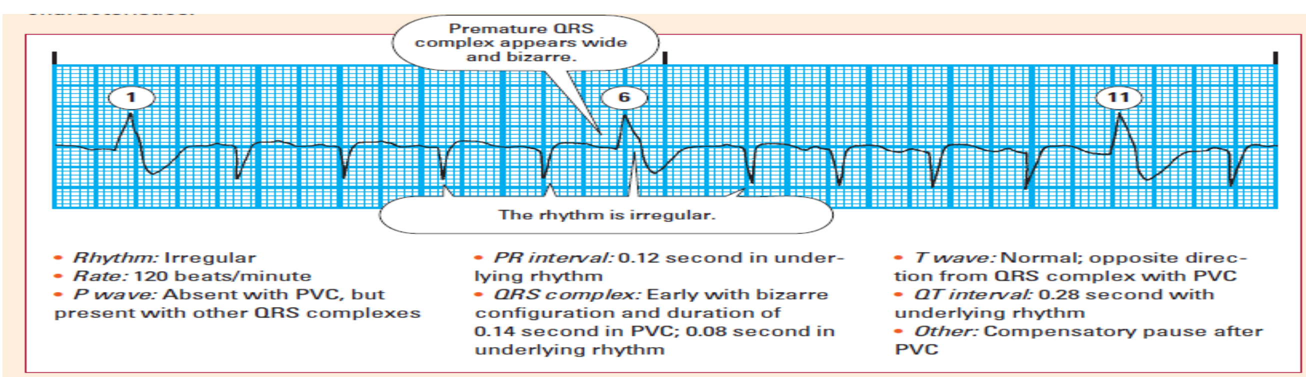


Figure 2.37 Identifying PVCs [2]

2.8.2 Idioventricular Rhythms. In this arrhythmia, the cells of the His-Purkinje act as a pacemaker and generate impulses so the idioventricular rhythms act as a watchdog and prevent the ventricular interruption. As it is mentioned before this arrhythmia happens when there is a block in the heart function and none of the heart pacemaker can generate impulses so supraventricular impulses cannot go to ventricle. Idioventricular rhythms may combine with heart block. Several factors can cause this arrhythmia such as myocardial infraction (MI), pacemaker failure, digoxin toxicity, and metabolic imbalance.

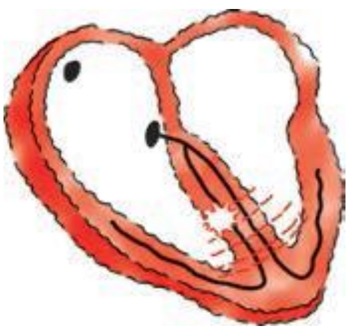


Figure 2.38 Idioventricular rhythms [2]

Idioventricular is called ventricular escape beat if only one idioventricular beat happens in the ECG signal. In this heart abnormality, the heart beat rhythm decrease to 40 beats per minute and can cause a delay in heart conduction cycle. Atrial rhythm and atrial rate are not measurable. As it is shown in, figure 2.39 in idioventricular rhythm the P wave are invisible or do not have conduction to the ventricles ECG signals. According to the absent P wave, the PR interval is not measurable. As the ventricular depolarization trace the QRS complex in the ECG, the QRS complex in this abnormality has a long duration with different abnormal shape. The T wave is in the opposite direction of the QRS complex. According to postpone which happens in the depolarization and repolarization the QT interval becomes longer than the normal one.

Patient who has idioventricular rhythm may feel dizziness or lightheadedness and in worst case, it can cause peripheral pulses or confusion.

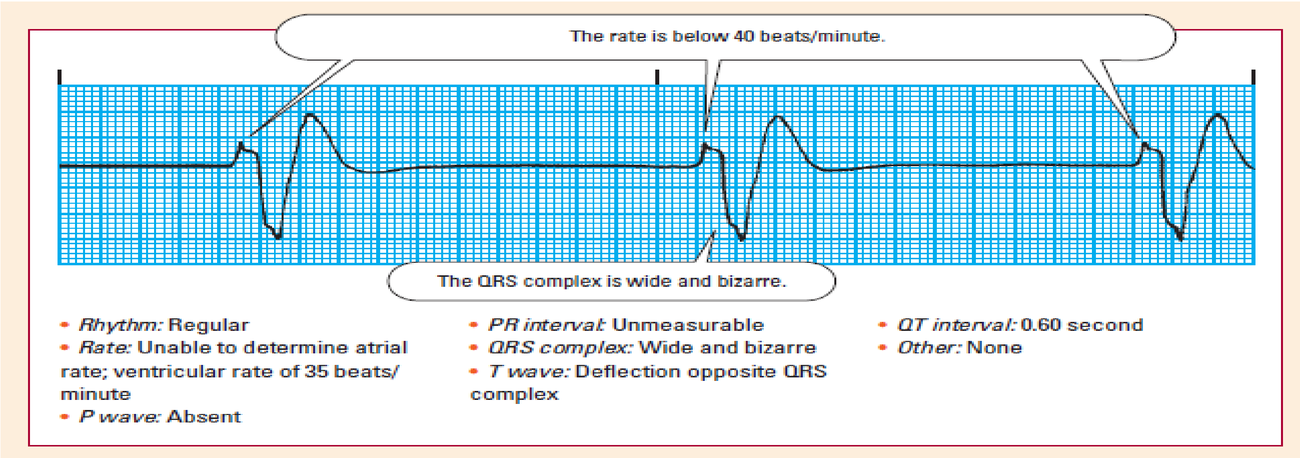


Figure 2.39 Identifying idioventricular rhythm [2]

This arrhythmia is called accelerated idioventricular rhythm if the heartbeat increases to 100 beats per minute. Figure 2.40 shows the ECG under this arrhythmia the QRS complex is wide and bizarre and the heart beat rate is rapid. [2]

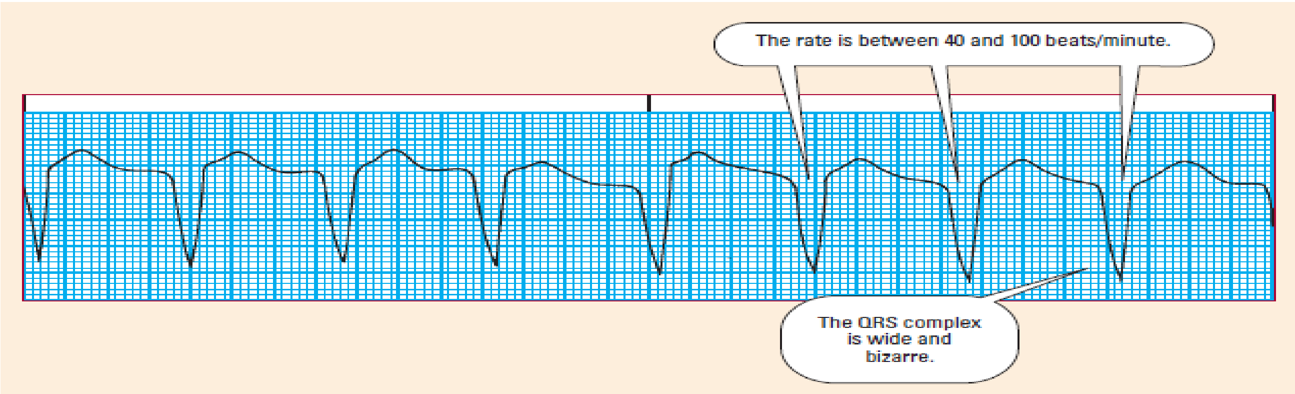


Figure 2.40 Identifying accelerated idioventricular rhythm [2]

2.8.3 Ventricular Tachycardia. In this heart problem ventricular rate increases to 100 beats per minute because three or more PVCs happen in a single row. If this heart failure continues, it can cause ventricular fibrillation and subsequently a cardiac death. It is an extremely fast and unstable arrhythmia, which lasts for nearly 30 seconds, and continues with more serious heart problem. Ventricular tachycardia usually happens when the automaticity of the heart increases. Ventricular tachycardia happens because of several conditions such as myocardial ischemia, MI, coronary artery disease, valvular problems, electrolyte imbalance, using drugs like digoxin, procainamide, cocaine.

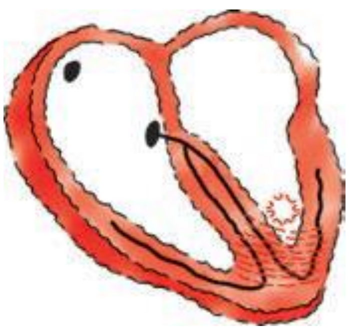


Figure 2.41 Ventricular tachycardia [2]

According to the figure 2.42 the atrial rhythm and rate is not obvious to detection. At first glance, the ventricular rhythm is regular but it may have abnormal pattern and as it is mentioned before, the ventricular rate as rapid as 100 to 250 beats per minute. As same as other ventricular arrhythmias the P wave is absent and the QRS complex's shape is ambiguous subsequently the PR interval is not measurable. In this abnormality, amplitude of the QRS complex increase and its duration becomes longer than normal condition but the shape of the QRS complex is uniform. Beside the P wave, the QT interval is not measurable and the T wave has an opposite direction of the QRS complex. [2]

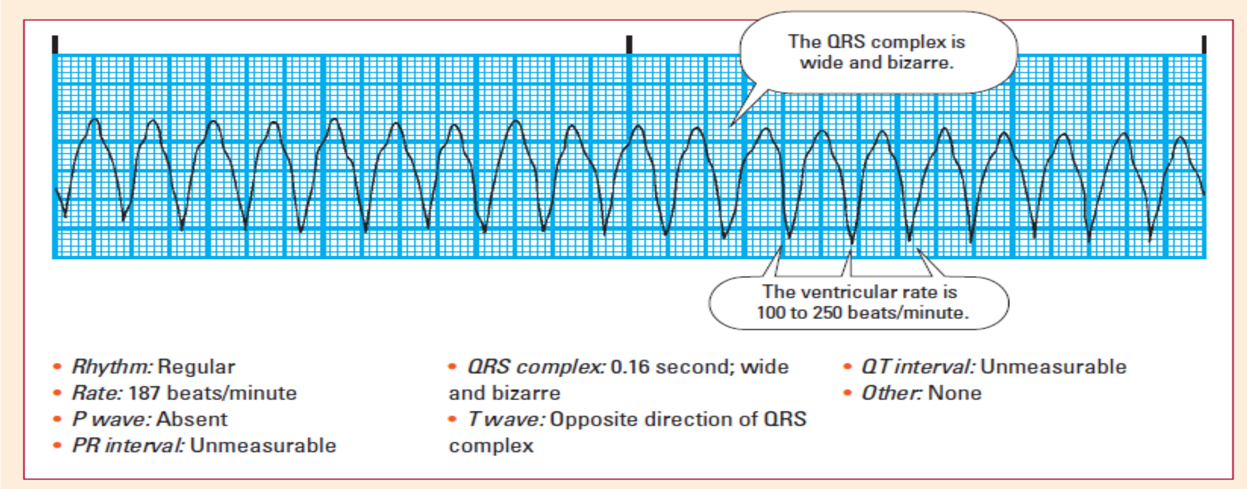


Figure 2.42 Identifying ventricular tachycardia [2]

2.8.4 Ventricular Fibrillation. In ventricular fibrillation, impulses are originated from many, different sites of the ventricles so the electrical activity of the heart has an irregular pattern. It can cause heart syncope and sudden death. There are several factors that can cause ventricular fibrillation such as myocardial ischemia, MI, some heart disease, electric shock, serious hypothermia, electrolyte imbalance, using some drugs like digoxin.

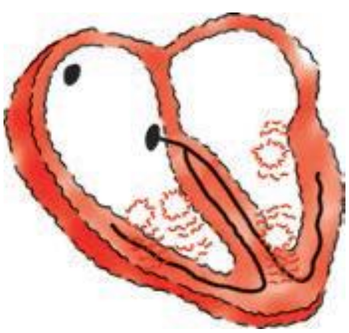


Figure 2.43 Ventricular fibrillation [2]

As it is illustrated in the figure 2.44, none of the atrial and ventricular rhythms can be detected in the ECG signal also they do not follow a regular pattern, as consequence none of the ECG components such as P wave, PR interval, QRS complex, T wave, and QT interval cannot be detected. The ECG components, which are larger than normal ECG, are easier to interpret than smaller ones. This arrhythmia is a serious heart problem that can cause cardiac arrest without a detectable blood pressure and femoral pulse. [2]

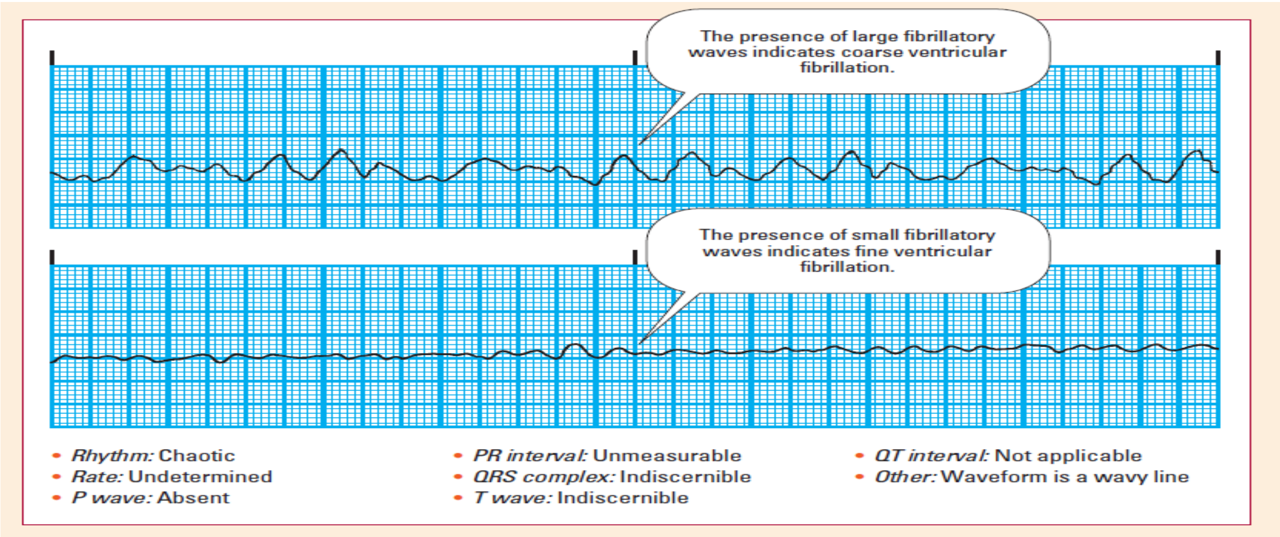


Figure 2.44 Identifying ventricular fibrillation [2]

2.8.5 Asystole. Asystole happens when the ventricular contraction stops. The electrical activity of the heart completely stops this occurs after a long duration of the heart arrest. As this problem is so serious, it is important to diagnose this heart failure. Sometimes it is difficult to distinguish asystole from ventricular fibrillation. Asystole is also called arrhythmia of death, the patient with this heart problem needs rapid initiation of CPR and quick treatment. The main reason of asystole is inadequate blood flow to the heart; several causes can be considered as the reason of this heart failure such as MI, massive pulmonary embolism, electric shock, hypoxemia, electrolyte imbalance, using drugs or overdosing drugs like cocaine.

Figure 2.45 Asystole [2]

As it is shown in figure 2.46 on the ECG none of the components can be observed and the ECG is very similar to a flat line. In this heart problem there is no electrical activity however sometimes the P wave can be observed. There is no atrial or ventricular rate happen in asystole so no interval can be measured. [2]

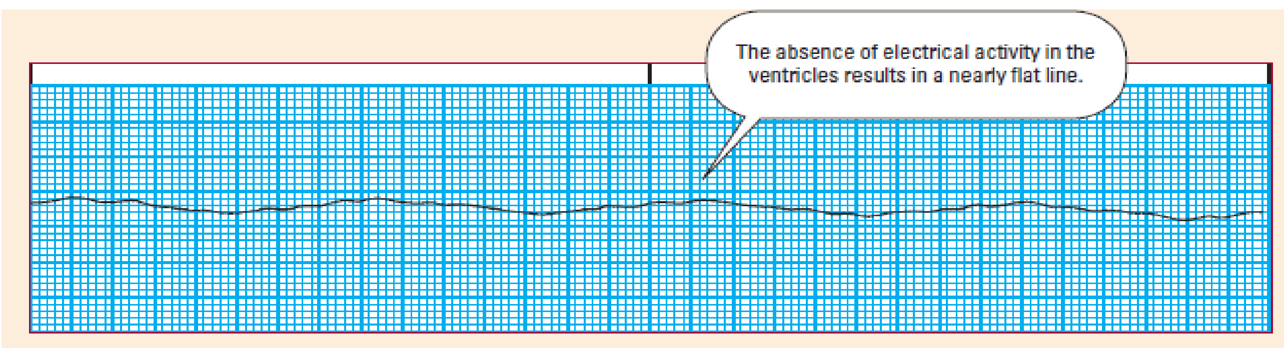


Figure 2.46 Identifying asystole [2]

2.9 Atrioventricular Blocks

Atrioventricular heart block happens because of several interruptions that occur in the conduction system between atria and ventricles. AV block can cause heart arrest or delay in the heart conduction. These arrhythmias can happen in AV node, bundle of His or bundle branches.

As it is mentioned before, heart impulses are originated in the SA node, although in this problem they are blocked at the AV node the atrial rate is normal. AV node blocks are divided into four main groups according to the number of impulses which are completely blocked, the speed of the ventricular rate, and the effect of the block on the heart. Several factors can cause AV block such as using certain drugs, congenital anomalies, MI, and conditions that disturb the heart conduction system. AV block may also happen because of any damage to the heart during the open-heart surgery. This damage may include mitral or tricuspid valve damage or any tissue injury.

AV blocks are categorized according to their harshness not their sites, based on the quality of the conduction of AV node. They are classified as first, second and third. [2]

2.9.1 First – Degree AV Block. First-degree AV block happens when impulses from atria are frequently postponed during conduction through AV node. In this problem conduction happens but with a long delay.

It can happen in normal and healthy people. MI and myocardial ischemia are two most important causes of the first-degree AV block but it can also happen by using medicine such as digoxin, calcium channel blockers, and beta-adrenergic blockers.

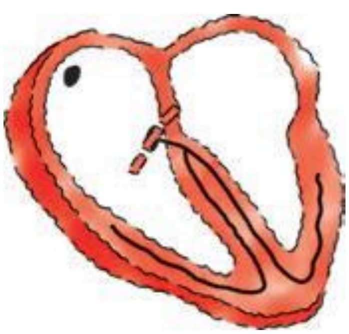


Figure 2.47 First- degree AV block [2]

As it is shown in figure 2.48, the ECG rhythm is normal but the PR interval is longer than normal heart condition nearly 0.20 second longer than normal. Other components of the ECG signal such as the QRS complex, the P wave that is followed by the QRS complex are abnormal. Sometimes a bundle - branch block may occur during the first- degree AV block subsequently the QRS complex becomes wider than normal condition. [2]

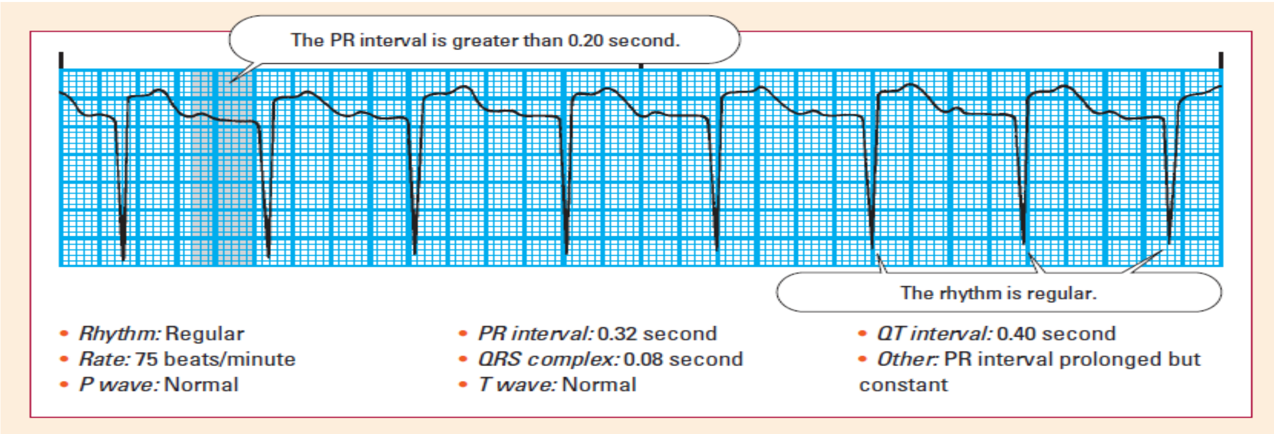


Figure 2.48 Identifying first-degree AV block [2]

2.9.2 Type I Second – Degree AV Block. Type I second – degree AV block is also called mobitz type I block, it happens when impulses which are originated from the SA node have a short delay from the previous one, so it continues until conduction that goes to the ventricles fail, then this cycle repeats.

Coronary artery disease, MI, cardiac medication such as beta- adrenergic blockers, digoxin, and calcium channel blockers are some causes of the type I second – degree AV block. This arrhythmia happens because the vagal stimulation increases. It is usually occur in healthy person.

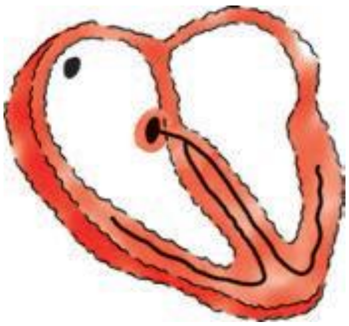


Figure 2.49 Type I second – degree AV block [2]

According to the figure 2.50, the ECG has a normal rhythm (atrial rhythm) because of the normal SA node function. The PR interval becomes wider until the P wave fails to conduct to the ventricles, so the ventricular rhythm is irregular and this pattern repeat. When the P wave fails to conduct to the ventricles, a QRS complex does not follow that P wave. [2]

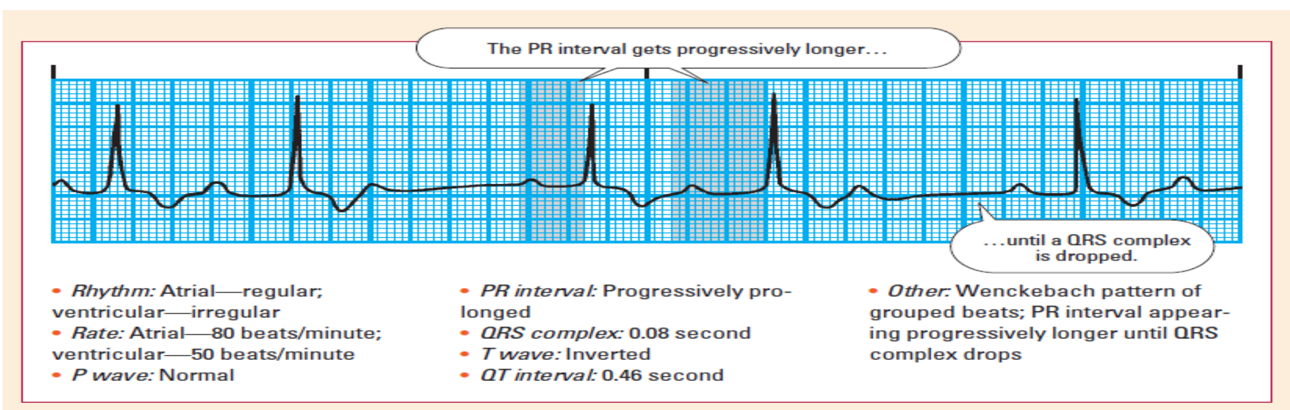


Figure 2.50 Identifying type I second – degree AV block [2]

2.9.3 Type II Second – Degree AV Block. This arrhythmia is also called mobitz type II block, it is not as common as type I but more dangerous than that. It happens when some impulses from the SA node fail to conduct to the ventricles. The PR interval in the ECG under this heart problem is not measurable, instead of PR interval AV node conduction and infrequent dropped beat are visible in the ECG signal.

Several factors can cause this heart problem such as anterior wall MI, backward changes in the conduction heart system, or intensive coronary disease. This arrhythmia expresses a problem at the bundle of His or bundle branches. The ventricular rate becomes slower than the previous one.

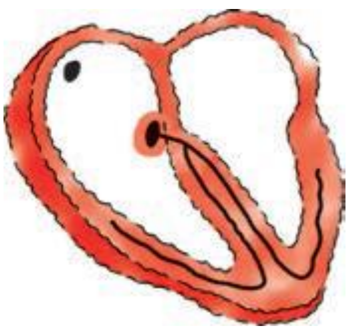


Figure 2.51 Type II second – degree AV block [2]

The ECG under this problem has a regular rhythm otherwise the ventricular rhythm depending on the type of block it can be regular or irregular (figure 2.52), if the block is stable then the rhythm is regular and when the block is suspended, the rhythm becomes irregular. During this problem, some of the QRS complex disappears. For each conducted beat, there is one PR interval but it is longer than normal case and is not measurable. [2]

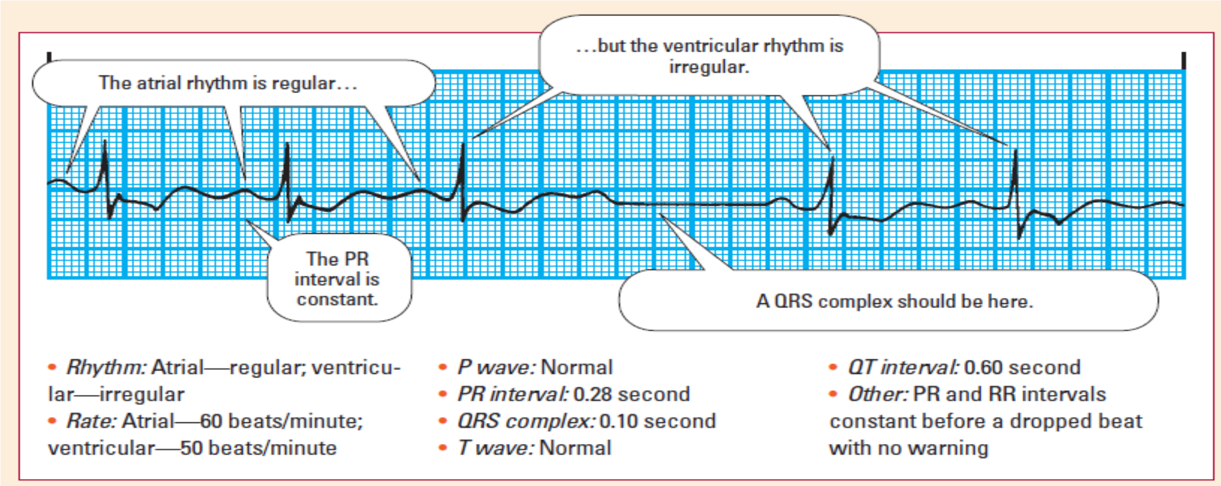


Figure 2.52 Identifying type II second – degree AV block [2]

2.9.4 Third – Degree AV Block. Third – degree Av block or complete heart block happens when impulses, which are originated in the SA node, are completely block in the AV node so none of the impulses can pass the AV node and cannot be conducted to the ventricles.

In this arrhythmia, atrial rhythm is completely regular between 60 to 100 beats per minute, because it is related to the SA node. Ventricular rhythm is originated in the AV node and stays at the rhythm between 40 to 60 beats per minute. In most of the cases, it is originated form Purkinje fibers and has a rate between 20 to 40 beats per minute. In this heart abnormality the P wave does not conduct the QRS complex. It can happen because of coronary artery disease, an anterior or inferior wall MI, backward changes in the heart, using some drugs such as digoxin, calcium channel blockers or injuries, which are caused, by open-heart surgery.

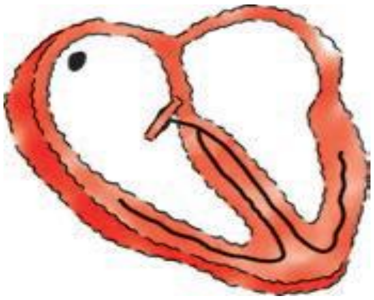


Figure 2.53 Third – degree AV block [2]

As it is illustrated in the figure 2.54, the atrial and ventricular rhythms are regular and the P wave and R wave are visible, but sometimes P wave merges with the T wave or the QRS complex. The PR interval is bizarre with no pattern. If the escape rhythm originates in the AV node the QRS complex is normal and the ventricular rate is between 40 to 60 beats per minute otherwise if it is generated in the Purkinje fibers the QRS complex will be wide and the ventricular rhythm will be less than 40 beats per minute. In general, the QRS complex is normal but the PR interval can be regular or irregular. [2]

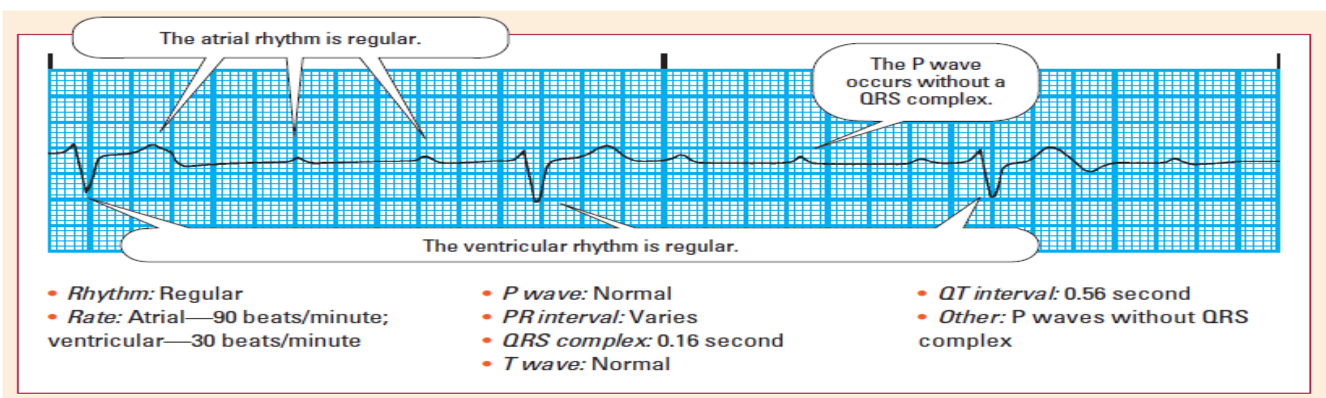


Figure 2.54 Identifying third – degree AV block [2]

CHAPTER III

SECURITY ISSUES AND CHALLENGES IN NETWORKING

This chapter is about three kinds of attack, which are used in the experiment. To interpret the effect of these attacks on the ECG signal, it is necessary to understand the concept of each attack.

Each system has its own vulnerability, so it can be threaten by any attacker. The attacker is a person or a kind of processing that use vulnerabilities of the system to harm or attack it.

There are three main components of security, which are considered as security triad or CIA triad. CIA stands for confidentiality, integrity, and availability. Any kind of attacks can cause loss of these components. Confidentiality means privacy, subsequently loss of confidentiality relates to the unauthorized access of data especially in this project access to the ECG signal. Second CIA component is integrity that relates to unchanged and unmodified data, so loss of integrity means data (ECG signal) which is modified from original data during transmission. Third and last component is availability that means data or computer can be operational when needed, so loss of availability usually happens during DDoS attack when all the computing resources are exhausted by the attack.

The first attack, which is generated and sent to the monitoring system, is TCP SYN attack. TCP or transmission control protocol is defined as layer four of network – level system, which makes the delivery stream reliable.

Data transmission in layer four is happens by establishing a TCP connection three-way handshake.

3.1 TCP Connection 3-Way Handshake

TCP connection in a network is established with a three way handshake. The first segment of a handshake is defined when computer A as sender tries to establish a connection to computer B as receiver, so it sends a packet to computer B with SYN=1 then in the second segment computer B sends a packet to A with SYN=1 and ACK=1 that means SYN bit and ACK bit are both set. Finally in the last or third segment computer A send ACK=1 to computer B that means both sides agree that a connection has been established. Figure 3.1 illustrates TCP connection three – way handshake. [3]

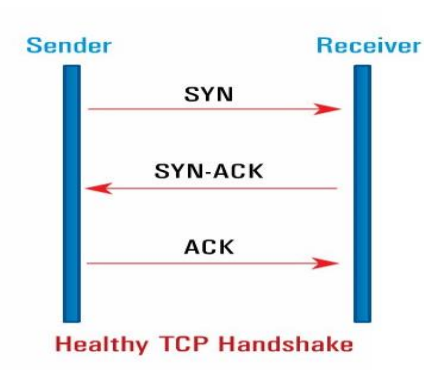


Figure 3.1 TCP connection 3-way handshake [25]

3.2 TCP SYN Attack

TCP SYN attack or in another word Flooding of Half Open TCP Connections is one of the attacks that is used in these experiments this attack relates to network layer four (transport layer). During this attack, the attacker sends a Flood of TCP SYN packets to the victim computer, so the victim computer tries to send SYN+ACK packet to the attacker but the attacker never responds with final ACK packet, as a result the connection is never completed. In every half-open TCP connection, the victim computer uses its useful computing resources such as memory to prepare for actual data, bandwidth and CPU. According to the timer which is set up by the operating system TCP half open connections are timed out, but before TCP half open connections are timed out useful computing resoureces is exhousted. This attack prevents victim to be able to do useful task so can cause Denial of Service (DOS) attack. Figure 3.2 shows half open TCP connection. [4]

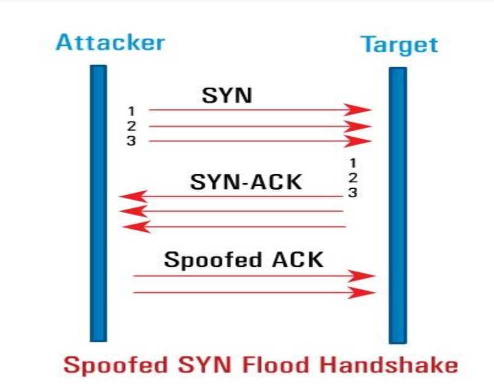


Figure 3.2 TCP-SYN attack (Half open TCP connection) [25]

3.3 PING Attack (ICMP Flood Attack)

ICMP or Internet Control Message Protocol is used in IP network administration and management such as diagnostic purposes, control purposes and error reporting. ICMP relates to the network layer or layer three. ICMP message format is shown in figure 3.3.

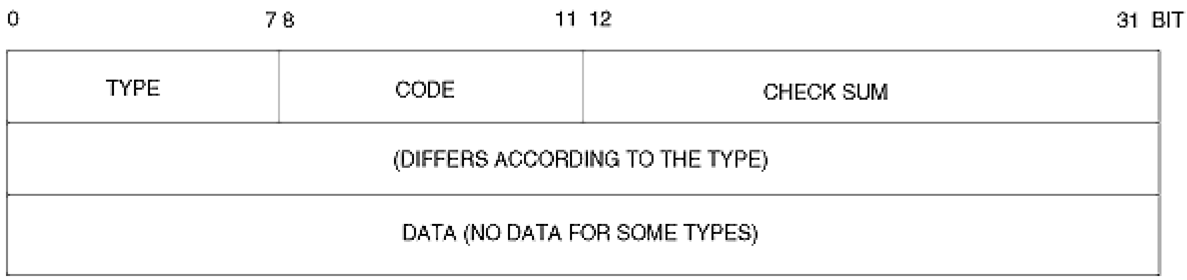


Figure 3.3 ICMP message format [5]

Similar to ICMP, Ping attack relates to the layer three (networking layer).In ping attack the attacker uses the Echo-request and Echo-reply messages to test attainability of a computer in a network. ICMP echo-request (ping) message is used in ping request message attack while ICMP echo-reply message is used in ping reply message attack. While responding to the one ICMP echo-request message use some of the processing power, if the target (end system) receives a barrage of ICMP echo-request then a large amount of its computing resoures and bandwidth will exhaust. [5]

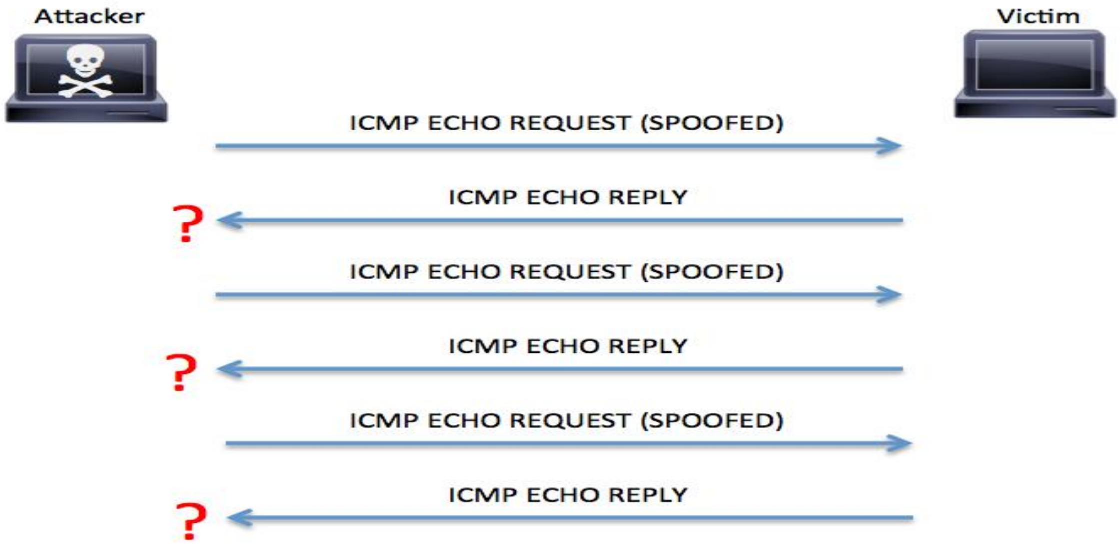


Figure 3.4 Ping attack (ICMP flood attack) [26]

3.4 ARP Attack (Address Resolution Protocol)

ARP is considered as layer 2.5 because it carries both MAC address as the hardware address (layer 2) and IP address as the layer – 3 address. It stars with ARP request packet broadcasting through the local area network (LAN). This ARP request packet contains the information of IP address, so the computer, which has the matching IP address, replies the sender of ARP request by ARP reply packet. The ARP reply packet has the hardware address of receiver and sends it to the sender. ARP request packets are broadcasting otherwise ARP reply packets are unicasting. Figure 3.5 shows the ARP conception.

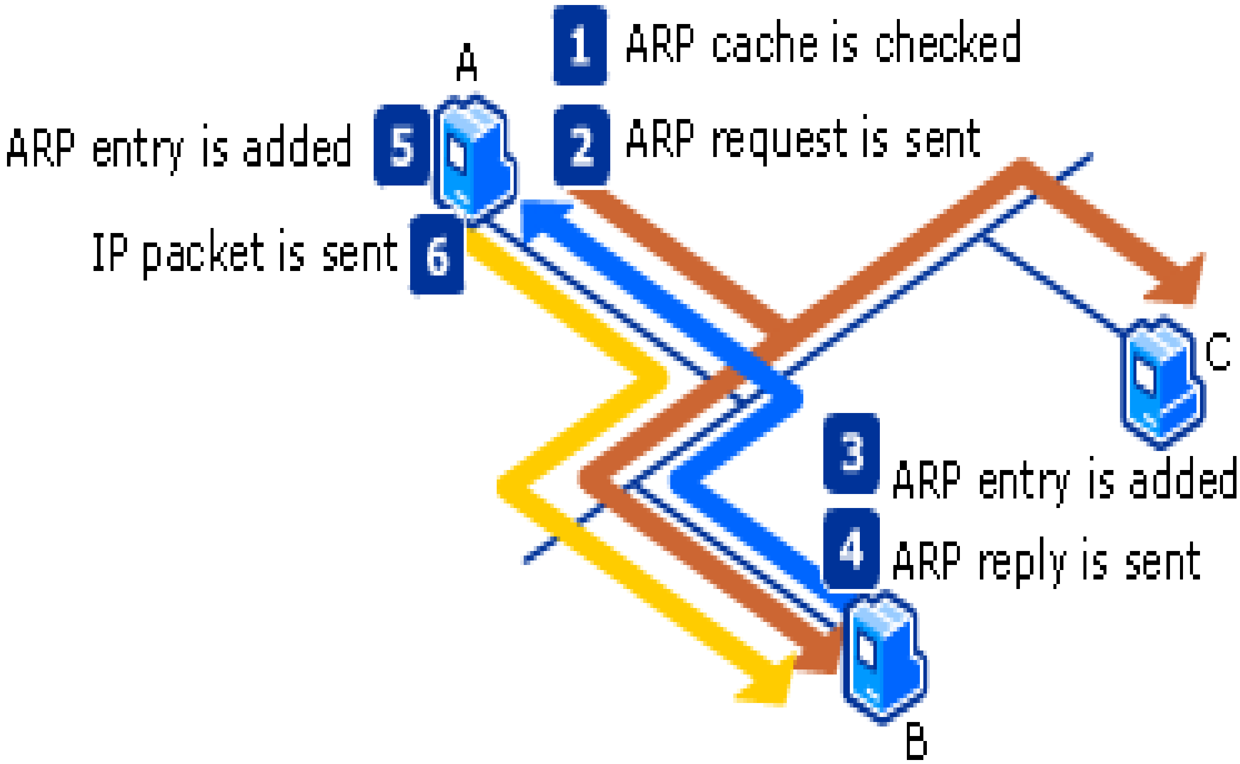


Figure 3.5 ARP request and ARP reply concept [27]

There are three main ARP attacks, which are named as Brute force ARP attack, or DDoS attack, ARP poisoning attack, ARP snooping or Man in the Middle attacks.

Brute force ARP attack or ARP based on denial of service (DoS) attack is generated when a stream of ARP request packets are sent to the target computer or target server. This barrage of ARP request force the victim computer or server to send ARP reply so it can waste computing resource, which include CPU, memory, bandwidth exhaustion. Some ARP attacks such as code red forces other computers in the local area network to generate a barrage of ARP request traffic and then send it to the victim computer.

In the ARP poisoning attack, the attacker or hacker changes, to the ARP table of the target computer with a wrong hardware addresses (MAC addresses). Hence, these wrong IP to MAC mapping is installed on the target and can cause DoS attack to the victim computer.

ARP snooping is the most common ARP attack, which is also called Man in the Middle attack. This attack is considered as a modified form of ARP poisoning because in this attack the attacker modifies the ARP table with an IP address, which matches its own IP address. As a sequence all the packets before going to the victim computer are received by the hacker computer and he can access to all the data which is sent to the victim computer. Figure 3.6 illustrates the Man in the Middle attack. [3]

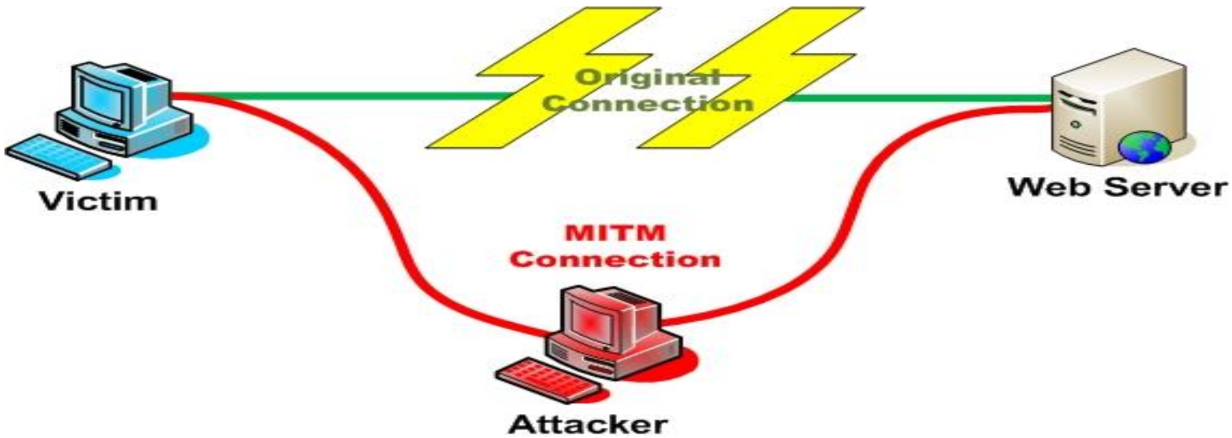


Figure 3.6 Man in the Middle attack [28]

3.5 Effect of Attacks in CIA Triad

As it is mentioned before each attack effects on the CIA components. In the TCP SYN attack by sending a barrage of TCP SYN packets computing recourses can happen in the victim computer so the CPU function may completely stop under this attack. As TCP SYN attack can cause denial of service (DoS) attack, the security component that is affected under this attack is availability.

The Ping attack, which is based on, distributed denial of service (DDoS) can be considered as an attack that has bad effect on the availability of the web based services.

As the ARP attack is divided in to three main attacks, each one can affect the system in a different way. Brute force ARP attack or DDoS attack and ARP poisionig can damage the availability similar to the two other attacks, which are mentioned before, otherwise ARP snooping causes loos of confidentiality by accessing to the vital data, which are sent from the server to the victim computer.

3.6 Prevention of Network Attacks

Each type of attack has a specific solution in order to prevent their malicious effect on the network system.

Preventing TCP SYN packets can be easy if access list is available. By limiting the number of IP addresses which want to access to the server, however in public server or mail server, which is used in the internet this solution is not possible, because diagnosing which incoming IP address is good and which is not is not practicable. Some options to prevent TCP SYN attack are such as Increasing the size of the connection queue or SYN ACK queue, reduce the time out duration which is waiting for the three-way handshake to be completed, and use a vendor software patches to distinguish a problem.

There are two most important ways to prevent against Ping attack. One can be checking the source IP address of egress traffic (outgoing) and simply drop the IP address, which is considered as an external IP address and the other one, is not to allow the IP address messages directly broadcast from the intermediate systems.

ARP attack can be prevented by several ways such as clarifying static ARP entries for vital systems, monitoring ARP cache and determine any changes which happens in the table entries, restrict the number of entries' switch in the ARP table. The last and most important prevention way is using some software to detect the abnormality in the traffic through the network and changes of the ARP traffic. [3], [5], [6], [7]

3.7 The Most Important TCP SYN, PING, and ARP Attack in the Recent Years

TCP SYN attack first was used in 1996. This attack was used in ISP's (internet service provider) mail and Telnet servers. Subsequently it made an interruption in the Washington Post and The Wall Street Journal then the CERT solved this problem quickly.

As it is mentioned before, Ping attack also can cause DDoS attack. In the October of 2002, an enormous Distributed Denial of Service (DDoS) attack disturbed the web traffic on the internet. It interrupted 13 DNS main servers whose domain names and IP addresses depended on them. This attack took one hour, which was done by Ping – flooding of the root servers. During this attack the internet software consortium (ISC) which manages one of the victim root servers, had nearly 80 Mbps of traffic to its server; this amount of traffic was more than 10 times than normal load in the normal condition. [6]

Brute force ARP attack can cause DDoS attack in the network. In summer of 2001, Code Red a worm was sent to the computers over internet. It damaged computer systems and caused billions of dollars of damage. This cyber-attack contained a text string Hacked by Chinese that appeared in the web page. This worm went to the memory of the computer and ran itself in the whole memory, so it caused the loss of availability by exhausting the memory. [7]

3.8 Cyber Threats on the Healthcare Industry

The most important aspect of cyber-attack in healthcare is about privacy and confidentiality. Attackers steal sometimes patients' information, which includes vital information such as patients' identification, disease background of the patients, and insurance information. The most considerable attack in this case is Man in the Middle attack, which can steal important information of the patients and abuse them. This large amount of data is called big data. Security issue becomes more important in the big data in healthcare filed. As these amount of data is used for diseases prediction and insurance agencies to reduce their expenses while improve services, integrity and authenticity are considered as two essential challenges of security in the healthcare. Attacker can harm the system with big data by inserting malicious and modified data; subsequently it causes loss of integrity. Processing the big data may face DDoS attack by the enormous amount of data in another word big data can cause loss of availability by itself. [8]

CHAPTER IV

LITERATURE SURVEY

In this chapter the content of papers, which are related to the content of this thesis, are mentioned.

The in the paper [9] whose title is ECG beat classification method for ECG printout with Principle Components Analysis and Support Vector Machines. In this paper, they investigated in three kinds of heart abnormality and one more which was normal condition of the heart. They classified these abnormalities in the shape of the ECG, these conditions were left bundle branch block beat (L), right bundle branch block beat (R), ventricular premature beat (V), and normal beat (N). This data processing had three main components, the first one is time series ECG beat recognition that is extracted from the ECG signal, and the second one is about some preprocessing way such as PCA and separate wavelet transform. Third and last one is ECG beat categorizing with SVM.

ECG beat recognition had nine steps, which started at ECG paper scanning or printed ECG signal, then they choose a segment of the ECG signal and removed the noise form the printed ECG, if black pixel were surrounded by white pixel it was considered as noise. Before noise rejection, they binarized the ECG to change the signal to pixels. This ECG signal had a thick shape so it contained extra data, in order to reach an accurate data the ECG signal was transformed to a thinner one by average algorithm. Next step was time series data extraction then data was normalized which generates zero – mean signal. For finding, the QRS complex they used Hilbert transform. According to these steps, the ECG beat was extracted. In addition, they used SVM method to detect the abnormalities by data processing, SVM training, and SVM evaluation. In this method, PCA was used to generate a vector space for DWT or discrete wavelet transform. Their method for classification had an acceptable performance with the 99.6367% accuracy.

A Novel Abnormal ECG Beats Detection Method paper [10] is about an algorithm that is used in order to find out the heart abnormalities in automatic systems such as real – time and mobile ECG processing.

Their method consisted of three main parts signal processing, training, and two-stage classification. They focused on four heart conditions such as normal sinus rhythm (NSR), premature ventricular contraction (PVC), left bundle branch block (LBBB), and right bundle branch block (RBBB).

In the first step as signal processing ECG signal was transformed to an individual ECG beat. In the signal processing for removing the baseline they used a method that estimated the baseline and subtracted it from the main ECG signal instead of using ideal high pass filter. Then the data (beats) were extracted and normalized. They used dynamic time warping for measuring the similarity between two sequences (two points of the ECG). After clustering, they selected six key points that were the P onset, Q and S valley R and T peak and T offset. In this method, the classification had two stage; first stage accepted the data with these two factors: the minimum distance should be less than threshold T and the second minimum distance should be longer than

M times in the minimum distance. If the data does not have these features then it will go to the second stage. The second classification included the SVM classifier, which detected the similarity between the different time intervals that were used as original and the test beat. The accuracy, which was achieved by this algorithm, was 97.24%, this method can be used in big data analysis and healthcare applications.

In the paper [11], Khalil and Sufi generated architecture of a CardioGrid system which analyzed a large amount of ECG signals. This system showed an acceptable behavior under the very heavy load of traffic according to the transferring data. Data could maintain reliable and scalable during the transformation. This architecture was considerable because it could help diagnose any heart disorder at early stage, also provided online abnormalities detection in order to save the resources.

They considered several factors to generate this system such as scalability, diagnosis, service provider database, disease diagnosis and processing, storage, performance module, transmission module, and diagnosis training module. ECG signals from different patients were captured and sent to the cardioGrid for analyzing. System scanned all ECG signals and found out the main components of the ECG such as P wave, T wave, U wave artifacts and QRS complex. Then averages of all intervals' durations were calculated such as PR interval, QRS complex, QT interval and RR interval. As soon as the length of these waves and intervals were not as same as the normal wave they were considered as abnormal condition. In the last step all, the ECG signals were reported to the healthcare centers via network.

In paper [12] Sufi, Khalil, and A.Mahmood designed a method for selecting high efficient data form the compressed ECG and analyzed it to diagnose the abnormalities of the heart. In the traditional ECG signal analyzing the ECG signal compressed because it has a huge size, so encoding the data is a crucial step. Analyzing the compressing signal has several advantages such as faster transmission and faster solution subsequently secured and efficient telecardiology, however this method has a considerable delay in decompressing step.

In the algorithm that they designed, they did not decompress the data and analyzed the ECG compressed signal from several sample of the ECG signal. The system, which was implemented by them, consisted of an acquisition device that captured the ECG signal from the body patient then transmitting those signals to the hospital or monitoring services with HTTP or MMS protocols via Bluetooth, WiFi, Near Field Communication (NFC) or Zigbee protocol. Compressing and encryption was taken place by mobile phone. For analyzing the ECG signal first they selected some parts of the compressed signal and then used clustering technique.

They choose 18 segments that 12 of them were normal and 6 of them were abnormal segments that were extracted from compressed ECG signal. They selected just 18 segments for decreasing the enormous amount of data, making the process faster to reach more detection that is accurate. They used Pearsons co-efficient for attribute subset correlation. By using this method, extra attributes would be eliminated, so it can reduce the effect of those extra attributes on the processing.

This process started whit an empty subset and each attribute was added one by one to the subset, each one processed at the time to decide whether it matched with the predicted class or not. After the generation of dataset, the algorithm checked those attributes, which were discarded initially. Algorithm kept those attributes that were more closely to the class. By using this algorithm the subset became smaller. In the next step sample ECG signal were compared to the sorted cluster, if the ECG did not match to the cluster it would consider as an abnormality and then created a new cluster. They used Expectation Maximization (EM) clustering technique for this algorithm. In this method heart abnormalities detection were achieved with 100% accuracy.

In paper [13] Li-ping, Mi, Jia-fei, and Jun designed a new algorithm for analyzing ECG signal. They described this algorithm in the paper “An Uncertainty Reasoning Method for Abnormal ECG Detection”. In general, there are two methods for analyzing the ECG signal knowledge base method and pattern recognition based method. Some researchers have used several algorithms such as decision tree, ECG classification by computing the RR interval, and using the support vector machine (SVM) method. Both knowledge method and statistical method had their own advantages, first one focused on the reasoning models and the second one focused on attributes and classification model.

In this paper, they created an algorithm, which included both methods. This algorithm started at diagnosing the heart beat abnormality, which consisted of three main steps, digital processing, attribute selection, and heart disease categorization. They used two groups of ECG classification: numerical features, which were related to the duration of intervals and amplitude of ECG components, and morphological features that were traced in the paper and used by cardiologist to detect the heart problem. Second step in this algorithm was certainty factor model (C-F) which was consisted of many reasoning rules, and it was efficient for processing uncertainty data. In the next step, they used Gaussian test method to evaluate the certainty factor. They observed that using feedback algorithm could improve the results in both sensitivity and specificity aspects.

They used two groups of data to test one from MIT-BIH arrhythmia database and another one included Lead II in MIT-BIH arrhythmia database. In the first experiment, the accuracy was 99.36% and in the second on was 85.68% with their modified algorithm of C-F model.

In paper [14] Jeong and Yu developed an algorithm to detect the changes in the ST interval. In the paper “Design of Ambulatory ECG Monitoring System to detect ST pattern change”, they described both the hardware and software that created. Beside other neural network that reduced the noise effect and considered the level of the ST interval their algorithm was considered both the ST interval level and shape.

In this paper, they explained hardware, which they designed. This portable ECG included multiplexer, instrumentation, amplifier, analog filter, and micro-controller and transmitter module. The signal was sent to the micro controller for processing but before that it the signal amplified and filtered. This device had four body surface electrodes to capture the ECG signal.

The algorithm that was developed by them consisted four main steps: first step was about ECG components detection, second step was polynomial approximation third and fourth steps were found out changes in level of ST interval and changes in its shape. They classified R, S and T wave before analyzing the ST interval because S and T wave were main points for polynomial approximation. They used QRS complex to find out the R wave. After ECG components, they used polynomial approximation process to make the ECG signal clean so this process was considered as a low pass filter. They measured 80 msec after the J point the ECG signal for conditions that heart beat rate was less than 120 bpm and 60 msec if the heart beat rate was more than 120 bpm, this measuring method was according to the European ST database and used the result for verifying elevation or depression of the ST interval. For evaluating the ST shape type the algorithm used the values of four points between S to T waves. ECG signals from European ST Database were captured from a person in two hours at the rest condition. The information that were collected by this algorithm could be useful to detect the heart abnormalities such as ischemia which is the cause of cardiac fraction.

In paper [15] Heged, Deekshit, and Satyanarayana explained different methods for noise elimination from the original ECG signal and several methods to analyze the ECG signal.

In their paper, they mentioned that heart problems could be diagnosed by three main methods, which were the ECG signal that was traced by leads, symptoms, and enzymatic test. They considered ECG components as the most important and common method so detecting the ECG component was an important issue. It consisted of the P wave, T wave, QRS complex and their intervals. Classification of the ECG waves depended on several aspects such as the quality of the ECG signal, the rules of the classification and methods, and testing and learning datasets that were used. Before signal, processing of the ECG the noise should be removed from it.

They explained these three factors as the noise generator in the ECG signal that included baseline wandering with low frequency noise, power line interference that were considered as equipment noise, and some random noise such as muscle noise and artifacts. In general, they divided filtering methods in two parts one is non – adaptive filtering and another one is adaptive filtering. In non-adaptive filtering, FIR filter and IIR filter were used. Adaptive filtering was considered more practical than previous one. It used high frequency filter to eliminate noise subsequently it could reduce the bias in the ECG frequency spectrum. Two most considerable filters that were mentioned in this paper were two point Moving Average filter and four point

Hamming filter. Wavelet transform was considered as the most common method for noise elimination.

ECG analyzing method included the detection of abnormal ECG components such as absence of the Q wave, changes in the shape and level of the ST segment that represented the ischemia and myocardial ischemia, and ventricular late potentials (VLPs). The most recent research in myocardial infraction was about a detection based on autonomic nervous system (ANS) on the SA node and the influence of the nervous system on the atrial fibrillation.

In paper [16] Wang and Zhang explained a new algorithm for identifying based on ECG signals. In the paper “Research on ECG Biometric in Cardiac Irregularity Conditions”, they presented a new method for identification beside traditional identification methods such as fingerprint recognition, face recognition and voice recognition. They used ECG morphology in this algorithm; this method was more efficient to compare with other biometric methods because ECG signal is unique, and easy to process. In general, scientists used normal ECG signal for identification whereas in this method both normal and abnormal ECG signals were used.

Their identification algorithm consisted of these steps: preprocessing, data processing, attributes extraction, modified algorithm templates, and template matching.

In the preprocessing step, they used different filters to eliminate the noise in the ECG signal such as moving average filter and Butterworth. They chose peak of the R wave from the QRS complex as the feature, which was extracted because this component was considered as a stable feature. They designed an algorithm, which was modified multi algorithm, in this algorithm two sets as normal and abnormal ECG signals were considered. They created the template of the algorithm by extracted the number of normal and abnormal QRS complex.

Entirely they used 67 QRS complex to create the template, then calculated the minimum interaction coefficient in the all-67 QRS complex, and defined it as the preset threshold. In the last step, they matched all this templates to original templates.

In spite of traditional methods that could predict just one heart arrhythmia by each algorithm, in this algorithm several heart problem such as left bundle branch block, right bundle branch block, premature ventricular contraction and atrial premature ventricular could diagnose with 100% accuracy.

In paper [17] Sahoo, Ari and Patra presented a new method in order to detect the heart abnormality with the focus on ischemia in the paper "ECG signal analysis for detection of Cardiovascular abnormalities and Ischemic episodes". Their detection algorithm was consisted of five main steps: preprocessing the ECG signal, attribute extraction, diagnosing heart abnormalities, beat categorizing, and ischemic episodes recognition.

The first step included two parts normalizing the ECG signal and then using filter in order to eliminate the noises that affected the ECG signal. The filter, which was used in this step, was a band pass filter. In the next stage different components of the ECG signal were measured, components intervals and their amplitudes ware used to detect several heart abnormalities such as bradycardia, tachycardia, bundle branch block, premature ventricular contraction, and Wolff-Parkinson-White syndrome (WPW). The most important components that were used in the cardiovascular abnormalities detection was the morphology of QRS complex, other components were the P wave, J point, T wave and the ST segment. For diagnosing the ischemia, the ST segment and T wave ware used. In general the ECG signal with the ST segment which had fluctuation level and shape could be considered as a ischemic episode.

They used sliding window technique to diagnose the ischemia. The ischemia beat could be detected if the duration of the window was 30 second and the window had more or equal to 75% of ischemia beats.

In the experiment stage, they considered both sensitivity and positive predictive accuracy (PPA) in their algorithm and the results that were calculated for those two parameters were 88.08% and 92.42%. They randomly chose 10 ECG signal records from the European ST-T segment dataset in order to examine the performance of their algorithm.

In paper [18] Dliou and Laaboubi explained a method to eliminate the noise from ECG signal also; they used the combination of two methods to design an algorithm for attribute extraction of ECG signal. In the paper “Noised abnormal ECG signal analysis by combining EMD and Choi – Williams techniques” they considered the ECG signal as a fluctuating signal which was combined by noise.

In order to remove the noise from ECG signal they used the empirical mode decomposition (EMD) which was proper for nonlinear and fluctuating signal such as ECG signal. They used intrinsic mode functions (IMFs) to divide the signal to smaller parts that was easier to process. In this step Hilbert transform was used for processing.

In the second stage the Choi – William mathematical method was used which included both time and frequency signal analyzing. As the ECG signal changed in time domain, traditional signal processing such as Fourier transform was not efficient anymore.

In the experimental step, they chose a patient who had the supraventricular arrhythmia. According to this method, the QRS complex had high resolution and was detected as narrow QRS complex, which showed the supraventricular arrhythmia.

CHAPTER V

EXPERIMENTAL SETUP AND RESULTS

In this chapter, first, the experimental setup is explained then the results are investigated and compared to the normal ECG signal under normal condition, which means capturing ECG signal without any network attack in rest condition.

5.1 Simulation Setup

In this research, the TCP SYN, ARP, and, Ping attacks were simulated and generated in the controlled environment of the networking research lab at the University of Texas Pan-American using multiple computers. These attacks were sent to the victim computer, which was an iMac-based computer. The computer had an Intel Core i5 processor with the speed of 2.5 GHz, the 8 GB 1333 MHz DDR3 memory, and AMD Radeon HD 6750M 512 MB graphics. A Gigabit Ethernet was used to support a speed of 1000 Mbps (1Gbps).

The experiment was done on four different operating systems on iMac platform; Windows 8 Enterprise Microsoft; OS X Lion, version 10,7,4; OS X Mountain Lion, version 10.8.5; OS X Yosemite, version 10.10.2.

As it is shown in figure 5.1 all the attack traffic were generated by simulating multiple computers on internet and then were sent to the victim computer (iMac platform).

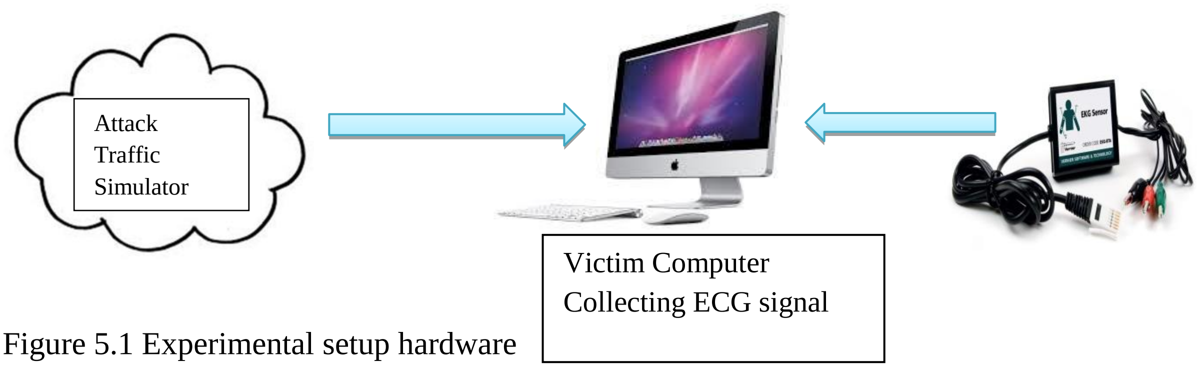


Figure 5.1 Experimental setup hardware

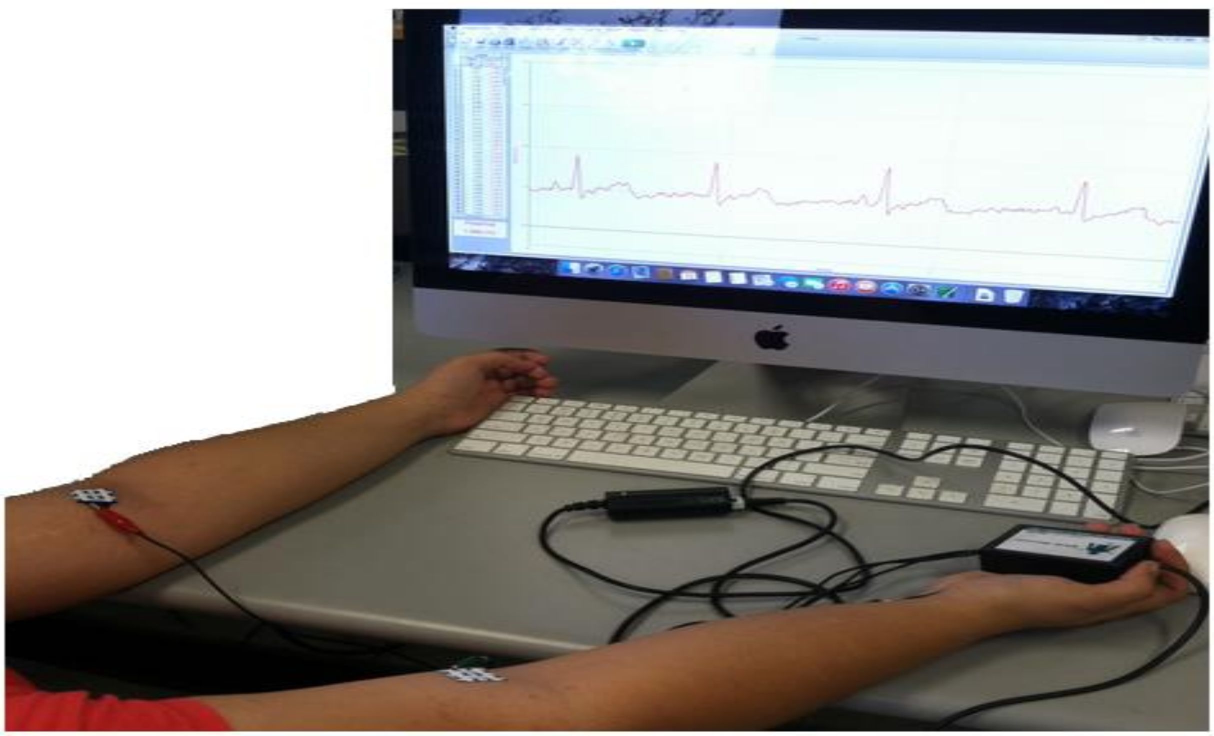


Figure 5.2 EKG electrodes on the body surface

To create a baseline for comparisons, measurements were done when no attack traffic condition, which is shown by 0% traffic load. The attack traffic was started at 0% load (i.e. no attack traffic), which was considered as baseline then it was increased by 10% of traffic load in each step until it reached to 100% load. For each traffic load, the ECG signal was captured, five minutes after sending the attack of the given load to the target computer.

5.2 Vernier EKG Sensor

5.2.1 Vernier EKG Sensor Hardware. Vernier EKG sensor as it is shown in figure 5.3, is a sensor that can capture ECG signal with three lead that are placed on the left and right arms (Red lead is plased on the upper left arm, Green lead is placed on the upper right arm and the Black lead is placed on the right wrist) . These leads are connected to the body surface via electrodes. This sensor also can capture the EMG recording. Vernier EKG sensor is not a clinical grade sensor and is used only for simple experiments in academic laboratories. The Verneir EKG sensor connects to the computer via USB port. [19]

5.2.2 Vernier EKG Sensor Software. The software that was used in this experiment was Logger Lite 1.8, 1.7, and 1.6. This software is basic real-time graphing and data collection software. The Logger Lite 1.6 is compatible with Mac OS X Lion .The Logger Lite 1.7 is compatible with Mac OS X 10. 8 and 10.9 and Windows 8.1 Microsoft. The Logger Lite 1.8 is compatible with Mac OS X 10.10. [19]

Figure 5.3 Vernier EKG sensor [19]

5.3 Parameters of Performance Interpretation

Parameters of performance evaluation, which were considered in this experiment, were the traffic load of the TCP SYN, ARP, and, Ping attacks and the effect of these attacks on the ECG signal. Some of the most important components of the ECG signal were calculated after each step. For each kind of attack there were eleven ECG signals were traced under effect of different traffic load. In the next part all, these components are calculated and compared with baseline.

5.4 Performance Results and Discussion

As it is mentioned in section 5.1 ECG signals were captured under effect of TCP SYN, ARP, and Ping attacks. To detect the abnormalities under attacks in the ECG signal first all the components of the ECG signal in the baseline are calculated. Figure 5.4 shows the normal ECG signal, which was captured with the Windows 8 Microsoft operating system, as it, illustrated in this figure, the ECG signal was captured for 3 second and the potential of the waves were in mV.

Figures 5.4, 5.29, 5.51, and 5.77 illustrate ECG Signal in normal condition with no network attack traffic; the components of ECG signal in four operating systems are shown in table 5.1 to 5.4. To understand the effect of networking attack in the ECG signal (in Windows 8 Microsoft, OS X Lion, OS X Mountain Lion, OS X Yosemite), the components of normal case are compared to the ECG signals under attacks. In this chapter, PQRS construct ECG signals when collected under effect of network attacks, using different operating systems, heart abnormalities showed different types of heart disease, which was false alarm.

5.4.1 Windows 8 Microsoft Results. In this section, first ECG baseline in Windows 8 is shown (Figure 5.4) and in table 5.1 all the components of ECG is calculated, then ECG signal was captured under ARP, TCP SYN, and Ping attacks.

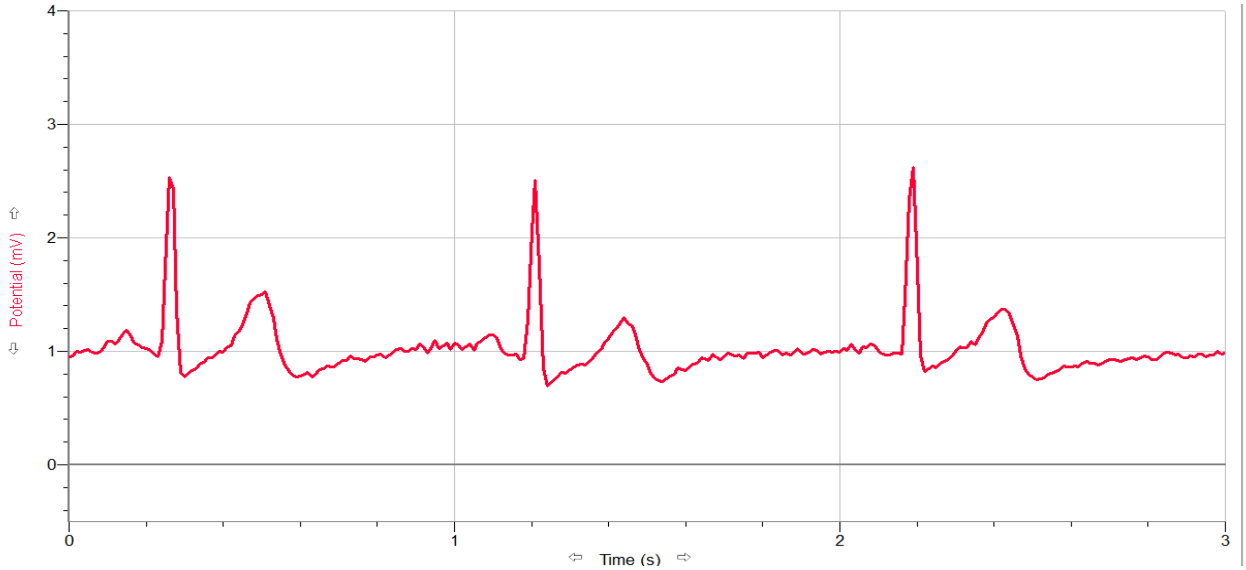


Figure 5.4 Baseline ECG collected by Windows 8 Microsoft operating system under normal condition

Table 5.1 Baseline values of ECG signal in Windows 8 Microsoft under normal condition

Feature	Value
R – R interval	0.61 s
S – T interval	0.08 s
P – Q interval	0.08 s
P wave amplitude	1.105 mV
T wave amplitude	1.188 mV
R wave amplitude	1.940 mV
QRS complex	0.16 s

5.4.1.1 ECG Data Collection Under ARP Attack. Three components of the ECG signal under ARP attack in Windows 8 changed considerably which were R-R interval, the P wave, and the T wave. As is illustrate in figure 5.5 the P wave decreased from 1.105 second to 1.079 second, in the captured ECG signals and the duration between two consequent R wave increases. Figure 5.5 shows in ARP attack in speed of 700 Mbps the R amplitude decrease sharply and the P wave amplitude is almost zero. These deviations from normal ECG signal can interpreted as junctional escape rhythm according to chapter II section 2.7.2. ARP attack cause delay on ECG monitoring subsequently the duration of R-R interval increase. All the ECG components were calculated and illustrated in figure 5.6 to 5.12. In figure 5.6 R-R intervals start to increase from 100 Mbps to 600 Mbps under ARP attack then in 700 and 800 Mbps drop suddenly but rise again. These changes can be interpreted as slow heart beat rate or bradycardia. Figure 5.7 shows S-T interval under ARP attack, which fluctuate by increasing the attack traffic load. In 700 Mbps it increased to 0.11 second which can be considered as the worst case for S-T segment. S-T segment deviation from the baseline can be interpreted as ischemia. P wave amplitude, which is illustrated in figure 5.10, fluctuated same as S-T segment and can be considered as ischemia heart problem too. P-Q interval and QRS complex are illustrated in figures 5.8 and 5.9, which have a constant pattern only in 100 Mbps in both there are deviation from baseline. Increasing the QRS complex is referred to any ventricular problem and P-Q interval decreasing is an atrial disorder. Figure 5.11 shows a regular pattern for T wave amplitude the only abnormality is detected in 1Gbps under ARP attack that can be interpreted as a ventricular repolarization problem.

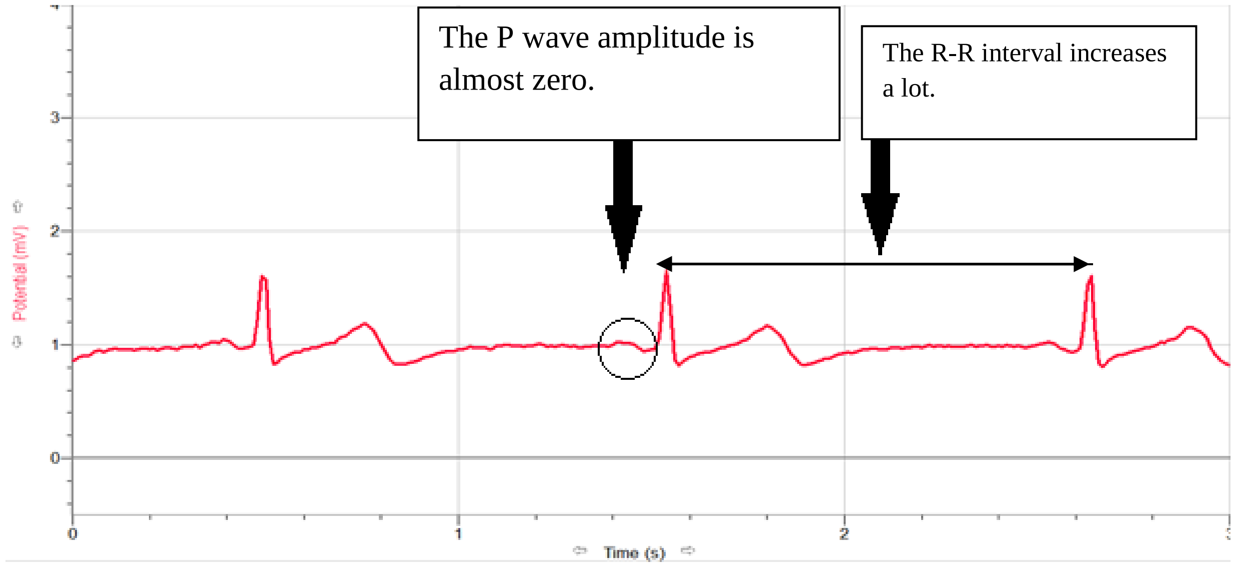


Figure 5.5 ECG signal under ARP attack at the speed of 700 Mbps in Windows 8

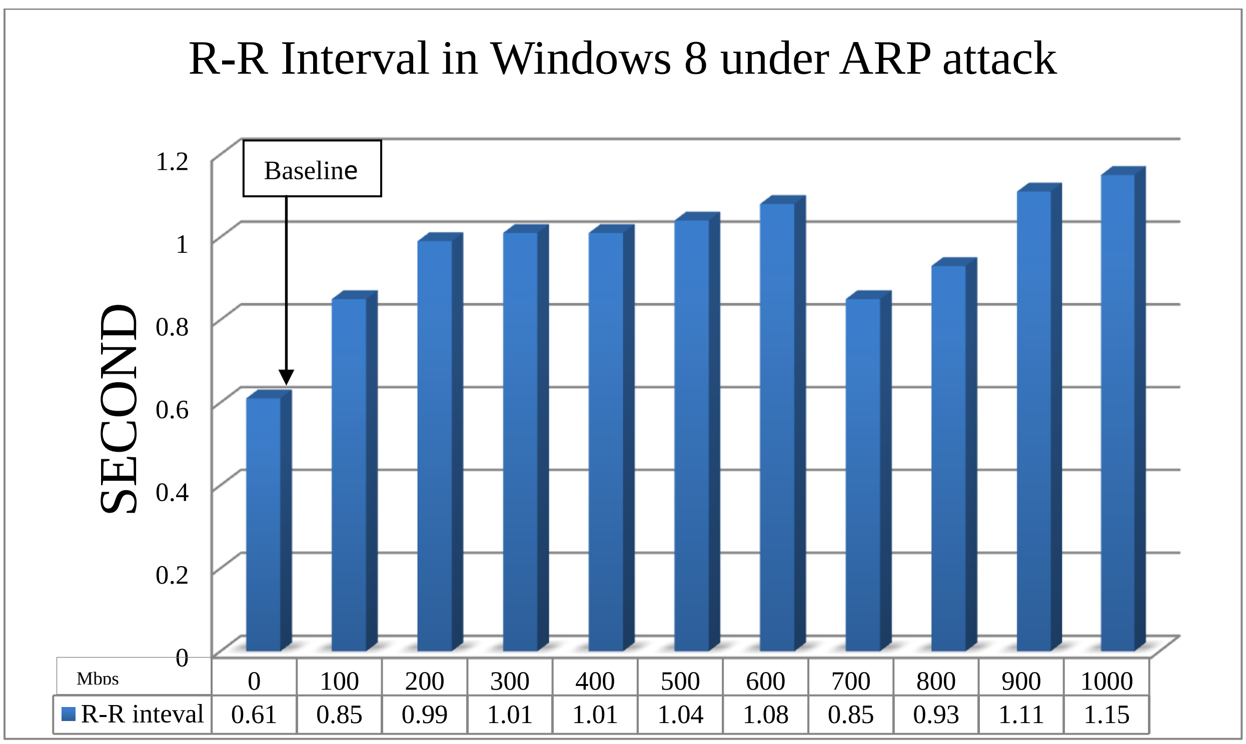


Figure 5.6 The values of R-R interval in Windows 8 under the ARP attack

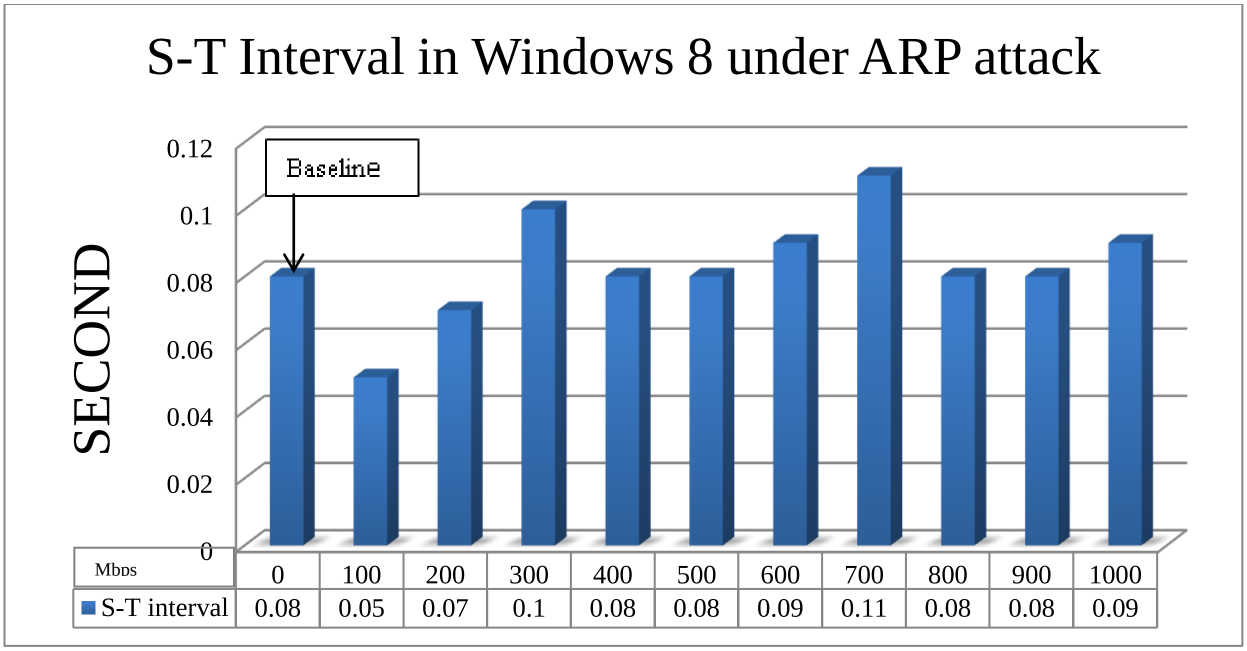


Figure 5.7 The values of S-T interval in Windows 8 under the ARP attack

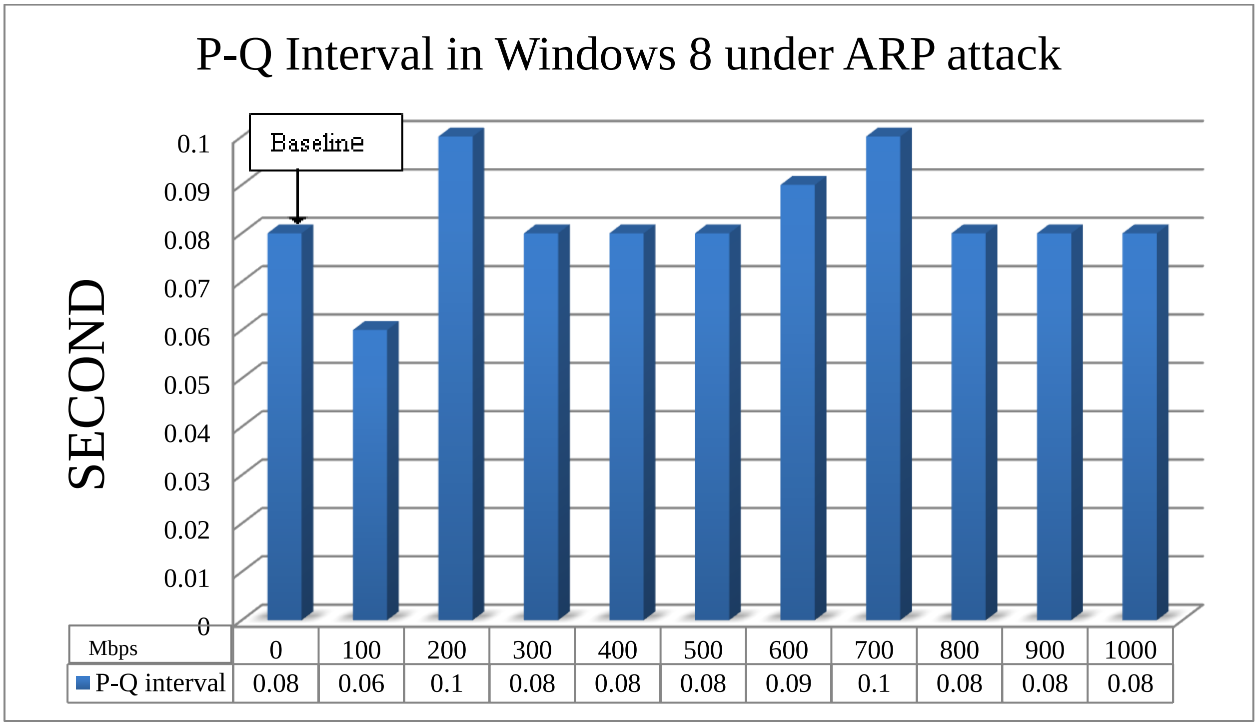
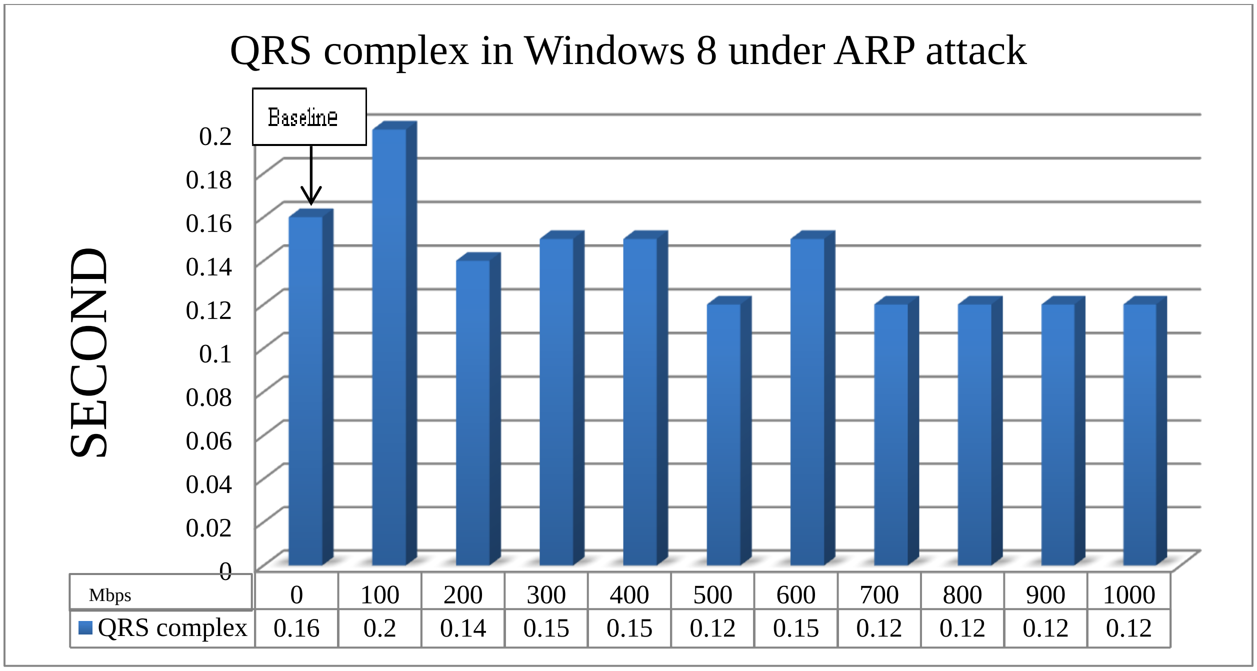
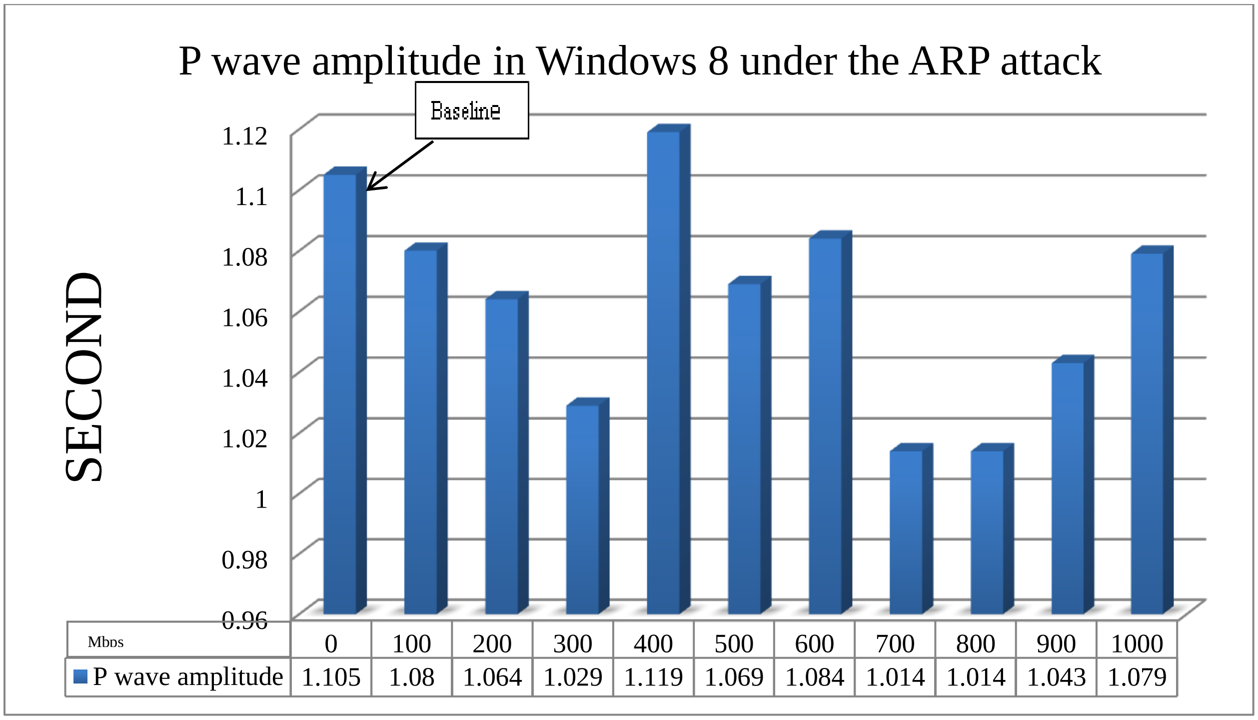


Figure 5.8 The values of P-Q interval in Windows 8 under the ARP attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
QRS complex	0.16	0.2	0.14	0.15	0.15	0.12	0.15	0.12	0.12	0.12	0.12

Figure 5.9 The values of QRS complex in Windows 8 under the ARP attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
P wave amplitude	1.105	1.08	1.064	1.029	1.119	1.069	1.084	1.014	1.014	1.043	1.079

Figure 5.10 The values of P wave amplitude in Windows 8 under the ARP attack

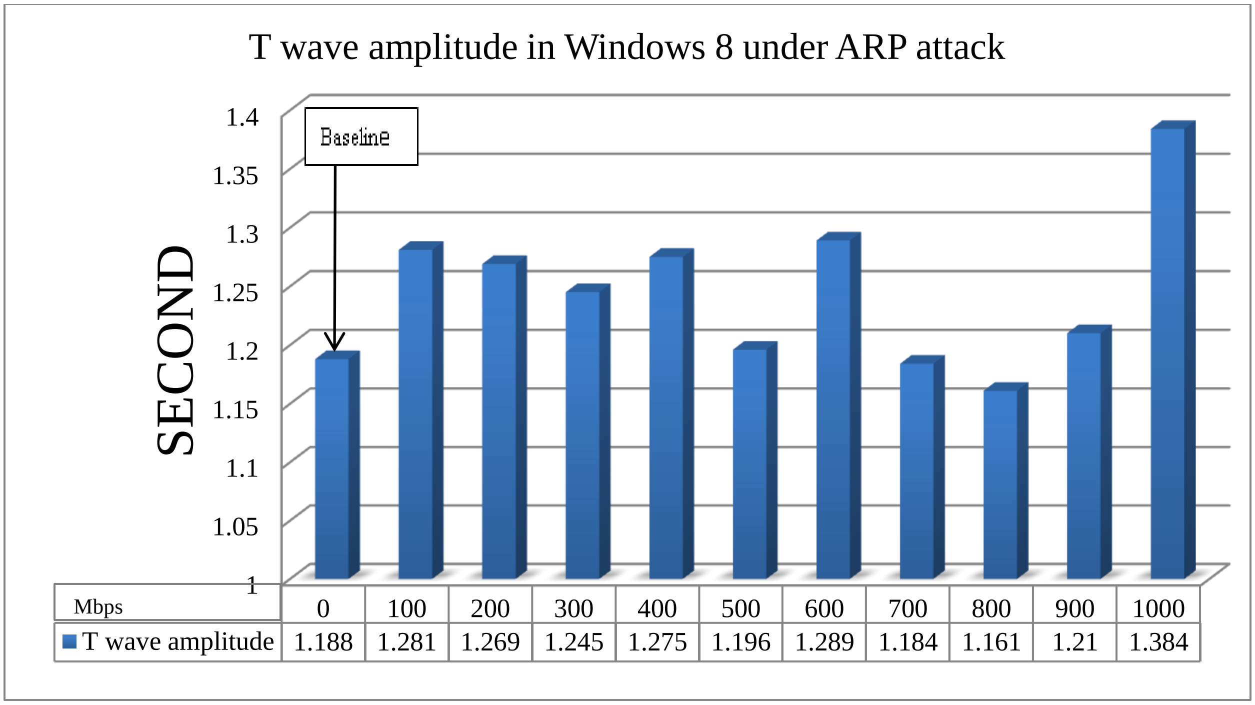


Figure 5.11 The values of T wave amplitude in Windows 8 under the ARP attack

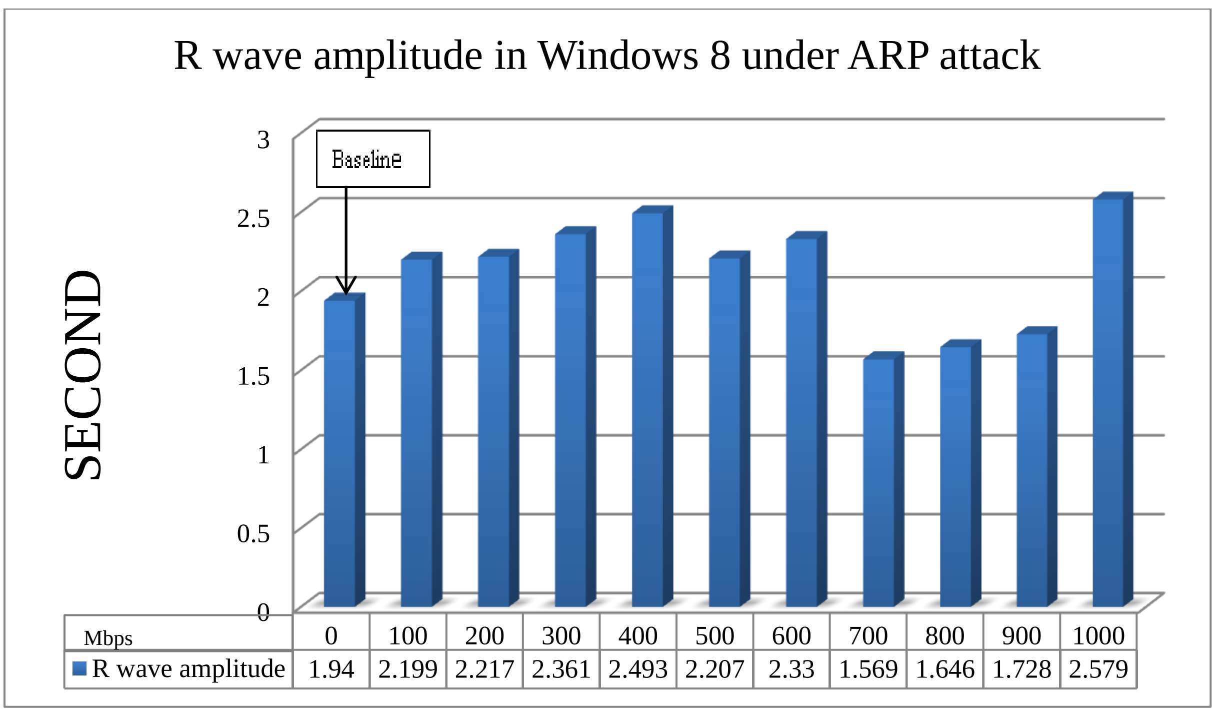


Figure 5.12 The values of R wave amplitude in Windows 8 under the ARP attack

5.4.1.2 ECG Data Collection Under TCP SYN Attack. TCP SYN attack effect on Windows 8 more than other attacks, during this attack on Mac platform in 800 Mbps to 1Gbps speed of the attack traffic all the computing resources were consumed so the Mac platform was unable to monitor ECG signal on those speed of the attack traffic. This attack caused delay, which generated long R-R intervals, also in 500 Mbps the amplitude of P wave changed to negative, which can interpret as premature junctional contraction with inverted P wave. As it is shown in figure 5.13 before QRS complex, there are several P wave and irregular rhythm, which can interpret as atrial fibrillation. As it is mentioned before during atrial fibrillation, atrial rhythm is irregular and the P wave becomes weird. All the ECG components were calculated and compared with baseline in figure 5.14 to figure 5.20 to find out which components of ECG under TCP SYN attack change more. Figure 5.15, which shows S-T interval, in 300 Mbps it increased 0.08 second to 0.1 second that is not considered as a serious heart problem. Figure 5.16, which shows P-Q interval, increase in 200 Mbps from 0.08 second to 0.11 second that is not considered as a heart problem. As it is shown in, figure 5.18 the P wave amplitude change to negative value in 100 and 500 Mbps that can be interpreted as PJC. Figure 5.17 shows a sharp decreasing in QRS complex, which means ventricular contraction problem. Figure 5.19 and 5.20 are illustrated T wave and R wave amplitudes that are almost constant and can be considered as normal heart function.

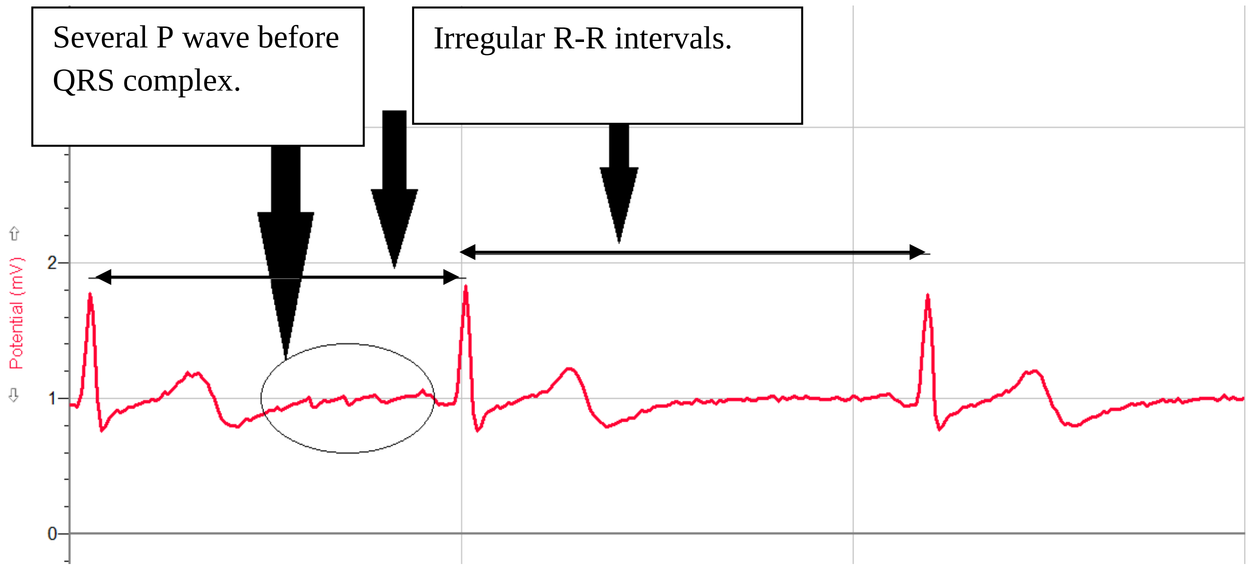
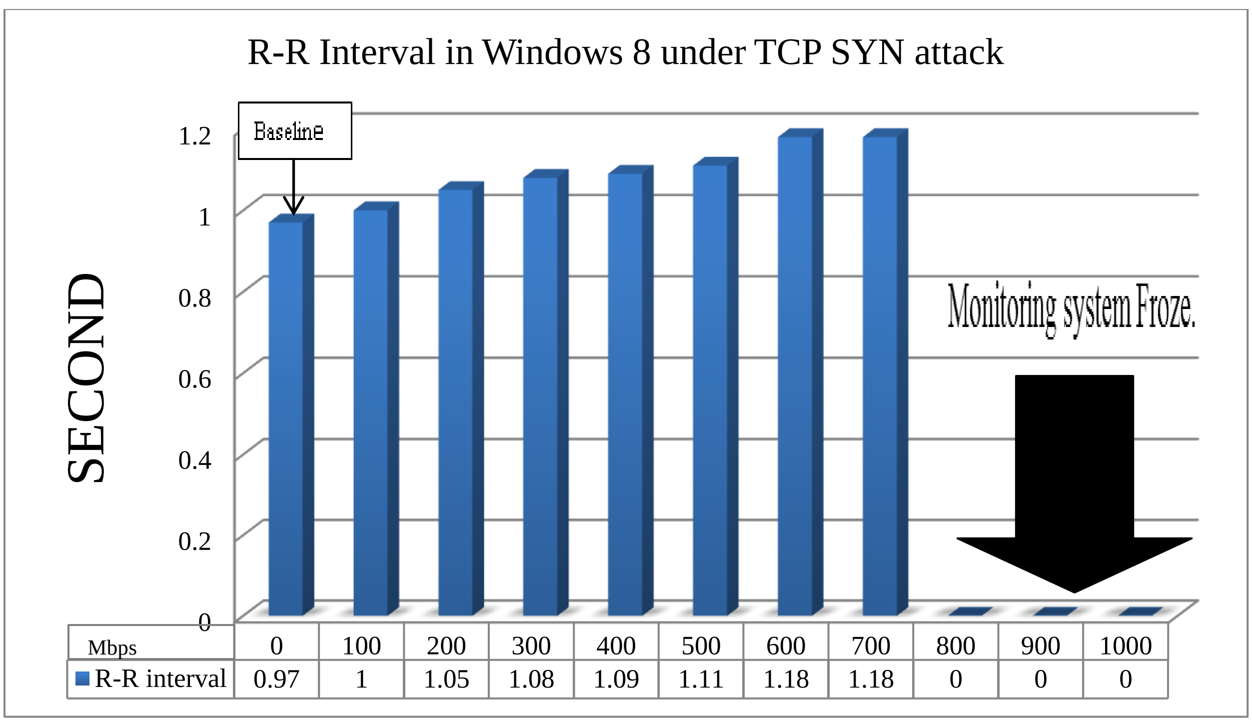


Figure 5.13 ECG signal under TCP SYN attack at the speed of 700 Mbps in Windows 8



Mbps	0	100	200	300	400	500	600	700	800	900	1000
R-R interval	0.97	1	1.05	1.08	1.09	1.11	1.18	1.18	0	0	0

Figure 5.14 The values of R-R interval in Windows 8 under the TCP SYN attack

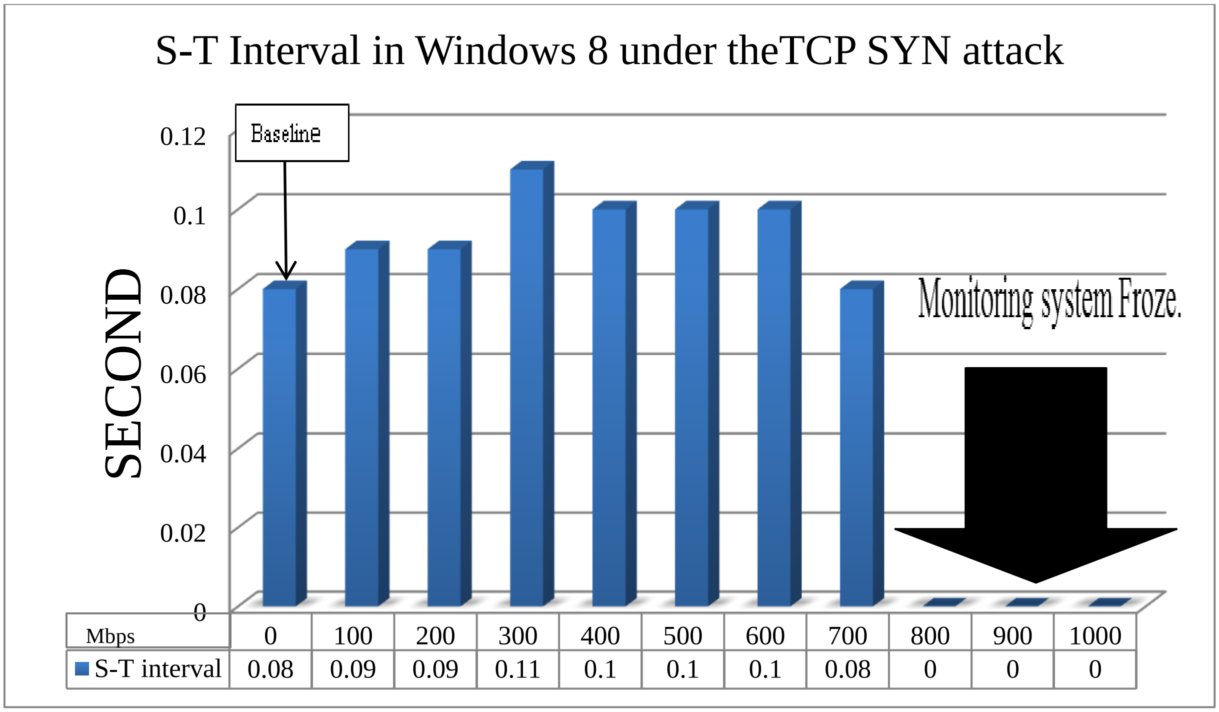


Figure 5.15 The values of S-T interval in Windows 8 under the TCP SYN attack

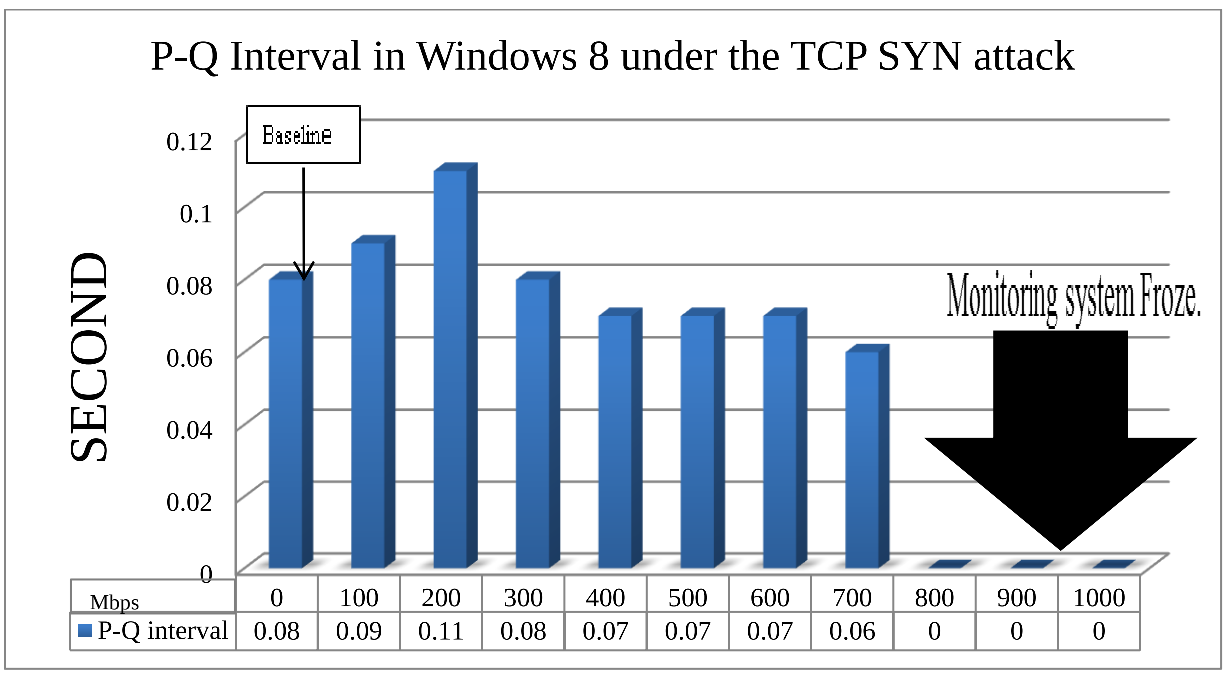
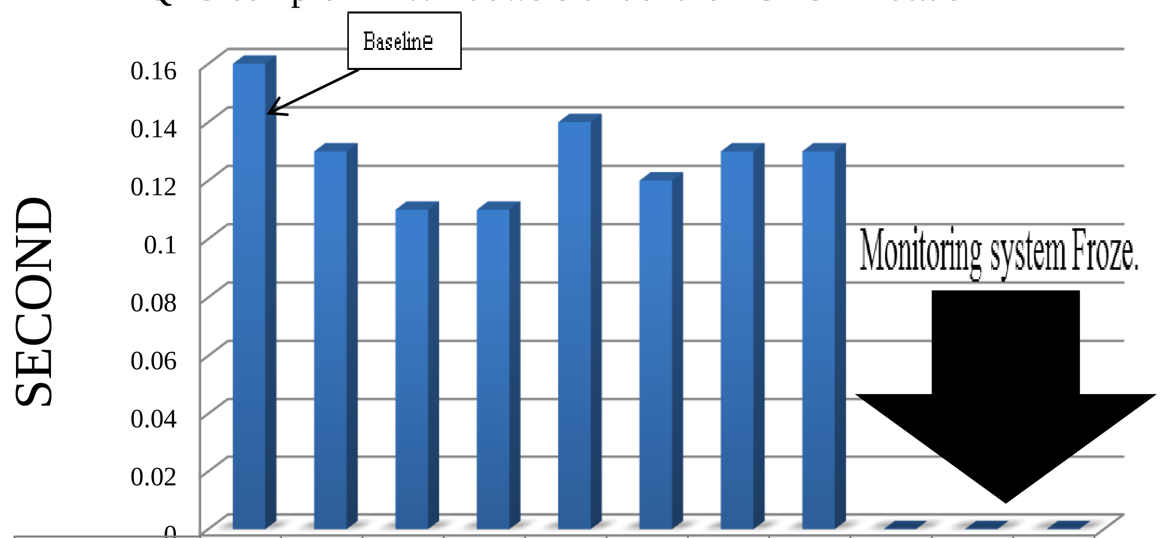


Figure 5.16 The values of P-Q interval in Windows 8 under the TCP SYN attack

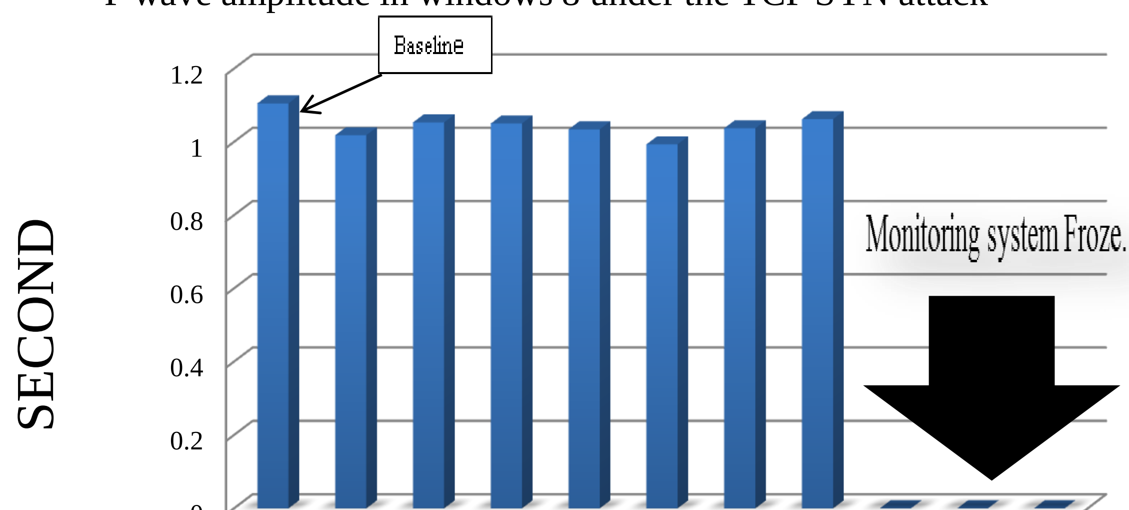
QRS complex in Windows 8 under the TCP SYN attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
QRS complex	0.16	0.13	0.11	0.11	0.14	0.12	0.13	0.13	0	0	0

Figure 5.17 The values of QRS complex in Windows 8 under the TCP SYN attack

P wave amplitude in windows 8 under the TCP SYN attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
P wave amplitude	1.105	1.018	1.053	1.05	1.034	0.993	1.037	1.062	0	0	0

Figure 5.18 The values of P wave amplitude in Windows 8 under the TCP SYN attack

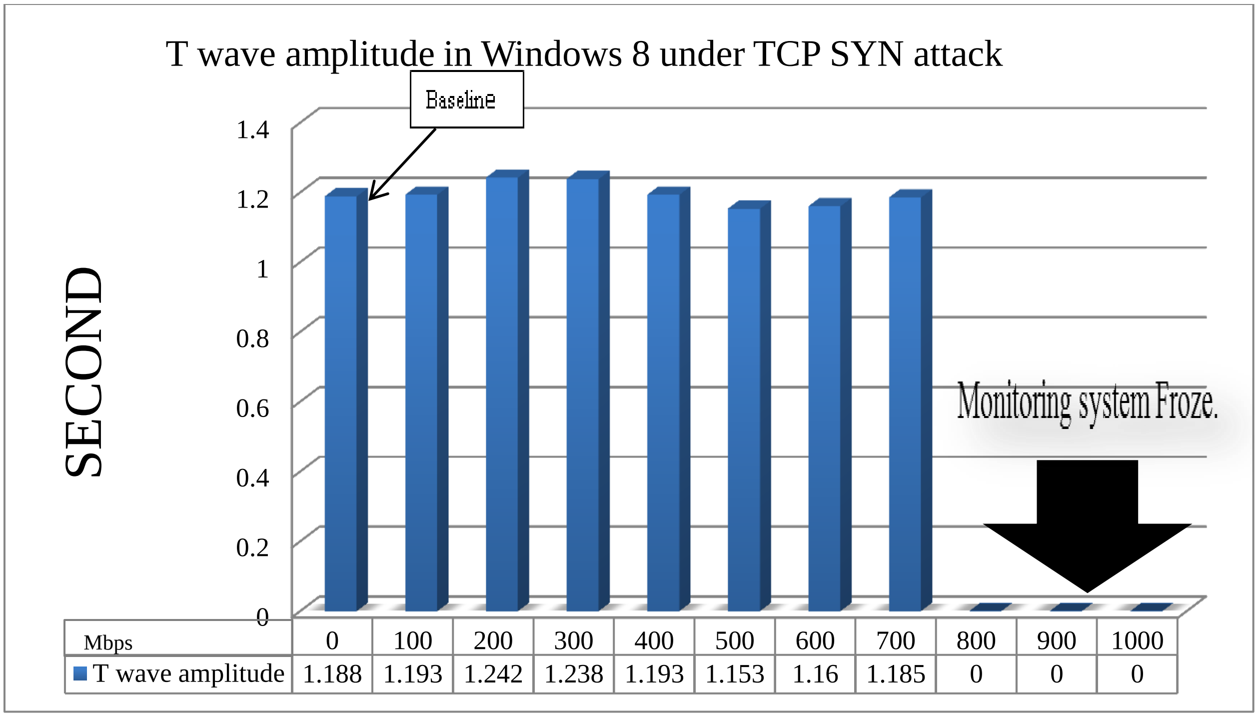


Figure 5.19 The values of the T wave amplitude in Windows 8 under the TCP SYN attack

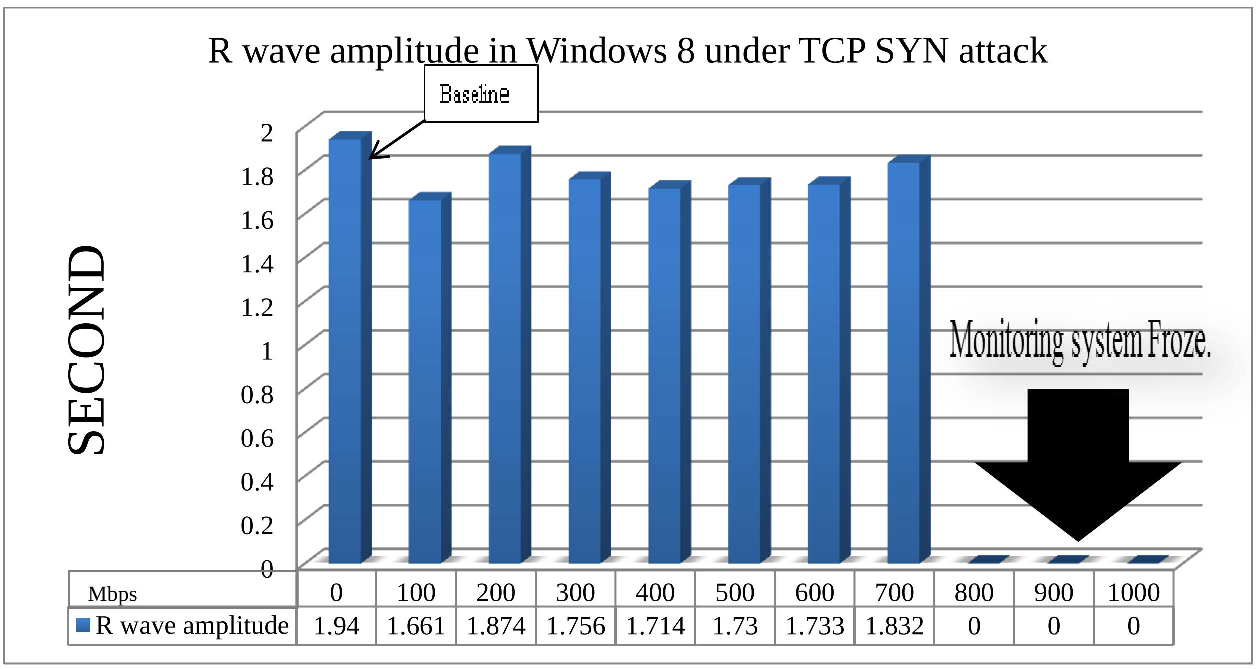


Figure 5.20 The values of the R wave amplitude in Windows 8 under the TCP SYN attack

5.4.1.3 ECG Data Collection Under Ping Attack. In the Ping attack, the two most obvious changes in the captured ECG were irregular R-R intervals and the lack of P wave. Therefore, the ECG signal under Ping attack can be interpreted as bradycardia, which shows slow heart beat rate. Figure 5.22 to Figure 5.27 show all the ECG components compare to the baseline. From figure 5.23, it is observed that S-T interval increases sharply and can be considered as ischemia. Figure 5.24 shows a sharp decrease in P-Q interval under Ping attack of 100 Mbps, which can send false alarm for atrial heart problem. QRS complex values, which are illustrated in figure 5.25, does not deviate from baseline to much so it does not show any heart problem. R wave amplitude does not change a lot so it cannot be interpreted as any heart problem. T wave fluctuated from baseline, which refers to ventricular abnormality.

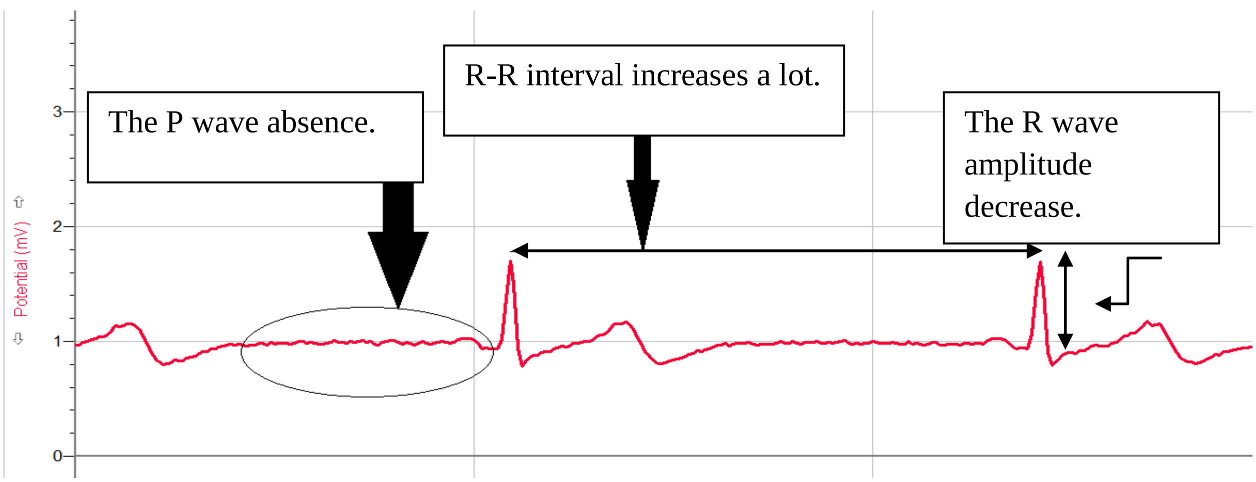


Figure 5.21 ECG signal under Ping attack at the speed of 1Gbps in Widows 8

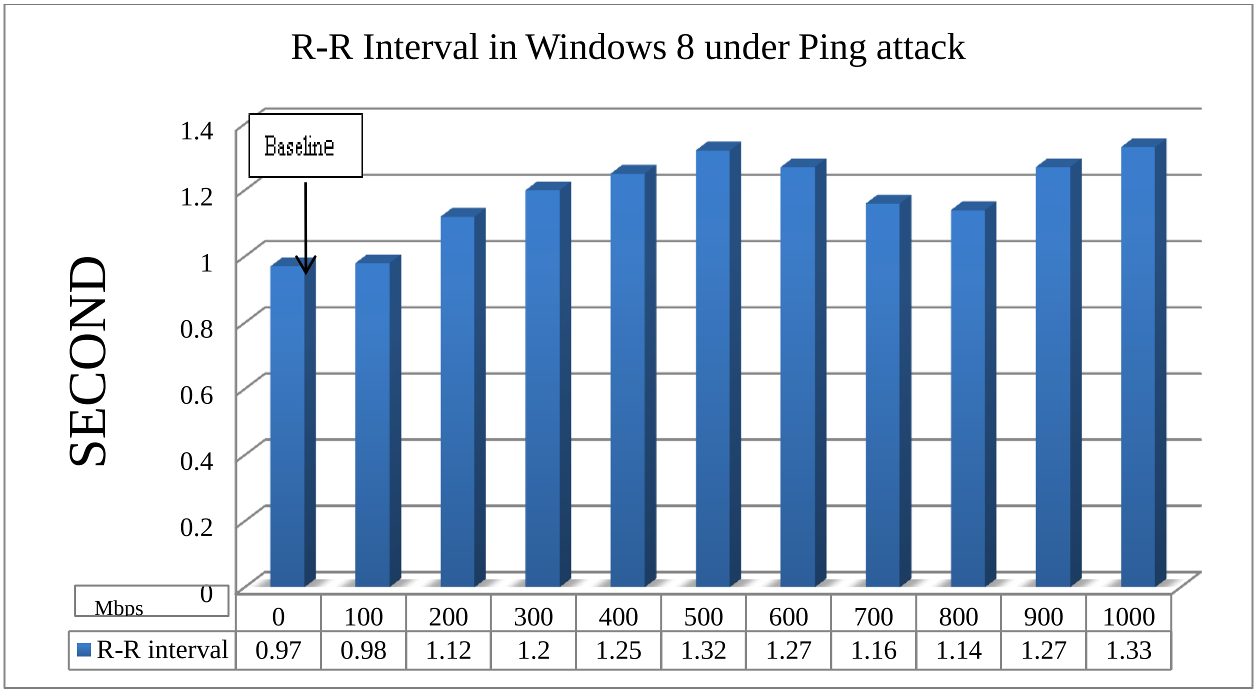


Figure 5.22 The values of the R-R interval in Windows 8 under Ping attack

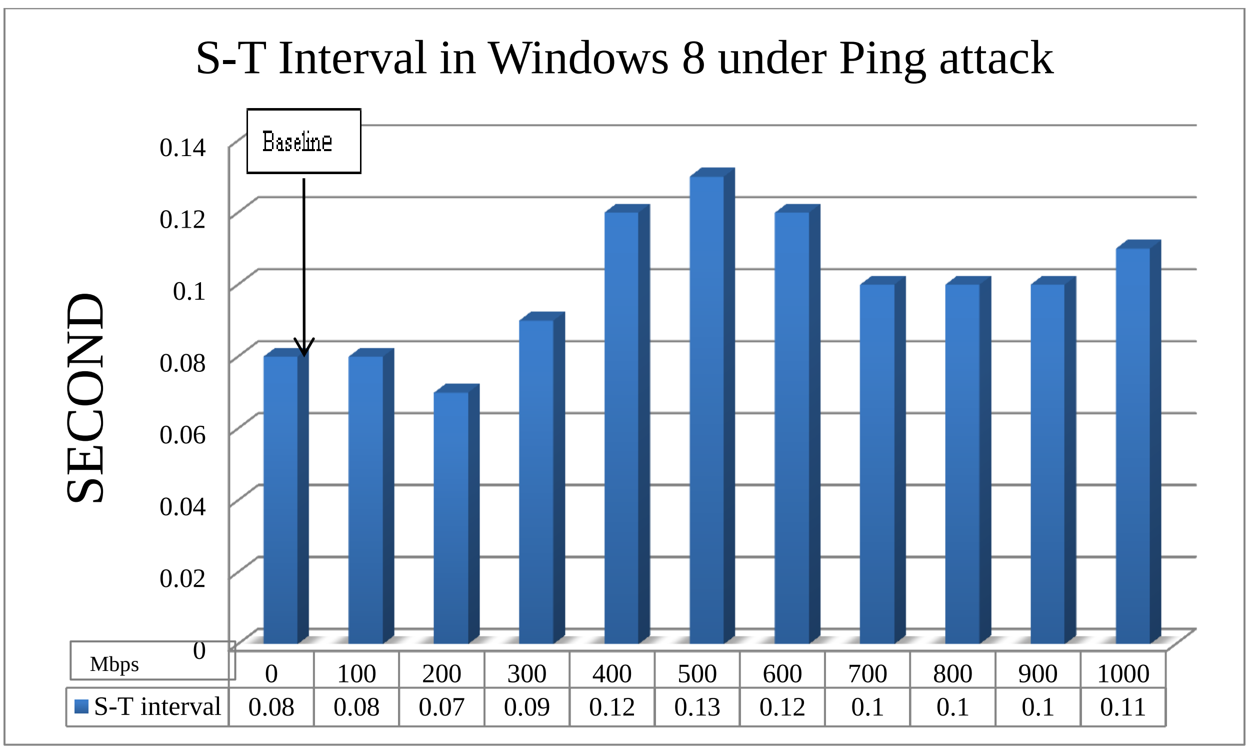


Figure 5.23 The values of S-T interval in Windows 8 under Ping attack

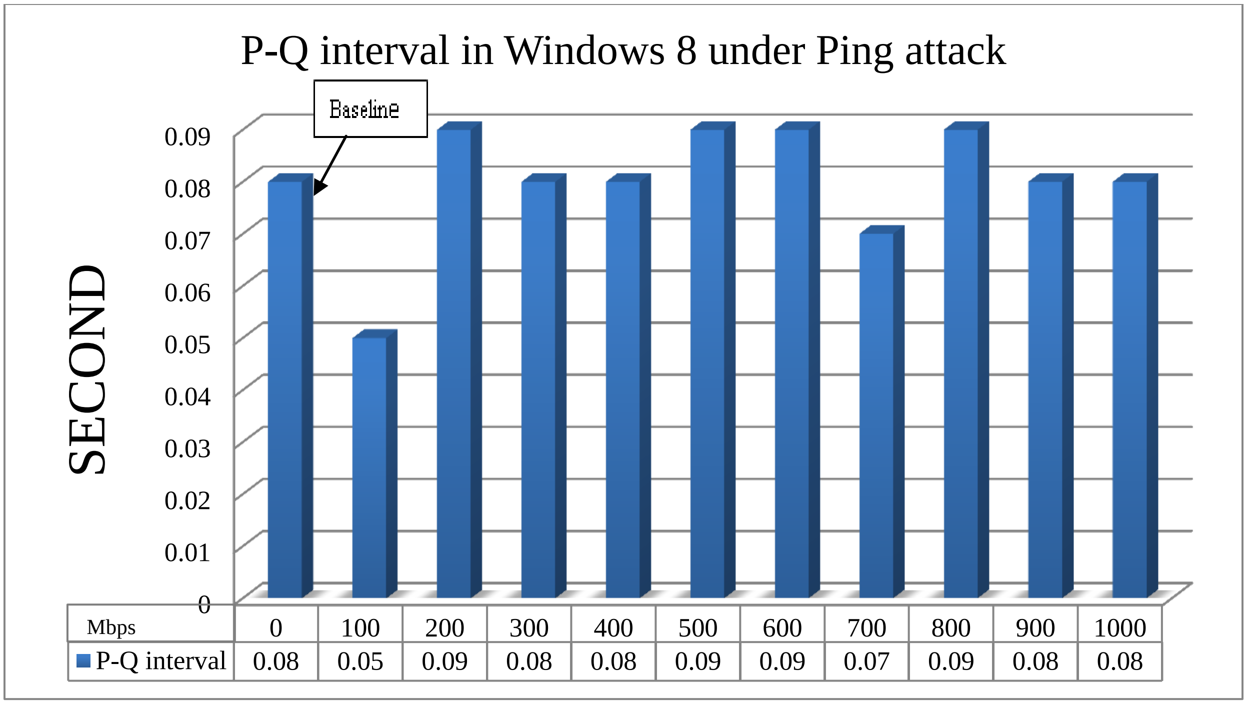


Figure 5.24 The values of P-Q interval in Windows 8 under Ping attack

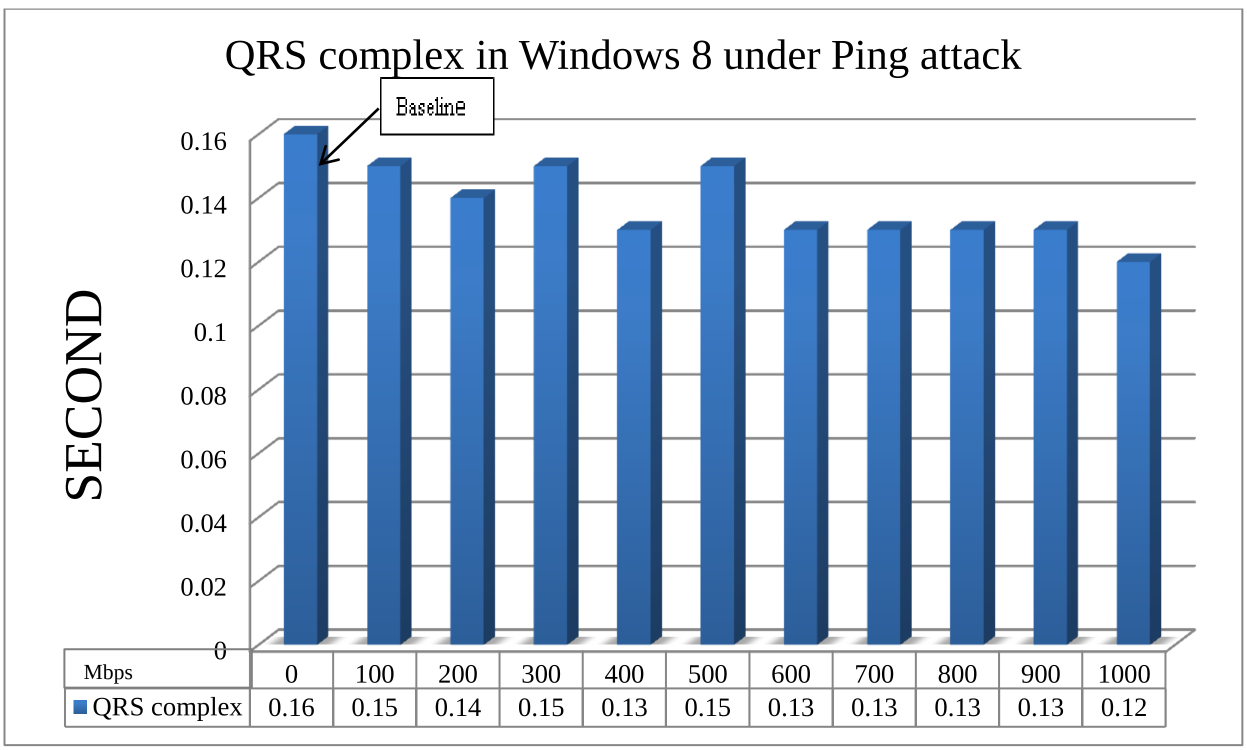


Figure 5.25 The values of QRS complex in Windows 8 under Ping attack

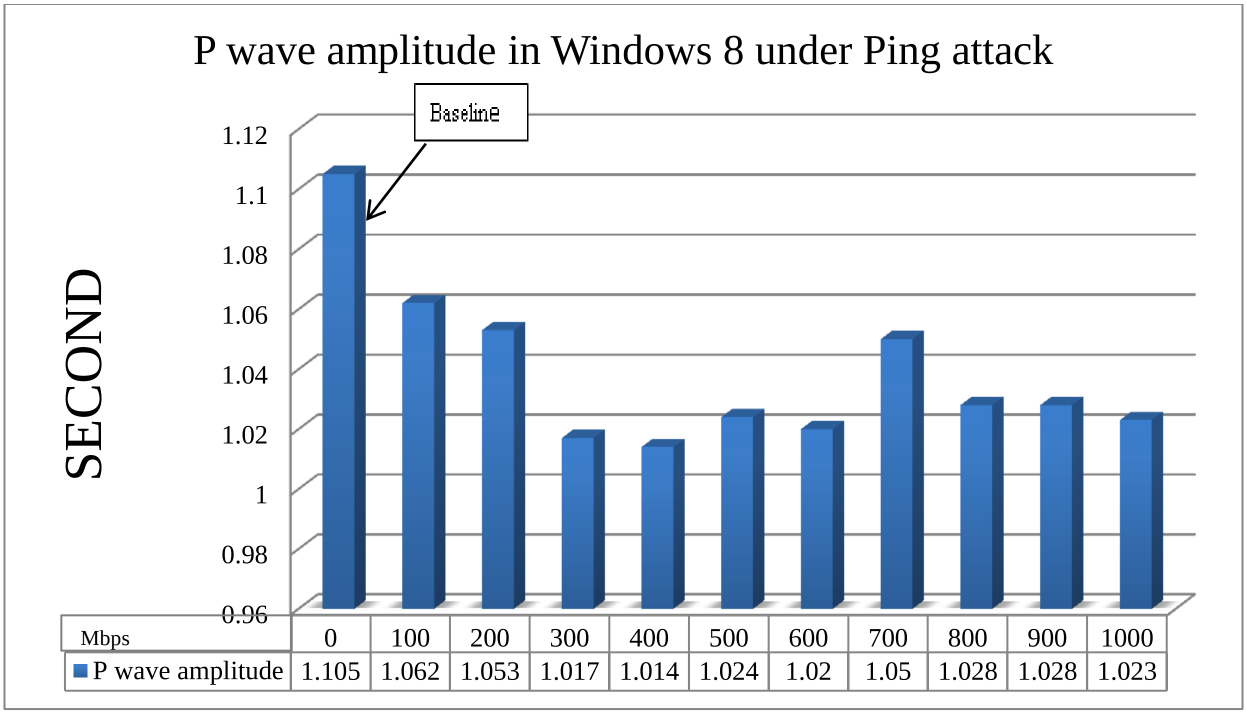


Figure 5.26 The values of P wave amplitude in Windows 8 under Ping attack

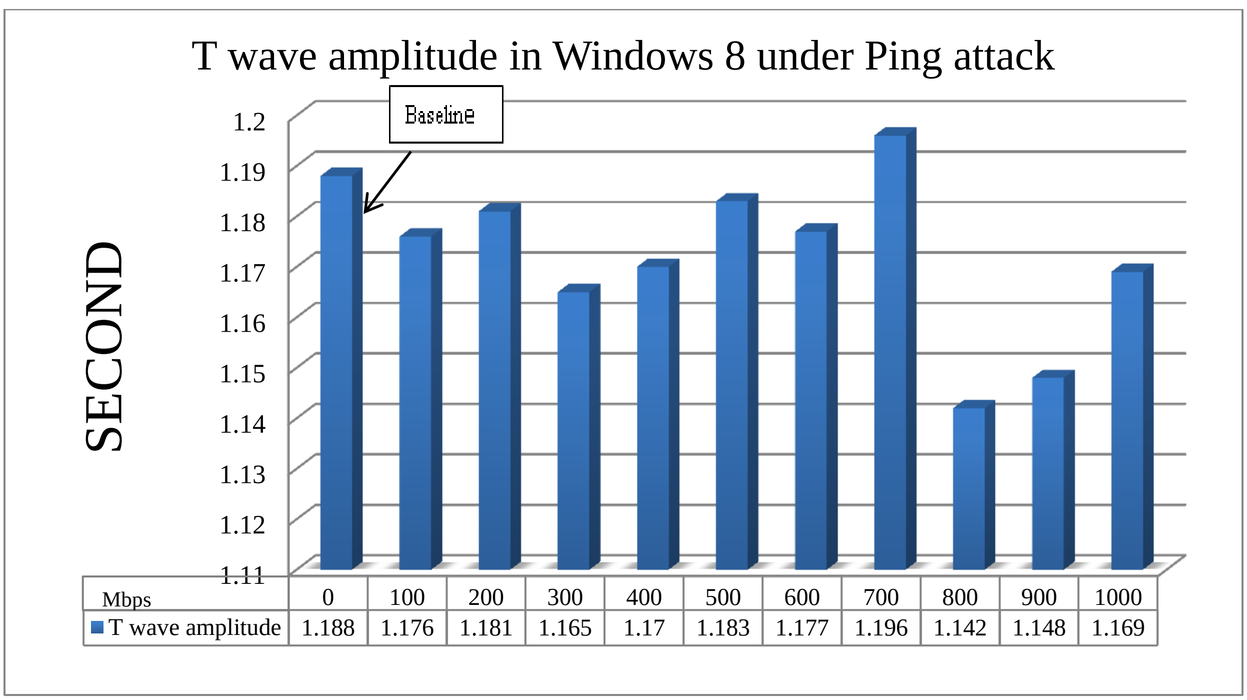


Figure 5.27 The values of T wave amplitude in Windows 8 under Ping attack

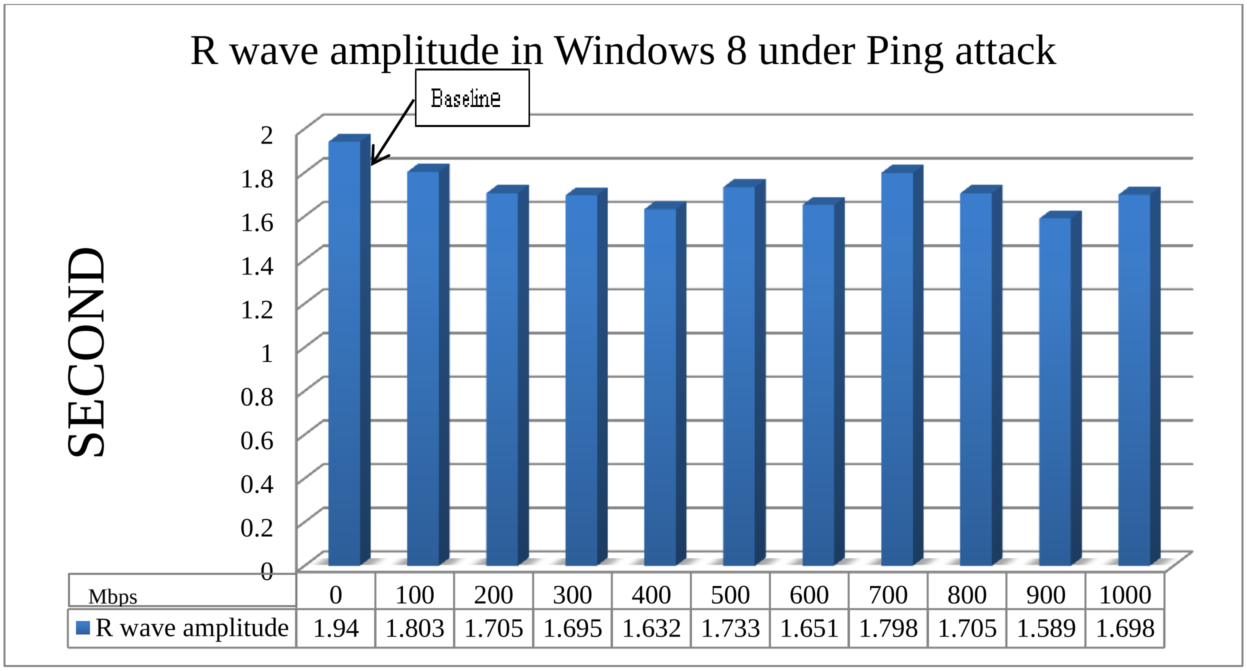


Figure 5.28 The values of R wave amplitude in Windows 8 under Ping attack

5.4.2 OS X Lion Results. In this section first baseline ECG signal in OS X Lion operating system is illustrated in figure 5.29 and all the components of baseline is shown in table 5.2. Then captured ECG signal is shown under different network attack.

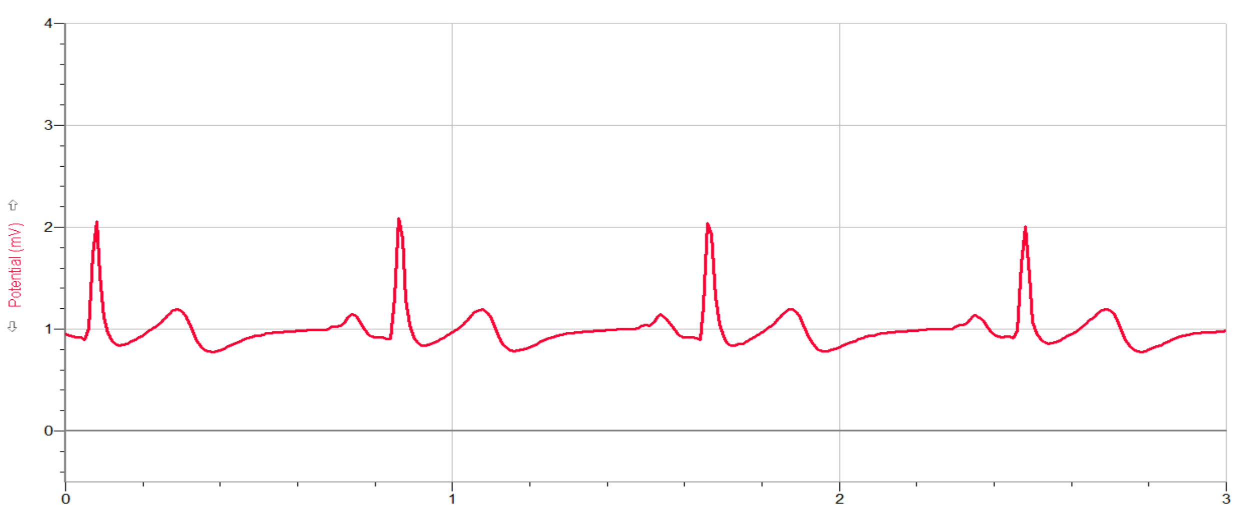


Figure 5.29 Baseline ECG collected by OS X Lion operating system under normal condition

Table 5.2 Feature values of ECG signal in OS X Lion in the normal condition

Feature	Value
R – R interval	0.80 s
S – T interval	0.05 s
P – Q interval	0.09 s
P wave amplitude	1.118 mV
T wave amplitude	1.160 mV
R wave amplitude	1.813 mV
QRS complex	0.15 s

5.4.2.1 ECG Data Collection Under ARP Attack. Figure 5.29 shows ECG signal in OS X Lion operating system in normal condition at rest. The R wave amplitude became irregular under ARP attack also the amplitude of P wave, T wave and QRS complex increased from normal condition as it is shown in figure 5.30 that was considered as the worst case. ECG under this attack can interpret as premature atrial contractions or just an abnormality of heart function with the atrial problem. In the figure 5.31 to figure 5.37 all, the ECG components were calculated and compared to the baseline in OS X Lion under ARP attack. In figure 5.31 the R-R interval increased by increasing the load of ARP attack, which simply can be considered as bradycardia with the slow heart beat rate. Figure 5.32 is shown fluctuating S-T interval which is interpreted as ischemia. Figure 5.33 shows that ECG signal under 700 Mbps has deviated from baseline that means there should be a problem in atrial contraction. As it is observed in figures 5.35 to 5.37 ECG under 400 Mbps changed most from baseline for P wave, T wave, and R wave.

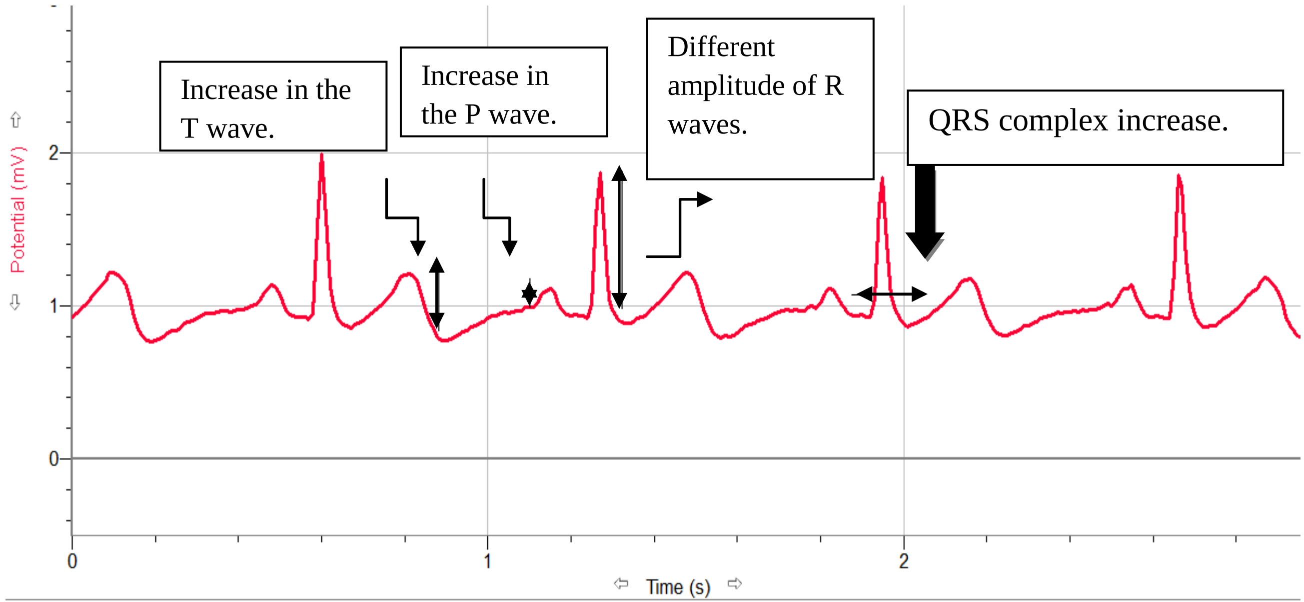


Figure 5.30 ECG signal under ARP attack at the speed of 1Gbps in OS X Lion operating system

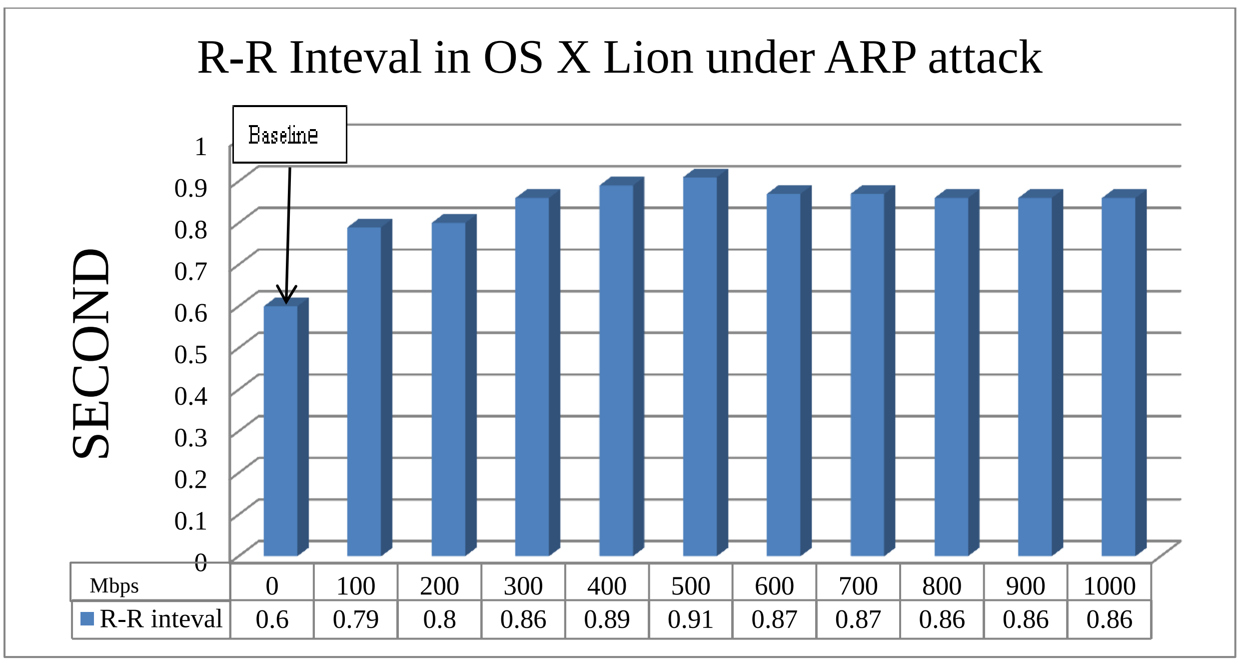


Figure 5.31 The values of R-R interval in OS X Lion under ARP attack

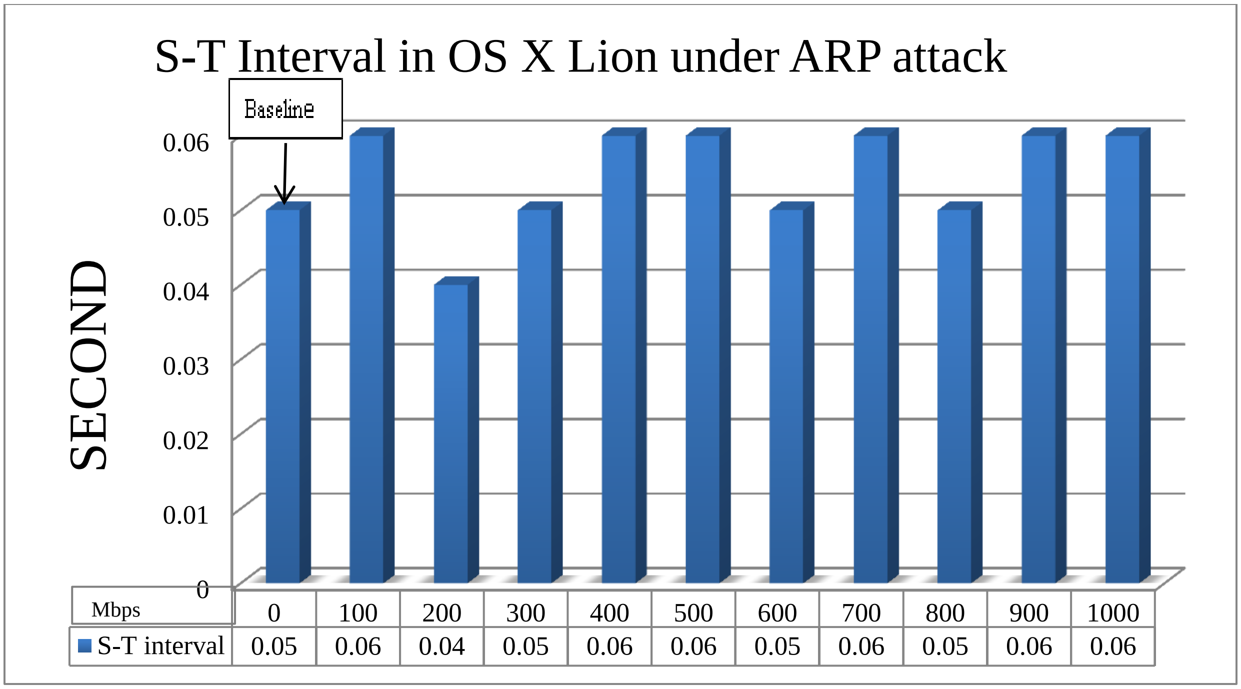


Figure 5.32 The values of S-T interval in OS X Lion under ARP attack

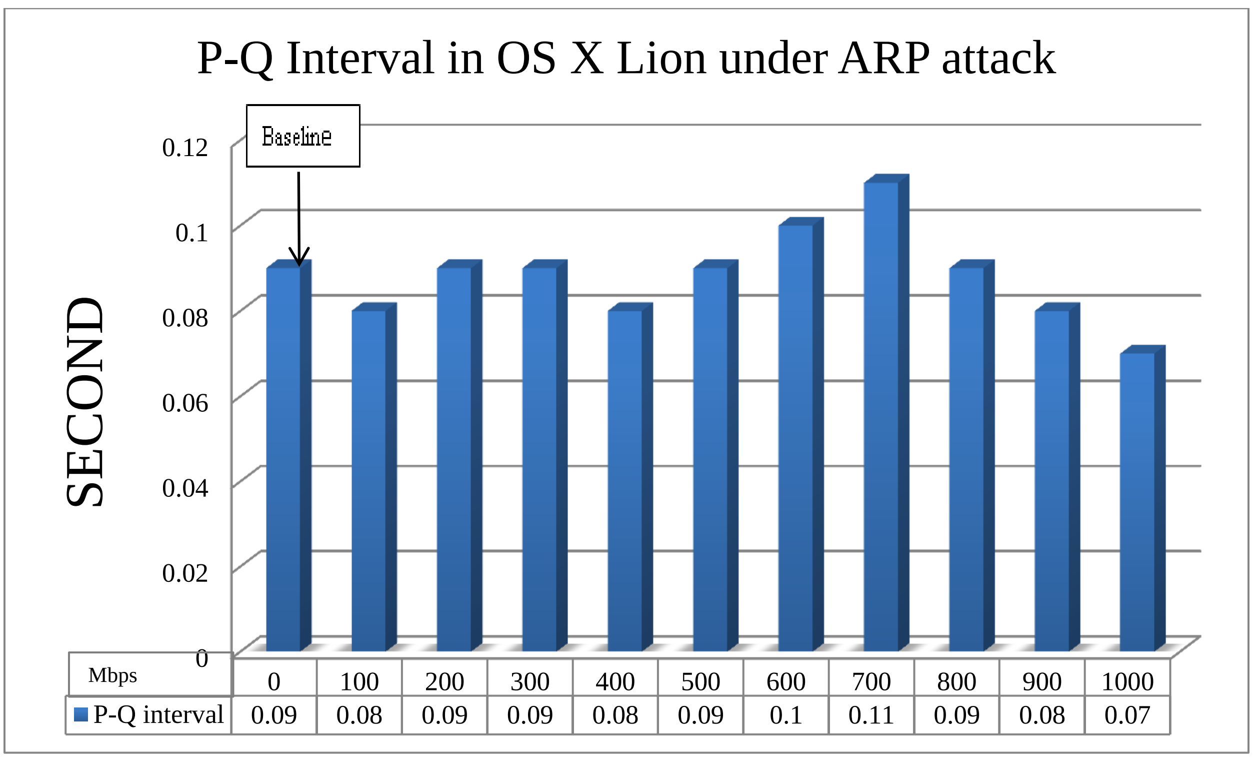


Figure 5.33 The values of P-Q interval in OS X Lion under ARP attack

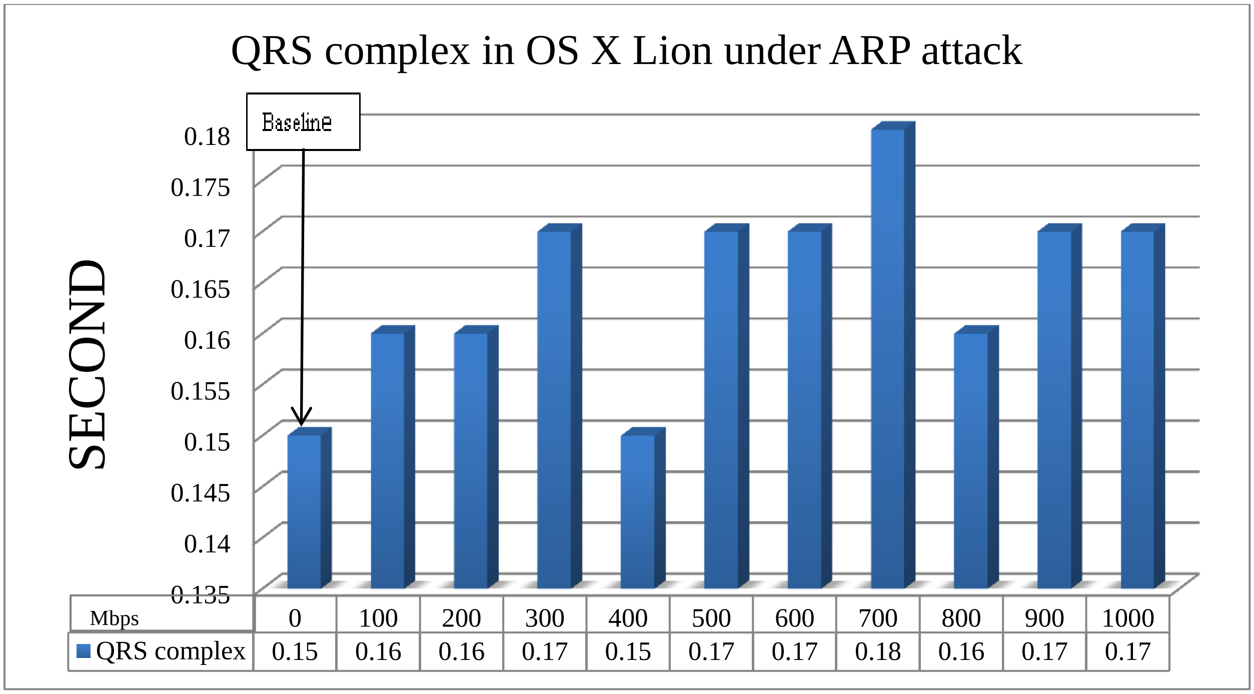


Figure 5.34 The values of QRS complex in OS X under ARP attack

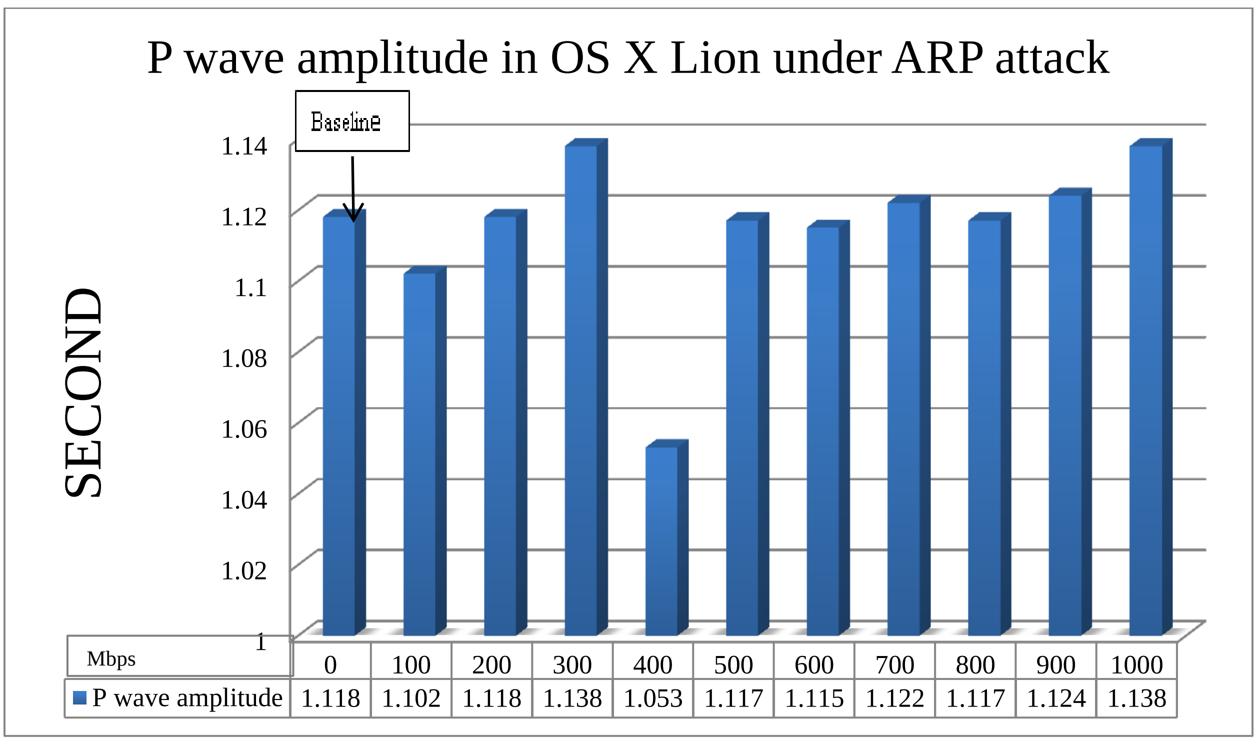
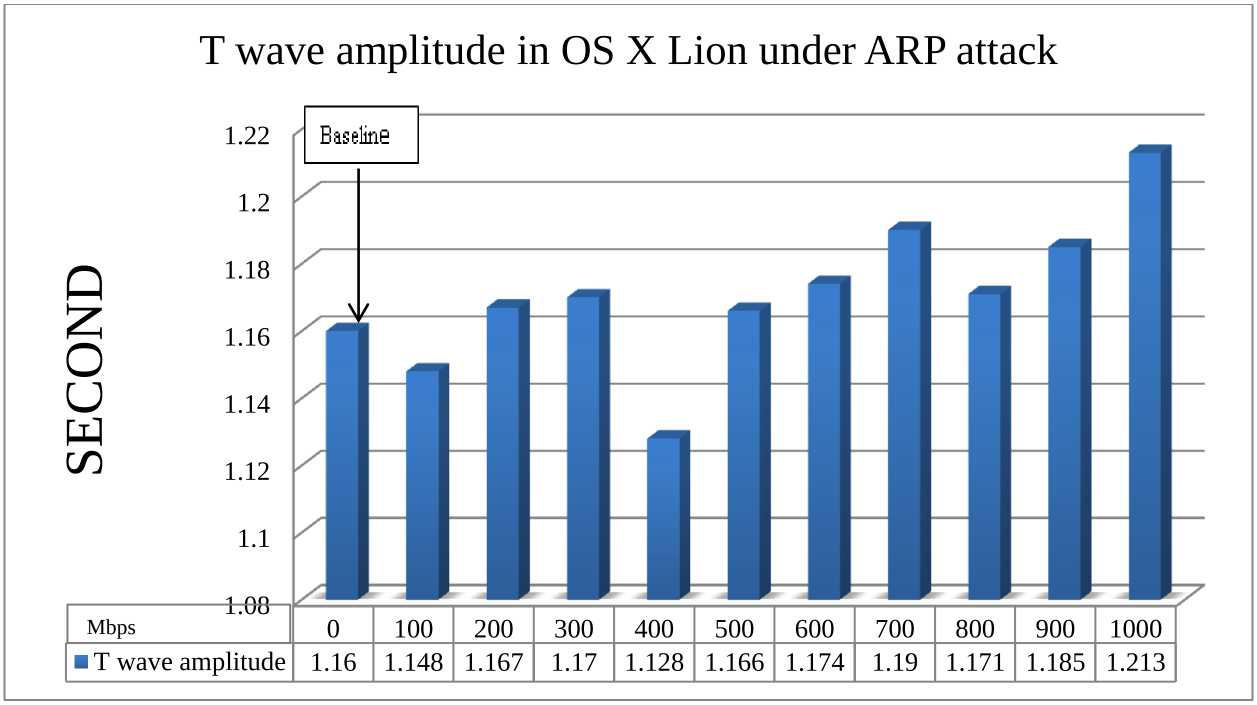
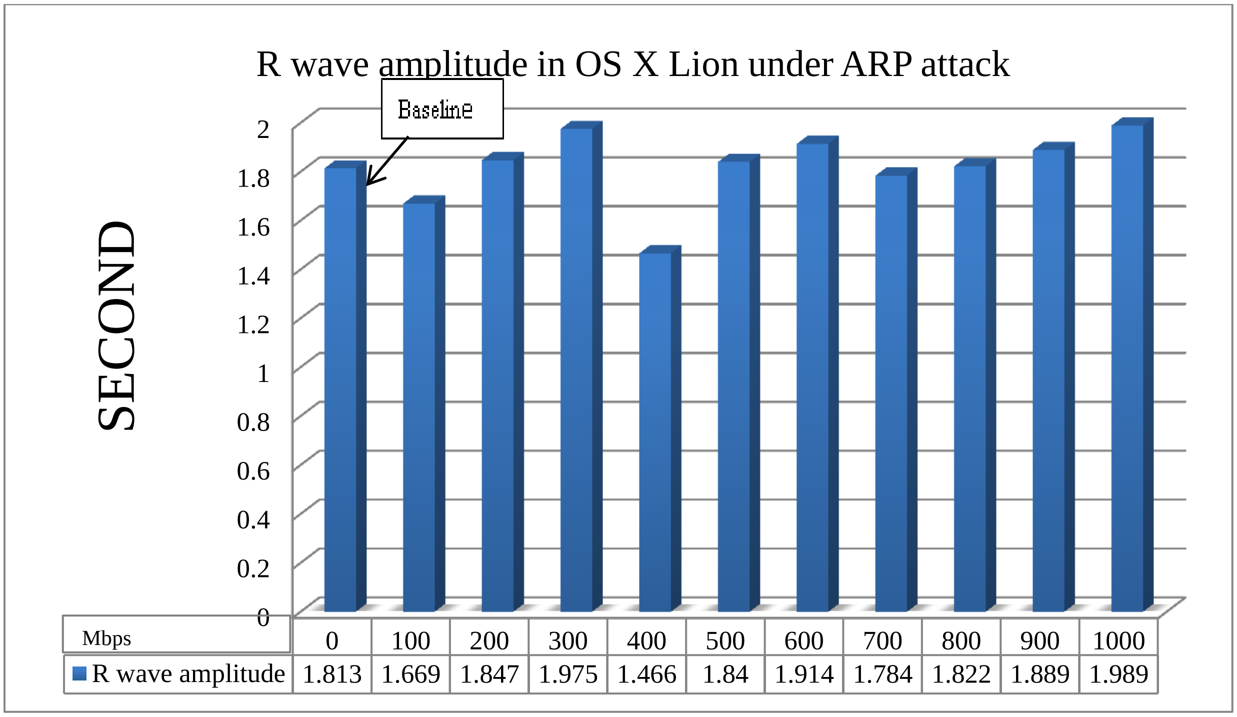


Figure 5.35 The values of P wave amplitude in OS X Lion under ARP attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
T wave amplitude	1.16	1.148	1.167	1.17	1.128	1.166	1.174	1.19	1.171	1.185	1.213

Figure 5.36 The values of T wave amplitude in OS X Lion under ARP attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
R wave amplitude	1.813	1.669	1.847	1.975	1.466	1.84	1.914	1.784	1.822	1.889	1.989

Figure 5.37 The values of R wave amplitude in OS X Lion under ARP attack

5.4.2.2 ECG Data Collection Under TCP SYN Attack. ECG signal under TCP SYN attack in OS X Lion operating system from 100 Mbps to 1Gbps speed of attack dedicated fluctuating S-T interval and the P wave amplitude which can interpret as a dangerous heart problem that is known as ischemia. During this heart abnormality the amount of oxygen, which is required for brain considerably, reduce and in the worst case, it can cause death. This heart problem is also called silent death. Figure 5.39 to figure 5.45 show the value of each component and then compare them to the baseline. Although R-R interval increased from 0.78 second to 0.91 second under 100 Mbps to 400 Mbps, it reached steady state after 400 Mbps, so in the worst case it can be considered as heart beat function when it slows down. Except QRS complex, which is illustrated in figure 5.42 that can be considered as normal condition, all other components fluctuated under each attack load. As it is mentioned above, it can be considered as ischemia.

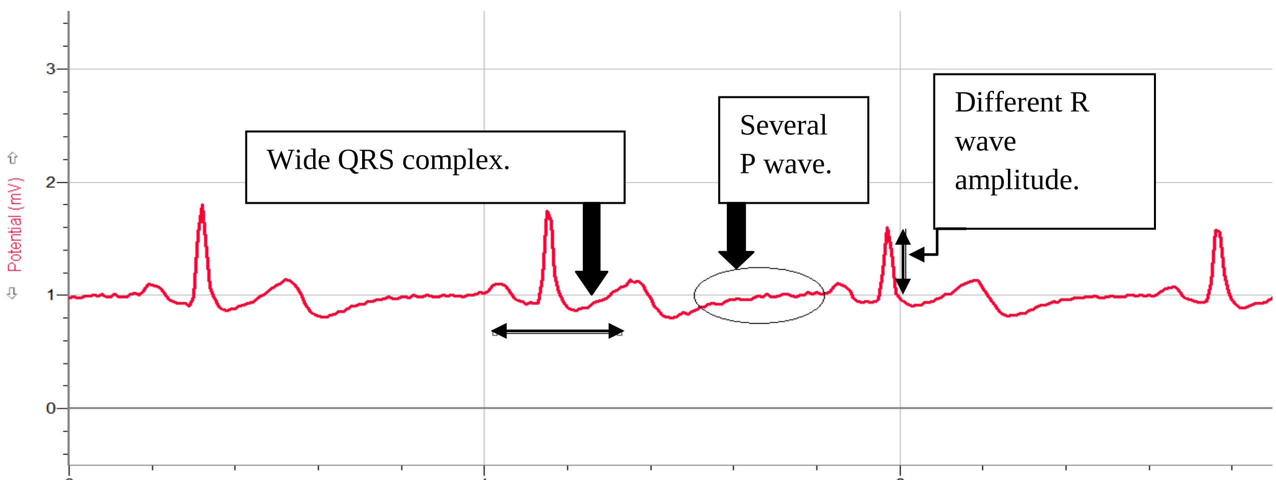


Figure 5.38 ECG signal under TCP SYN attack at the speed of 1Gbps in OS X Lion operating system

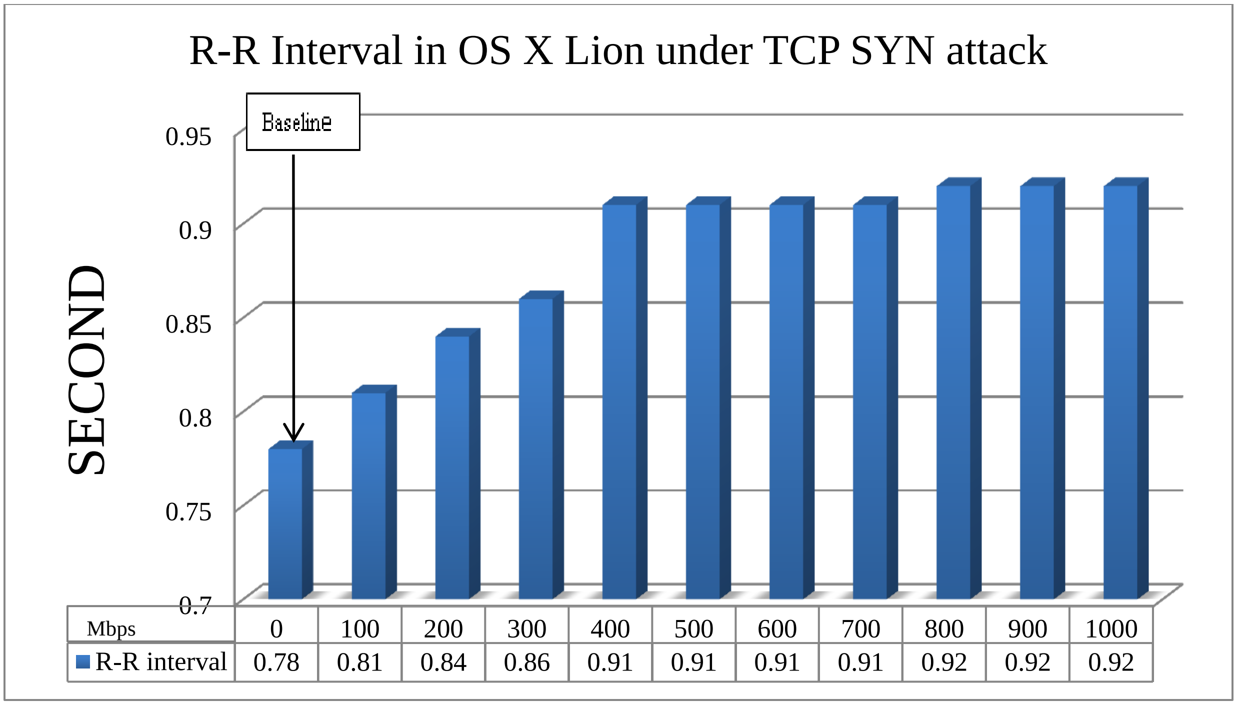


Figure 5.39 The values of R-R interval in OS X Lion under TCP SYN attack

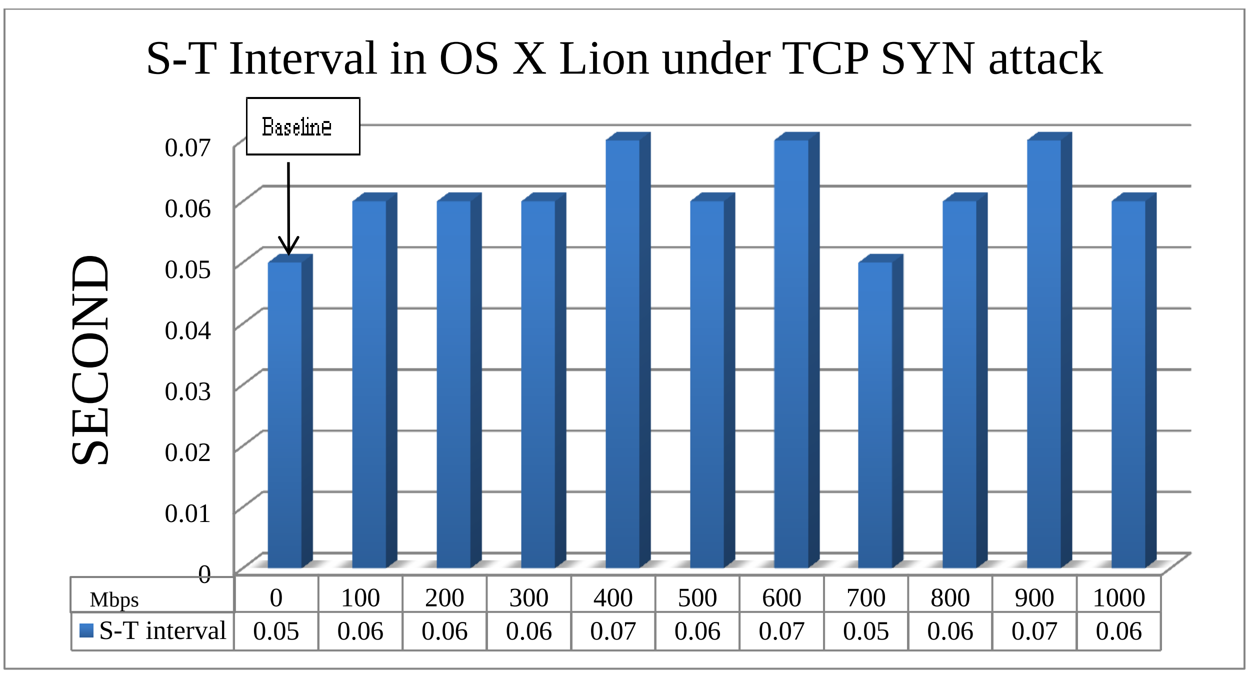


Figure 5.40 The values of S-T interval in OS X Lion under TCP SYN attack

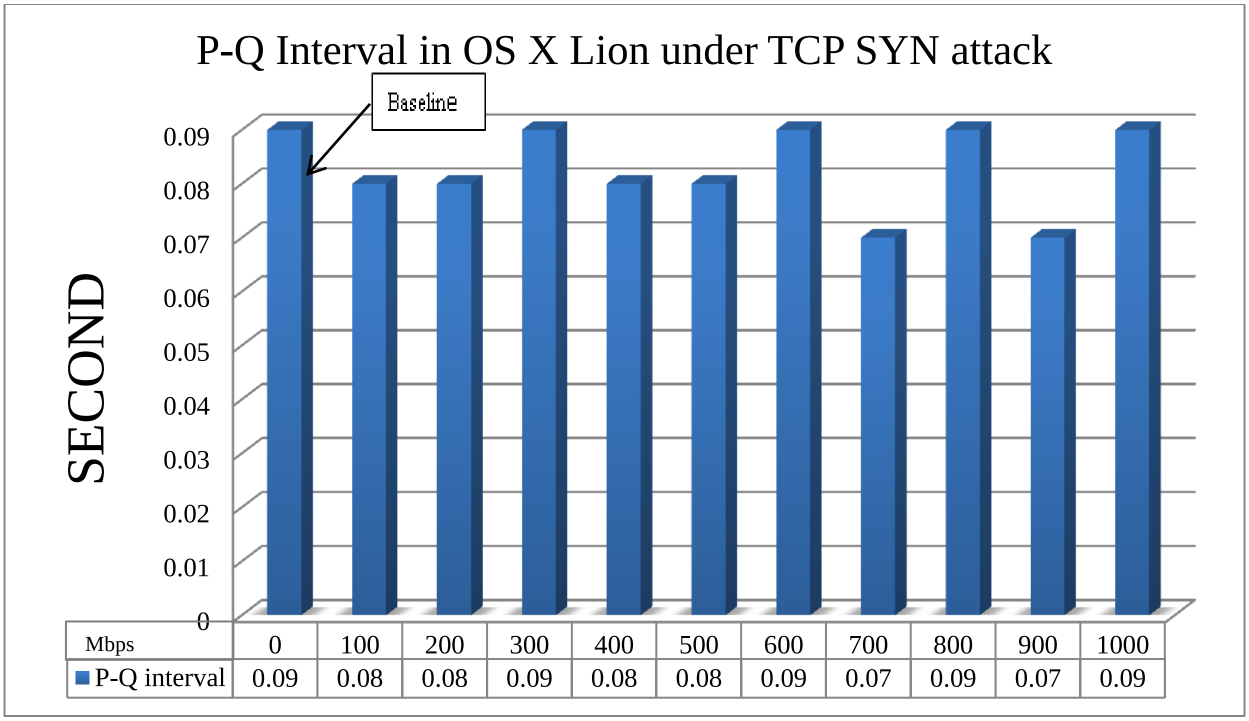


Figure 5.41 The values of P-Q interval in OS X Lion under TCP SYN attack

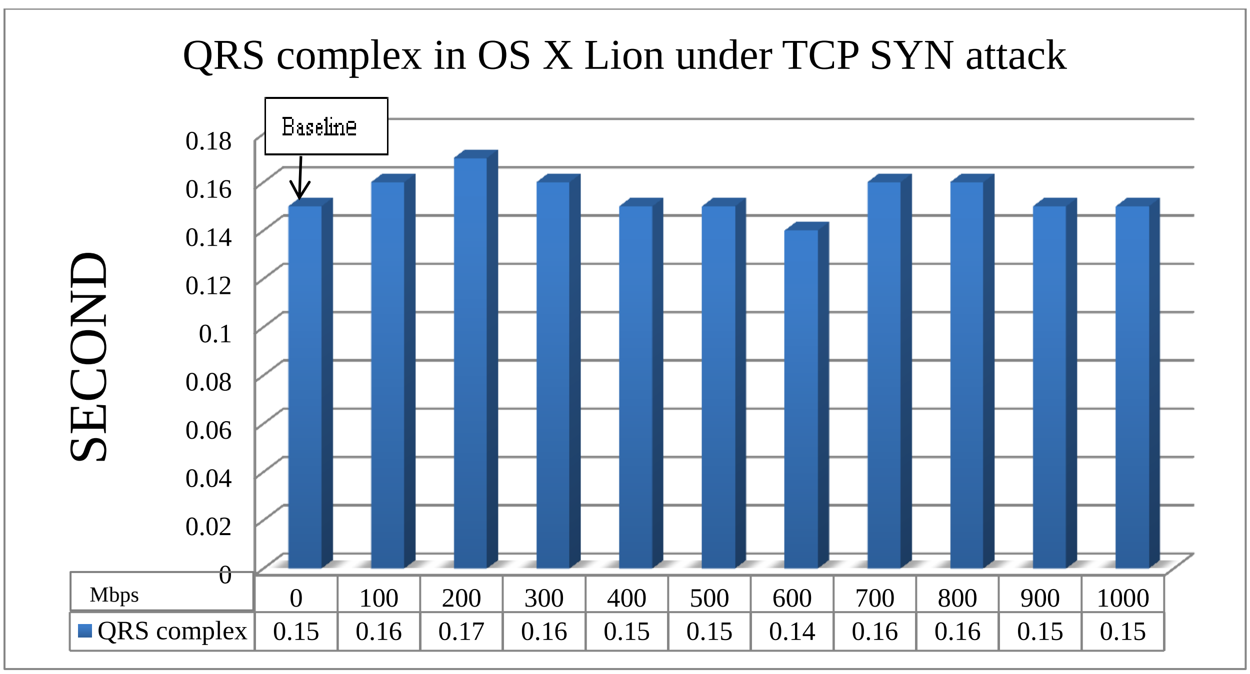


Figure 5.42 The values of QRS complex in OS X Lion under TCP SYN attack

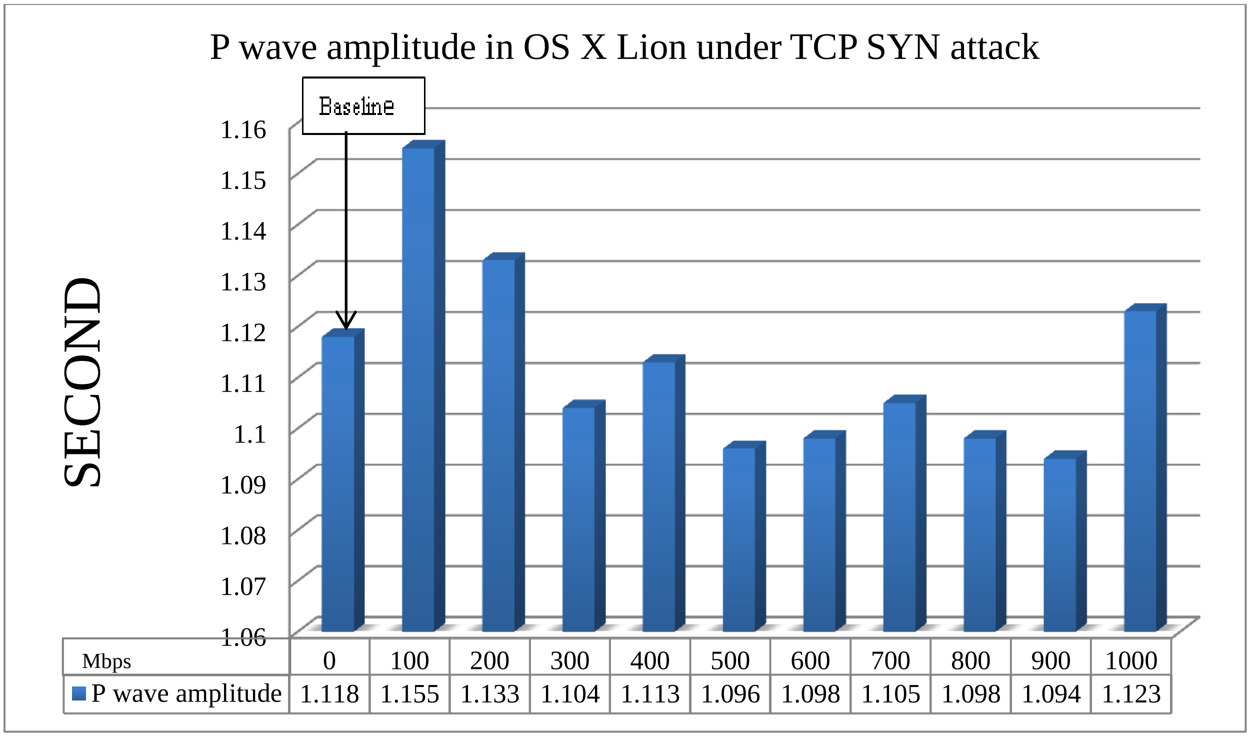


Figure 5.43 The values of P wave amplitude in OS X Lion under TCP SYN attack

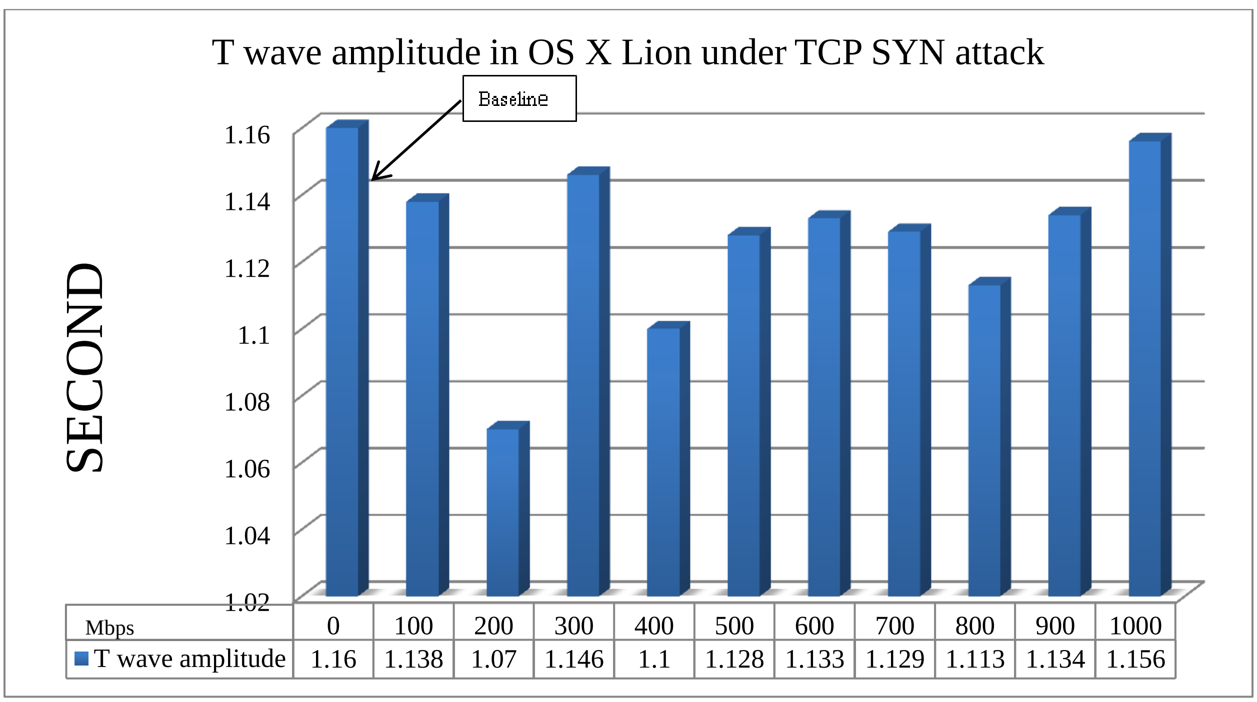


Figure 5.44 The values of T wave amplitude in OS X Lion under TCP SYN attack

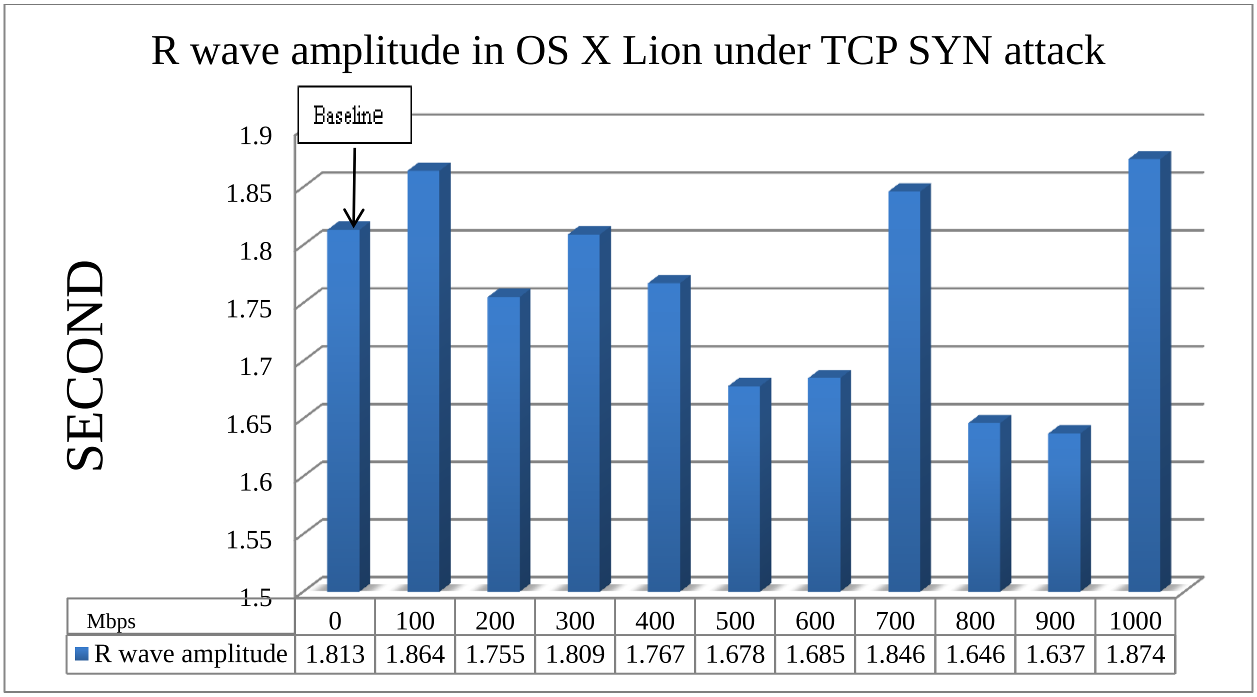


Figure 5.45 The values of R wave amplitude in OS X Lion under TCP SYN attack

5.4.2.3 ECG Data Collection Under Ping Attack. ECG signal under Ping attack of 1Gbps did not deviate from original signal (baseline). Only R-R intervals by increasing the speed of the attack from 100 Mbps to 1Gbps increased. In the worst case, QRS complex compressed in comparison with the baseline. Since the only difference between original signal and the worst case is increasing in R-R intervals, it can be considered as bradycardia. ECG components are illustrated in figure 5.47 to figure 5.53. Although QRS complex value under 1Gbps is as same as baseline during the whole experiment it changed a lot and it can be considered as a problem in ventricular contraction. According to figure, 5.48 S-T intervals deviated from base line more than other cases at 200 Mbps but as it did not deviate a lot it cannot be considered as a heart problem. P wave and T wave are shown in figure 5.51 and 5.52, P wave fluctuating is referred to the atrial problem and T wave fluctuating is referred to the ventricular problem.

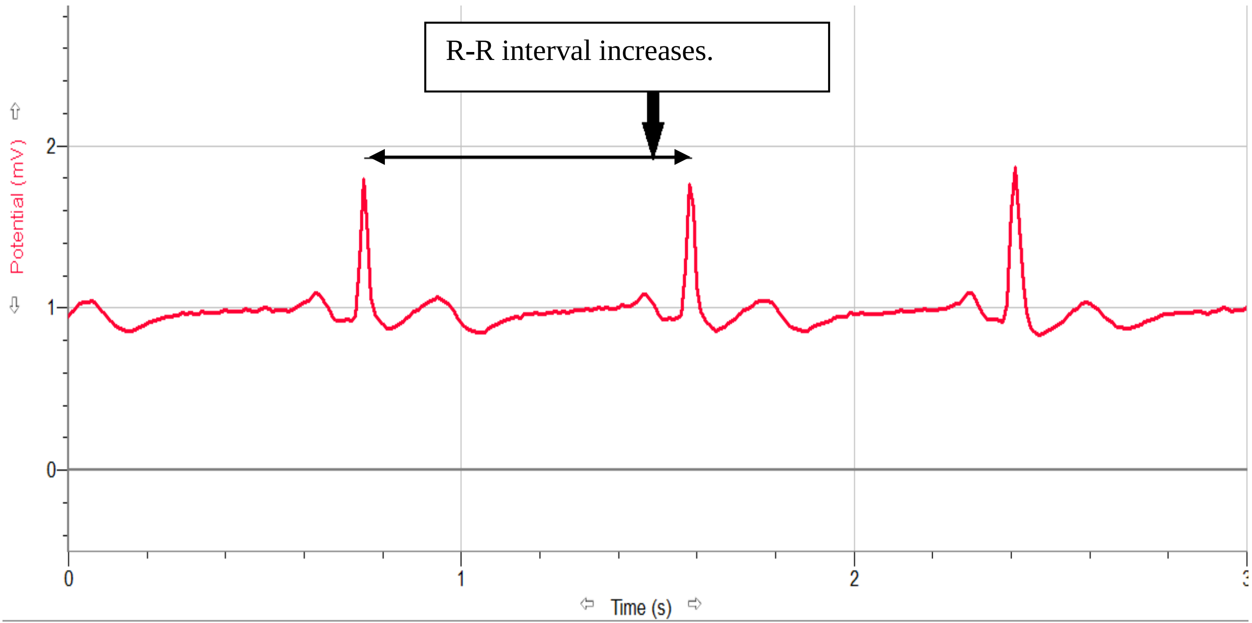


Figure 5.46 ECG signal under Ping attack at the speed of 1Gbps in OS X Lion operating system

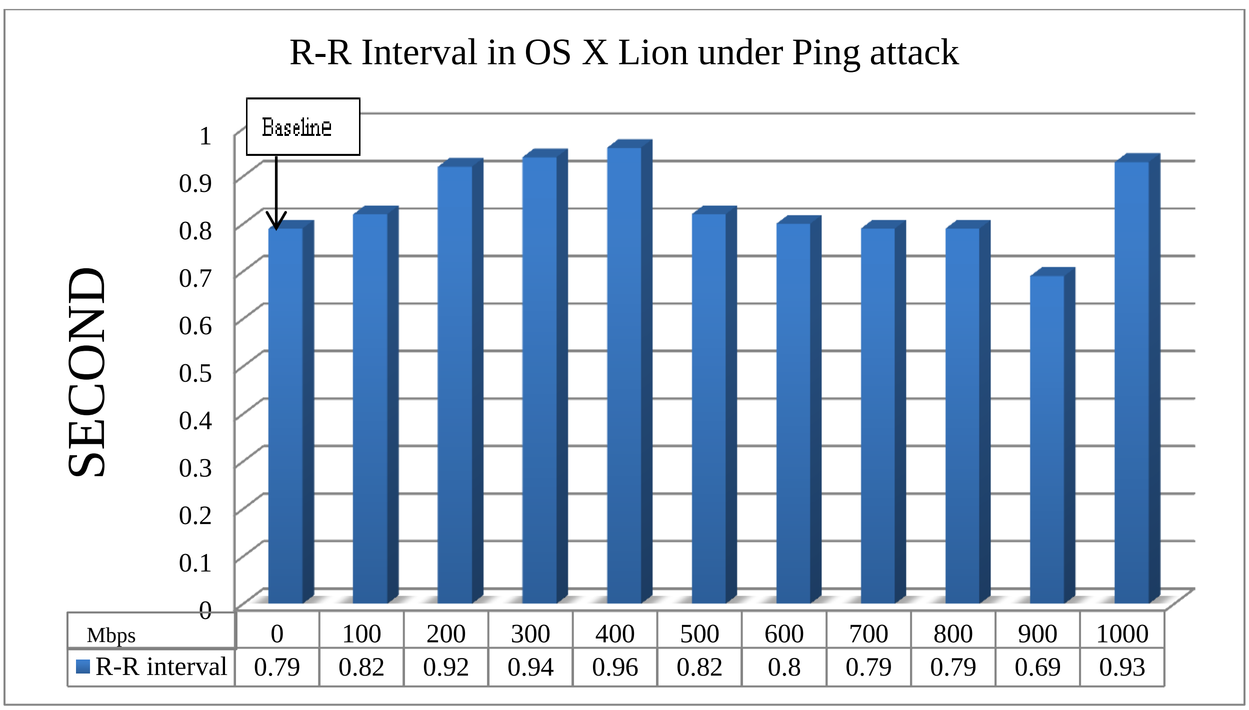


Figure 5.47 The values of R-R interval in OS X Lion under Ping attack

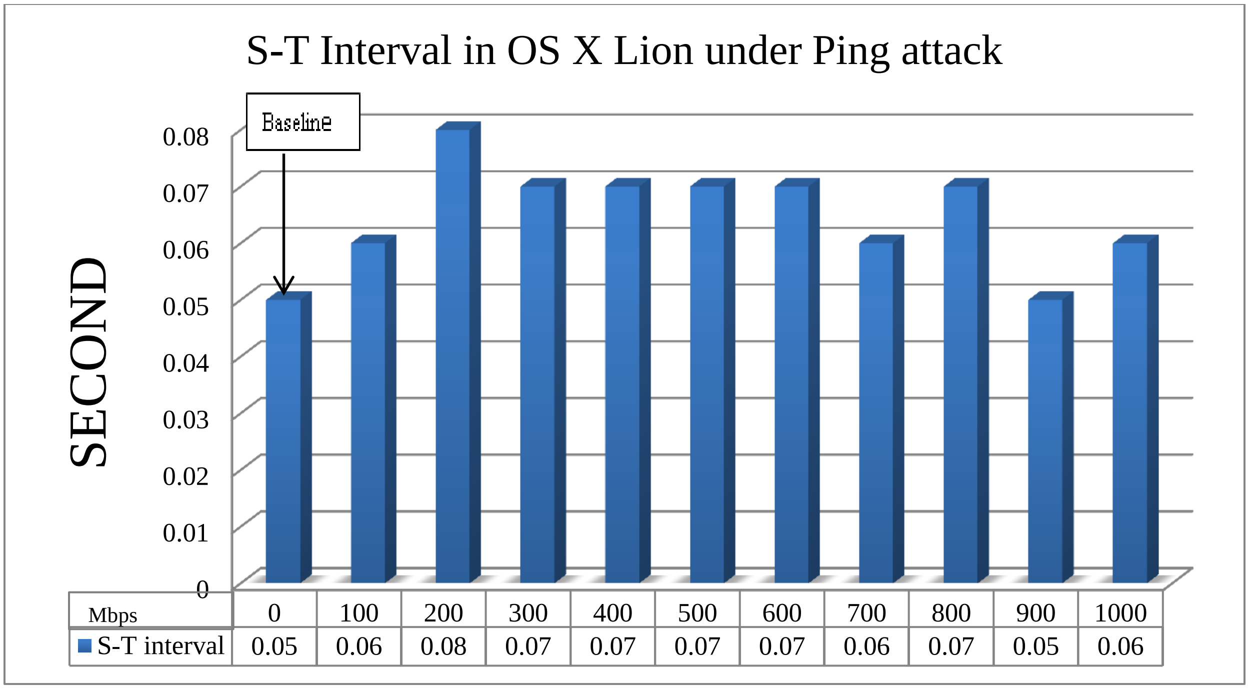


Figure 5.48 The values of S-T interval in OS X Lion under Ping attack

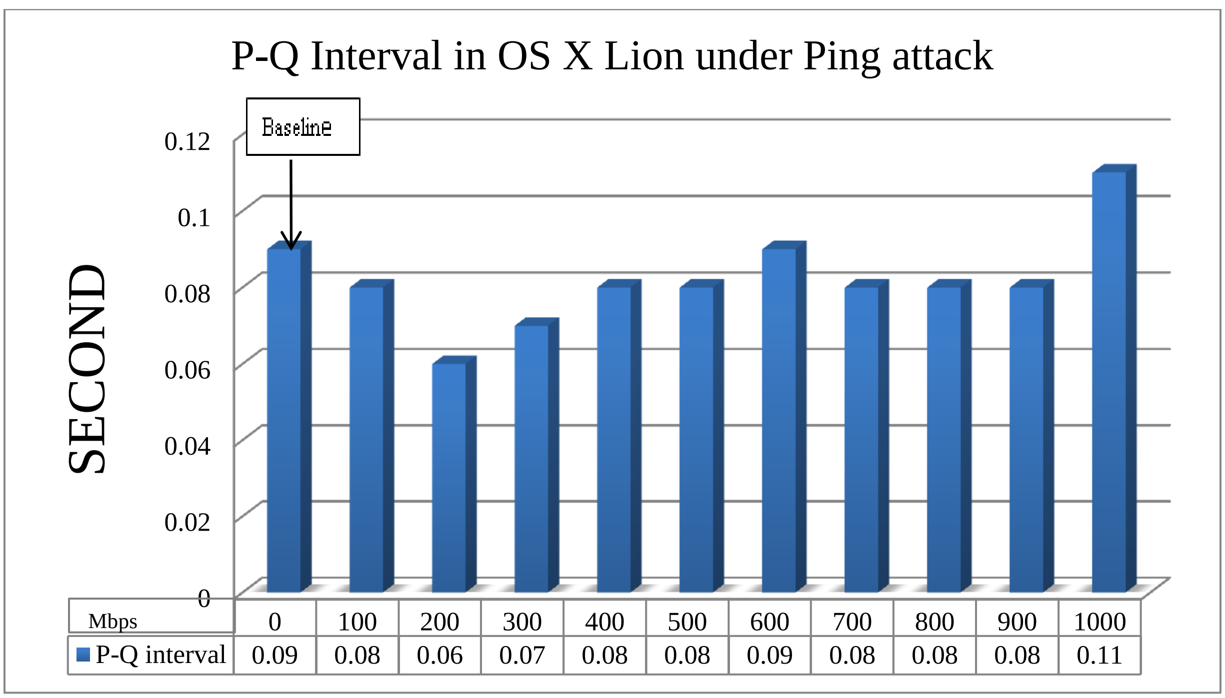
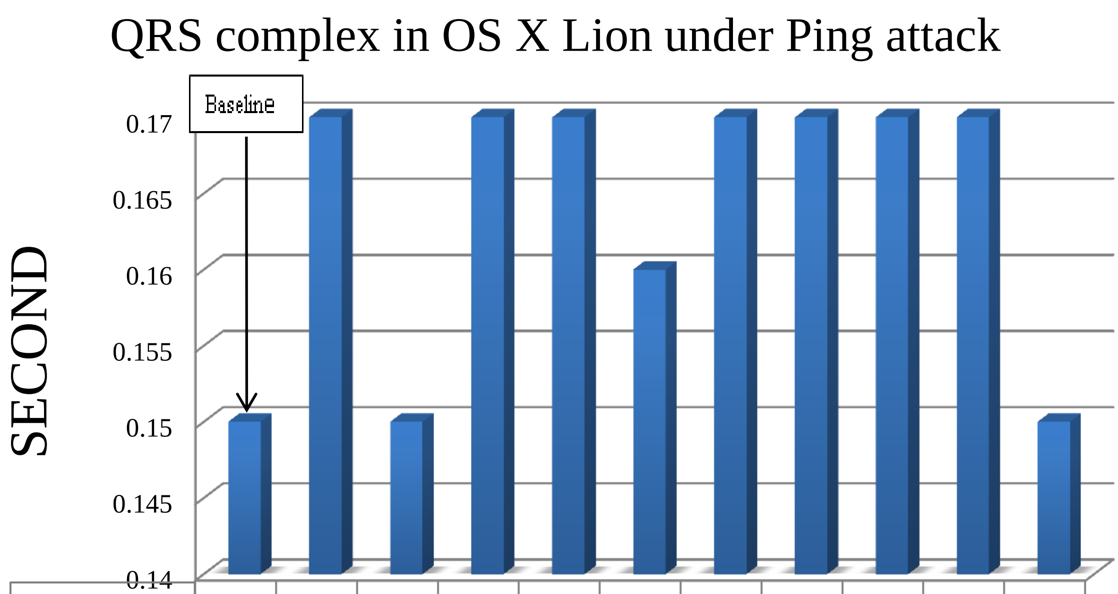
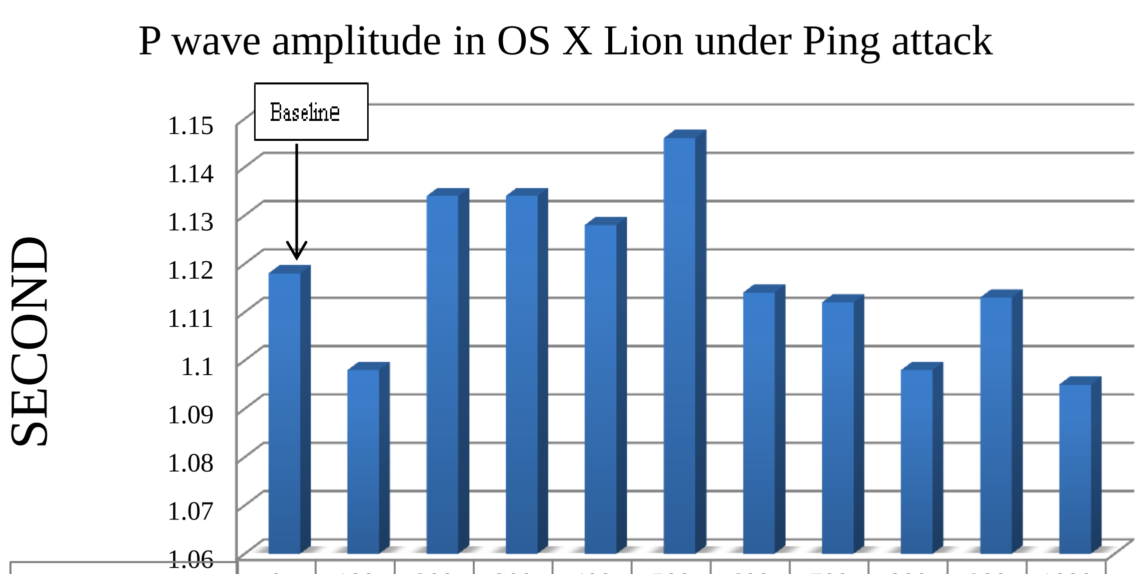


Figure 5.49 The values of P-Q interval in OS X Lion under Ping attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
QRS complex	0.15	0.17	0.15	0.17	0.17	0.16	0.17	0.17	0.17	0.17	0.15

Figure 5.50 The values of QRS complex in OS X Lion under Ping attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
P wave amplitude	1.118	1.098	1.134	1.134	1.128	1.146	1.114	1.112	1.098	1.113	1.095

Figure 5.51 The values of P wave amplitude in OS X Lion under Ping attack

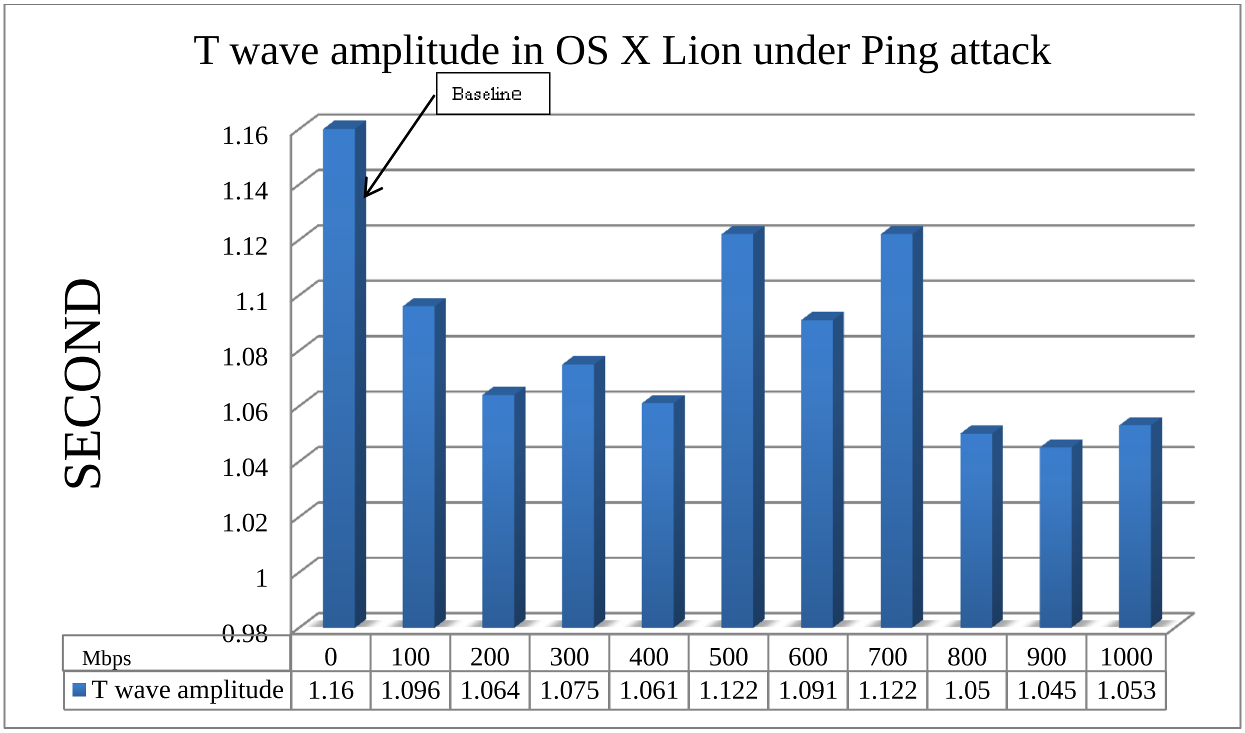


Figure 5.52 The values of T wave amplitude in OS X Lion under Ping attack

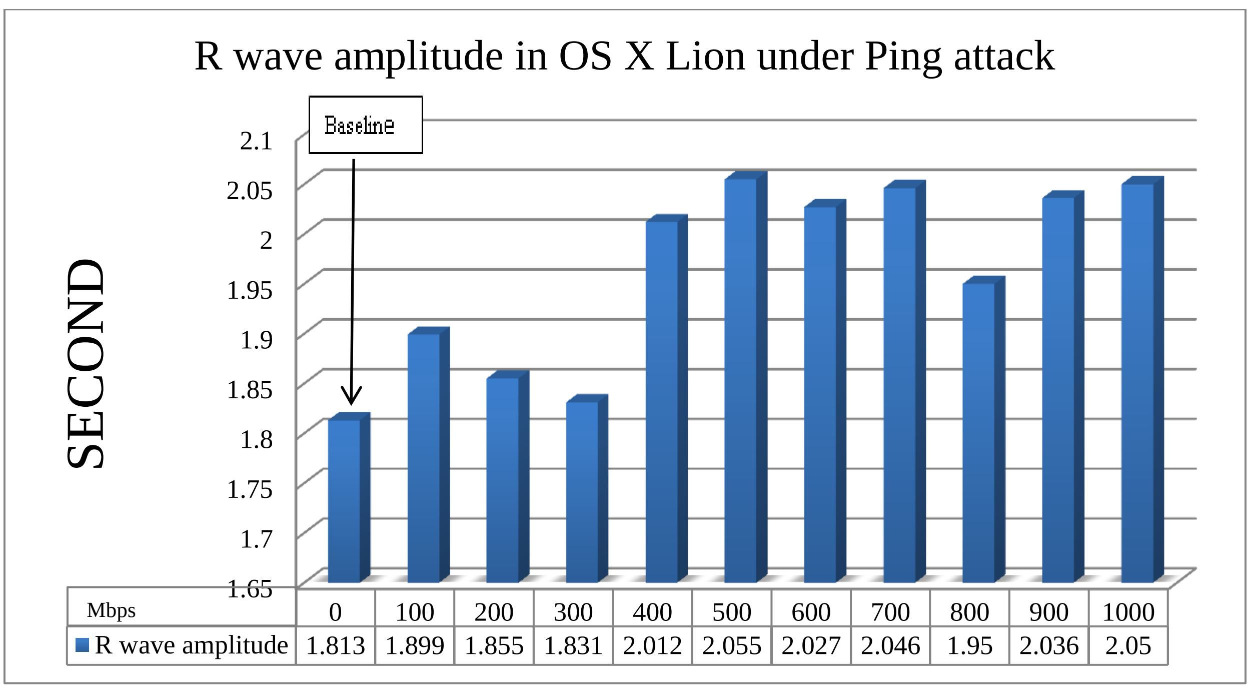


Figure 5.53 The values of R wave amplitude in OS X Lion under Ping attack

5.4.3 OS X Mountain Lion Results. In the third phase of the experiment ECG signal captured in OS X Mountain Lion. Figure 5.54 illustrates the captured ECG in the normal condition. All the normal ECG components were calculated in table 5.3.

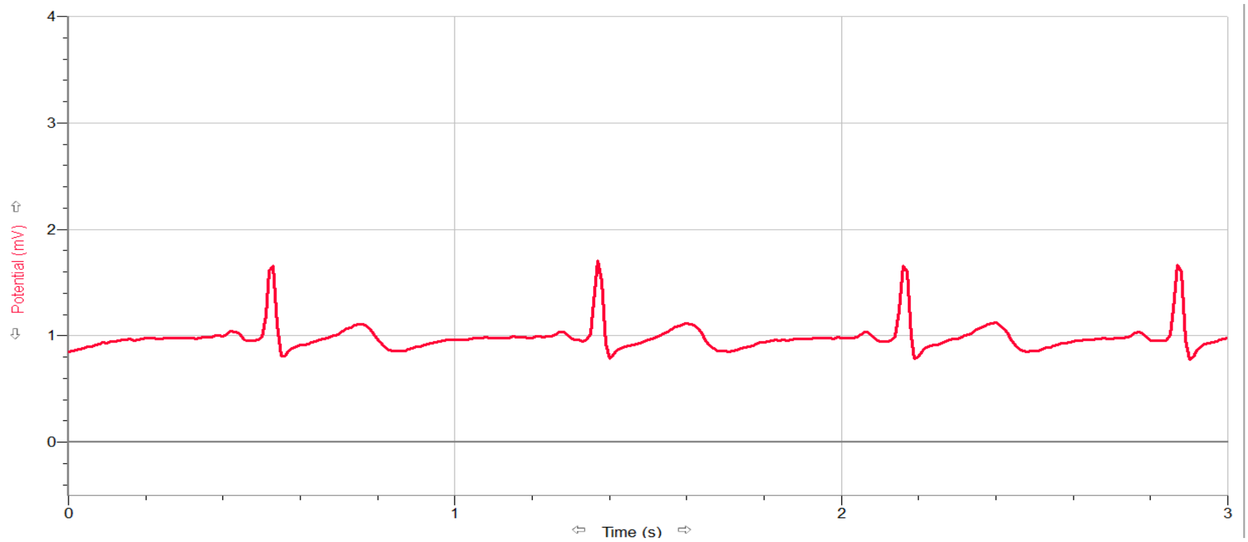


Figure 5.54 Baseline ECG collected by OS X Mountain Lion operating system under normal condition

Table 5.3 Feature values of ECG signal in OS X Mountain Lion in the normal condition

Feature	Value
R – R interval	0.84 s
S – T interval	0.09 s
P – Q interval	0.07 s
P wave amplitude	1.036 mV
T wave amplitude	1.115 mV
R wave amplitude	1.702 mV
QRS complex	0.13 s

5.4.3.1 ECG Data Collection Under ARP Attack. Figure 5.55 shows captured ECG under ARP attack at the speed of 1Gbps in OS X Mountain Lion. Two obvious deviations form original signal are irregular sinus rhythm and the absence of the P wave. Those factors can be considered as premature atrial contractions. As it is shown in, figure 5.56 R-R intervals did not change a lot from baseline. R-R interval is one of the most components of ECG signal so it is the first component that should be considered to detect heart abnormality. According to figures 5.57 to 5.59 ECG signal deviated from baseline under Ping attack of 800 Mbps and figures 5.60 and 5.61 deviated from baseline under Ping attack of 900 Mbps, all these changes can be considered as ventricular heart problem, but changes which are related to atrial contraction are more obvious.

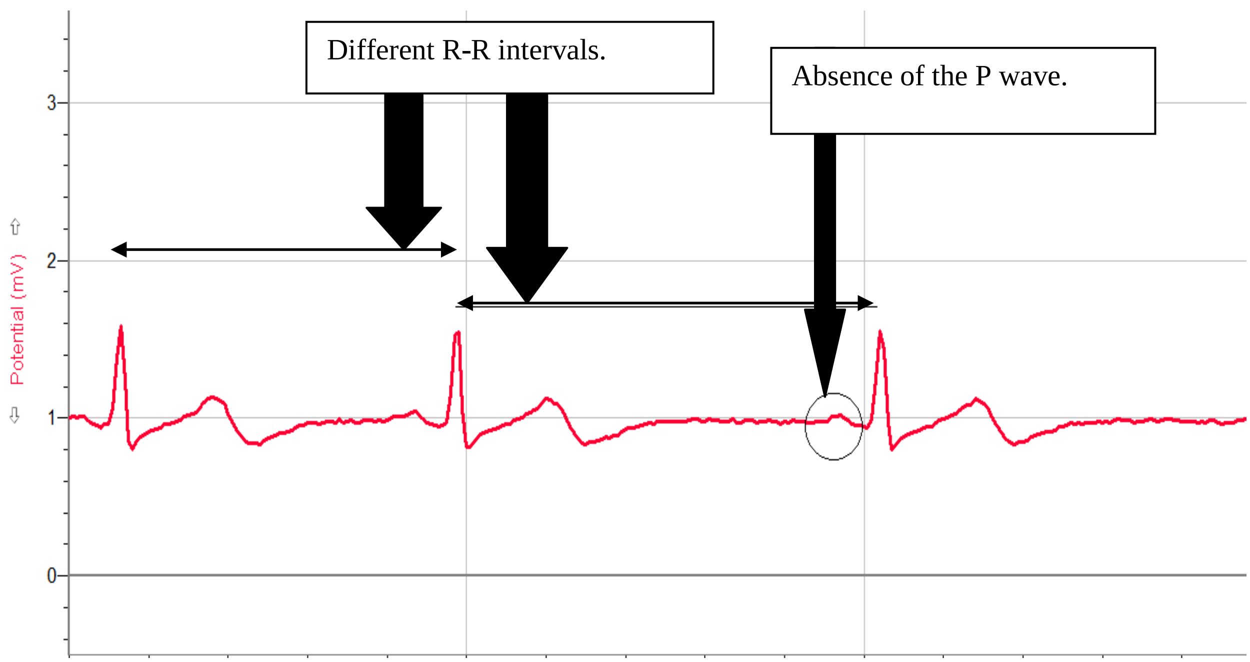


Figure 5.55 ECG signal under ARP attack at the speed of 1Gbps in OS X Mountain Lion operating system

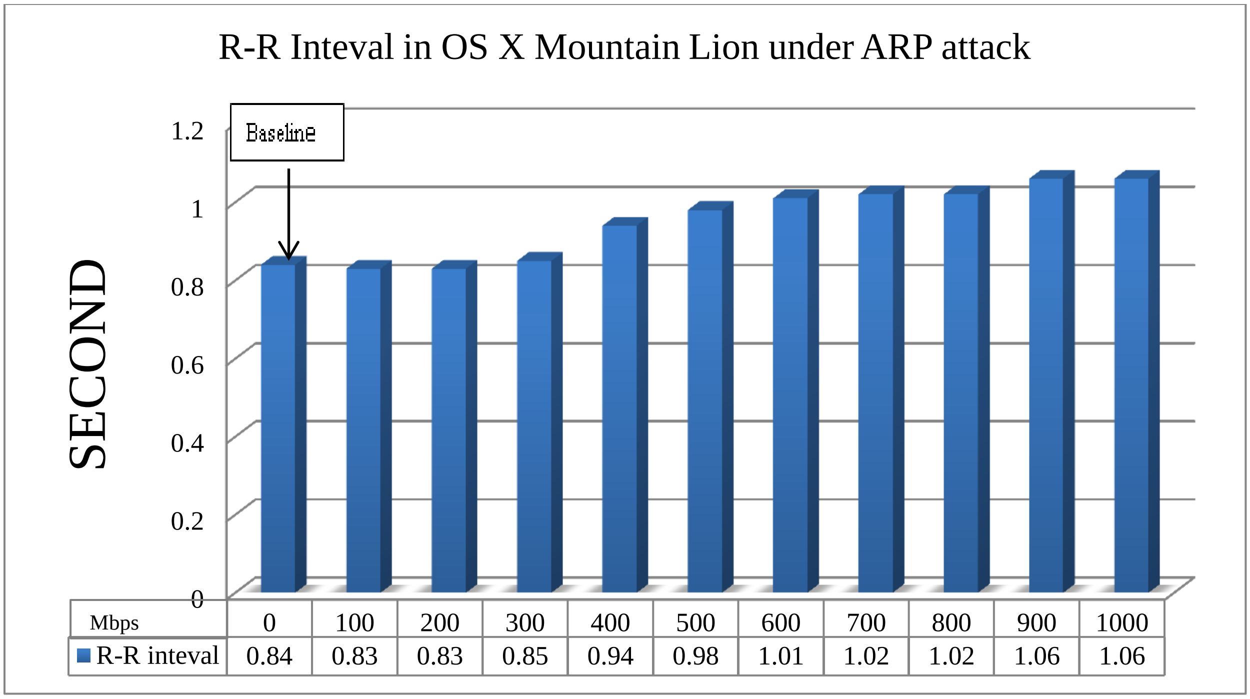


Figure 5.56 The values of R-R interval in OS X Mountain Lion under ARP attack

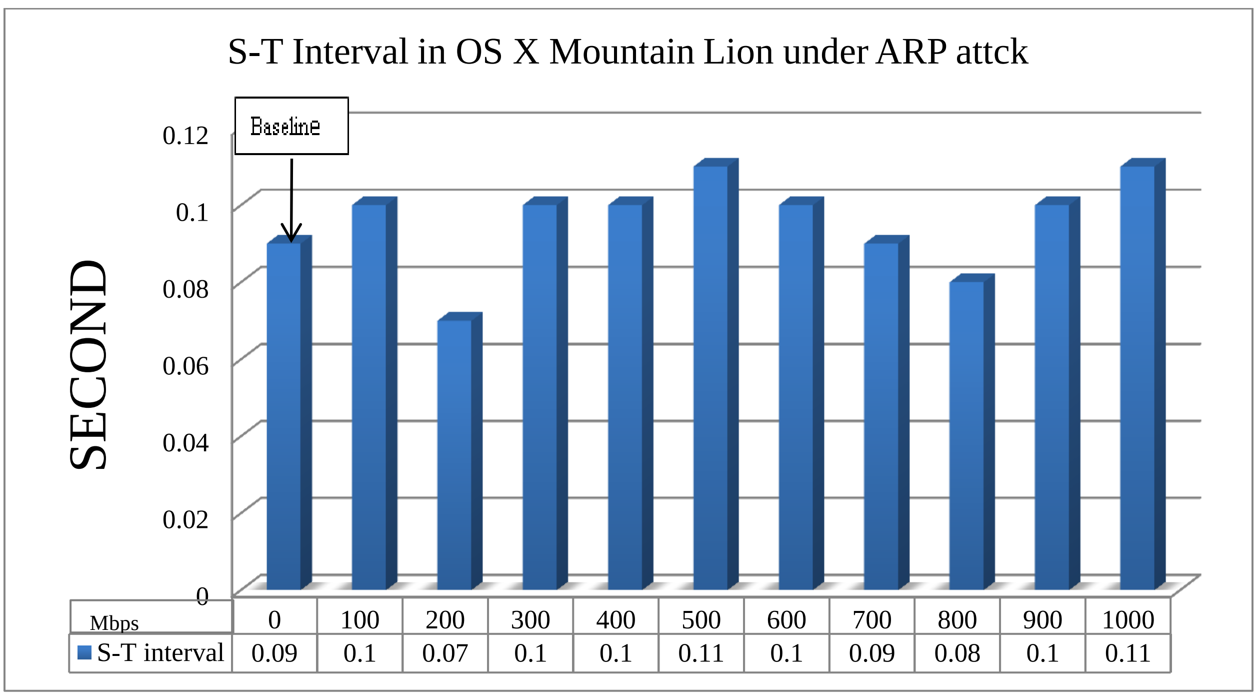


Figure 5.57 The values of S-T interval in OS X Mountain Lion under ARP attack

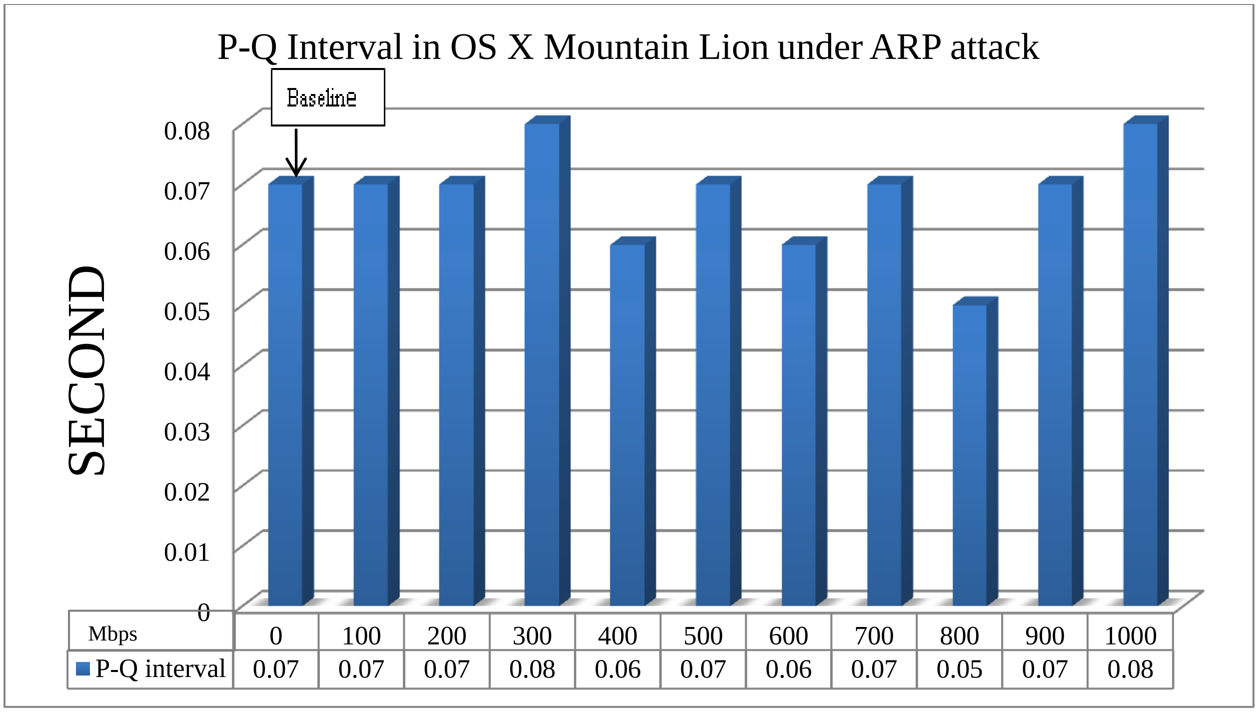


Figure 5.58 The values of P-Q interval in OS X Mountain Lion under ARP attack

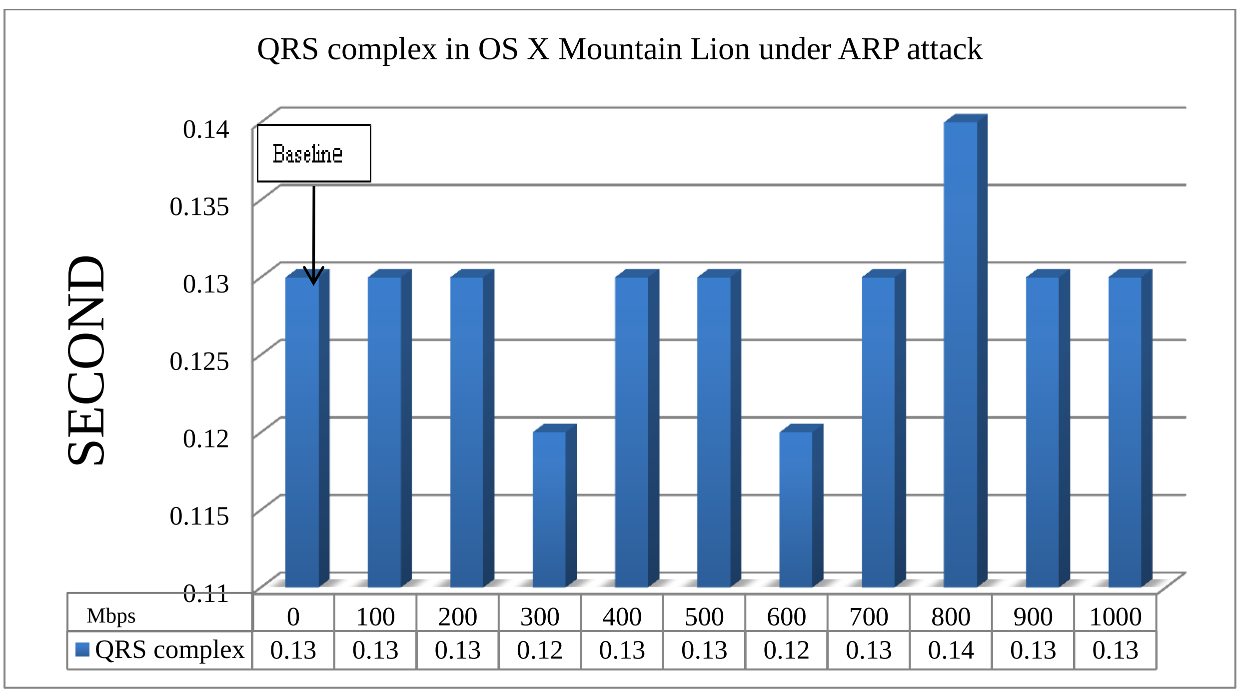


Figure 5.59 The values of QRS complex in OS X Mountain Lion under ARP attack

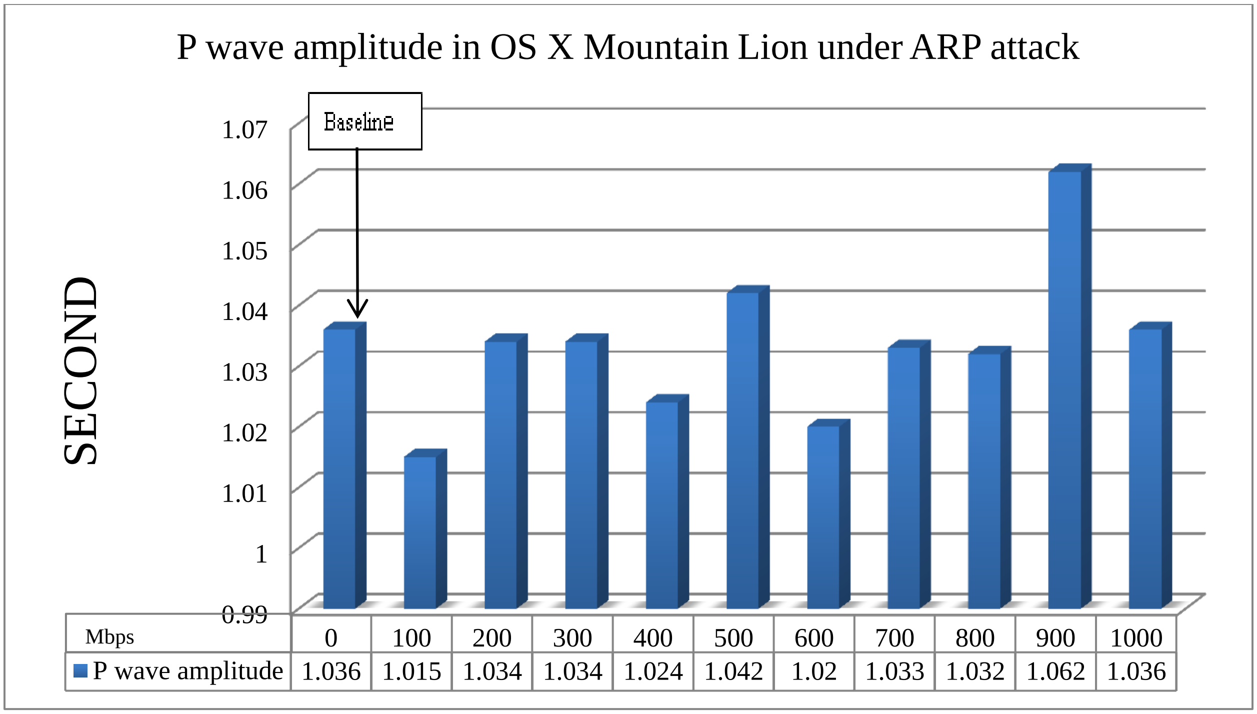


Figure 5.60 The values of P wave amplitude in OS X Mountain Lion under ARP attack

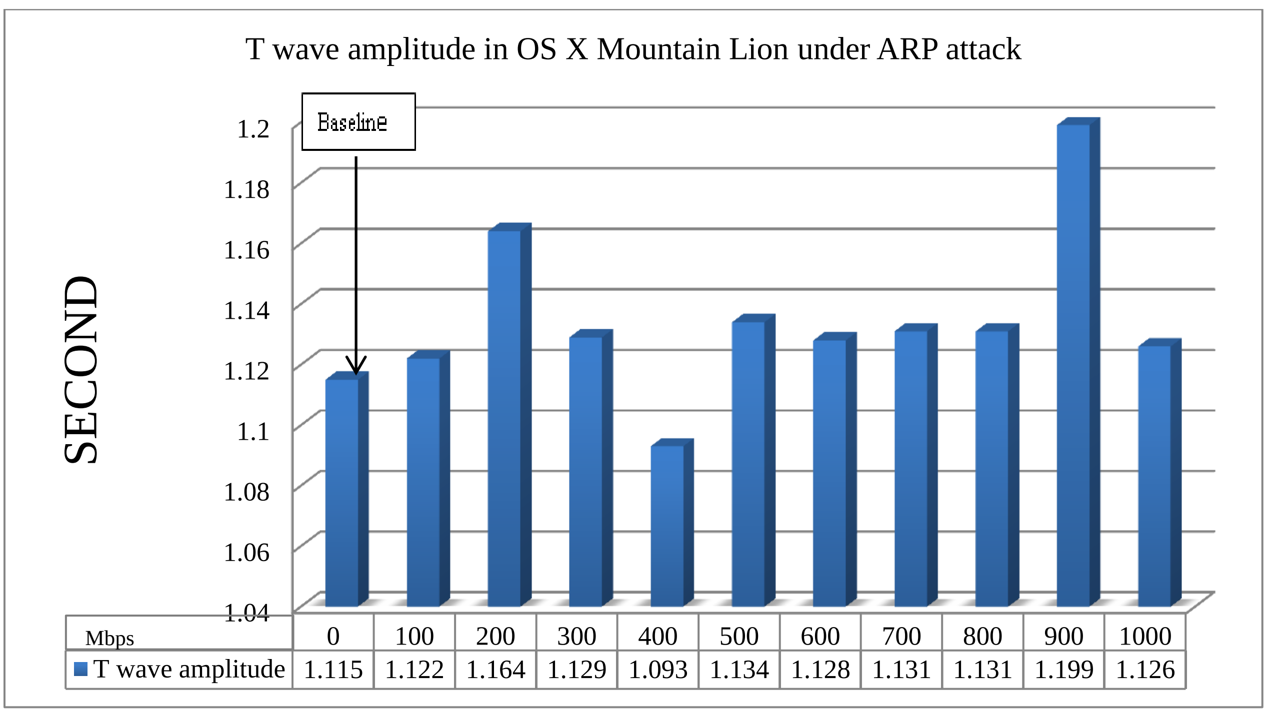


Figure 5.61 The values of T wave amplitude in OS X Mountain Lion under ARP attack

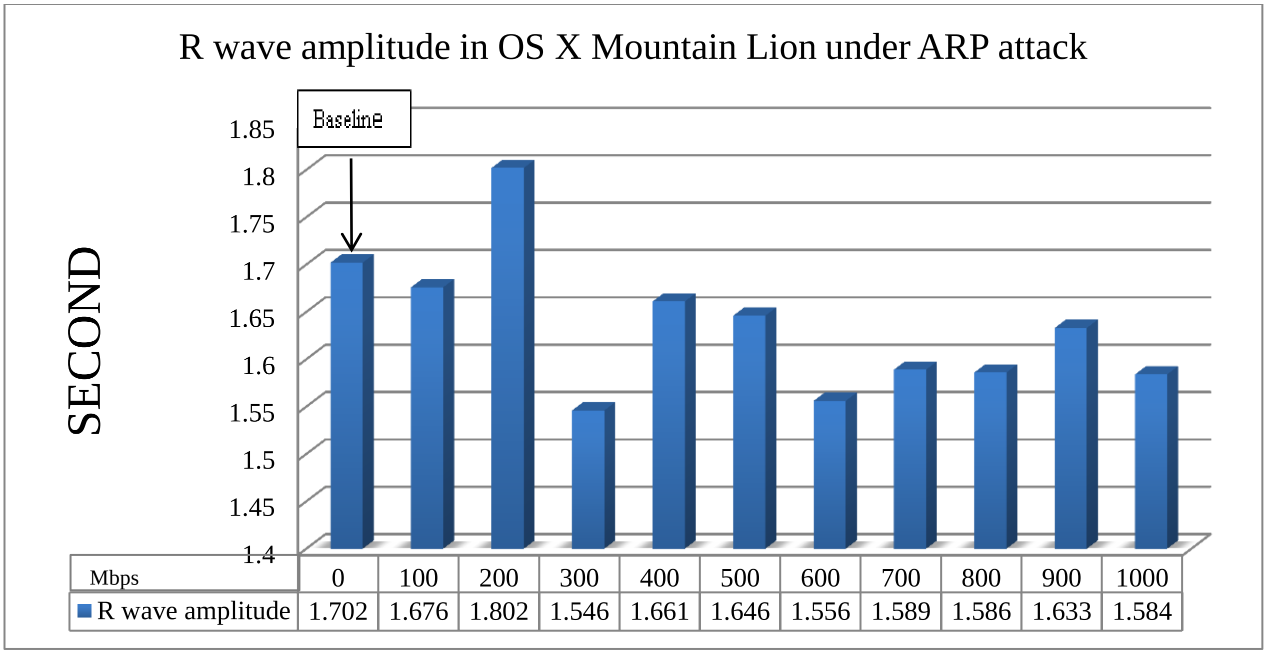


Figure 5.62 The values of R wave amplitude in OS X Mountain Lion under ARP attack

5.4.3.2 ECG Data Collection Under TCP SYN Attack. Captured ECG signal under TCP SYN had an increasing pattern in R-R intervals and decreasing pattern in the amplitude of R wave. At the speed of attack at 700 Mbps the P wave and T wave are abnormal and their amplitudes are almost same. Figure 5.63 shows abnormalities in the P wave, T wave and R wave that can be considered as sick sinus syndrome. Figure 5.64 shows irregularly in sinus rhythm that can be known as a heart problem. Figure 5.65 to figure 5.71 illustrate all the ECG components. According to figure 5.66 and figure, 5.67 S-T interval and P-Q interval did not deviate from baseline considerably.

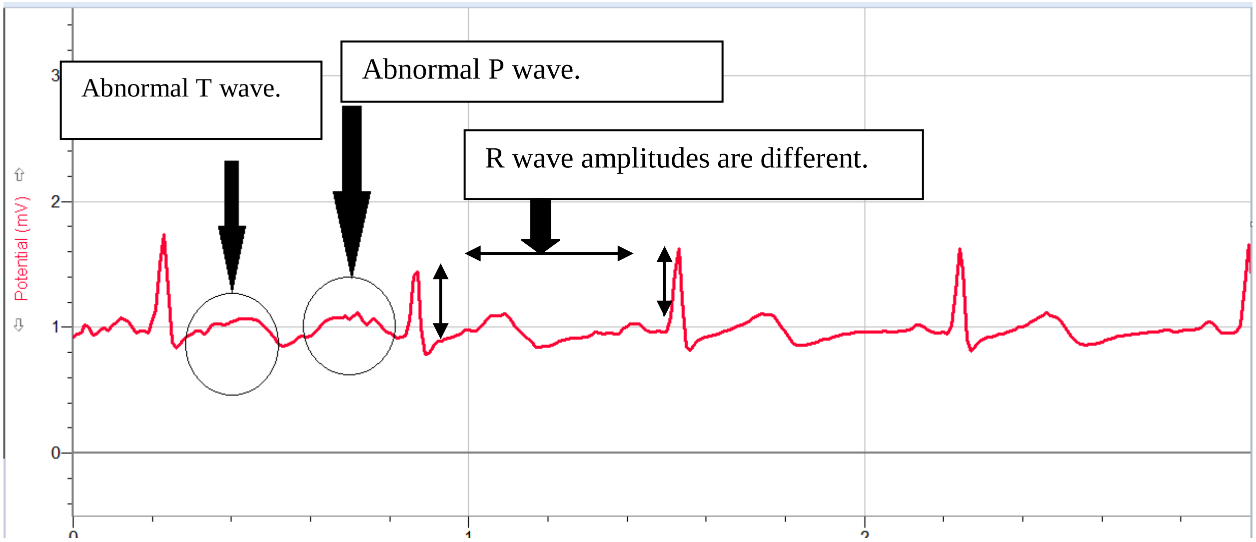


Figure 5.63 ECG signal under TCP SYN attack at the speed of 700 Mbps in OS X Mountain Lion operating system

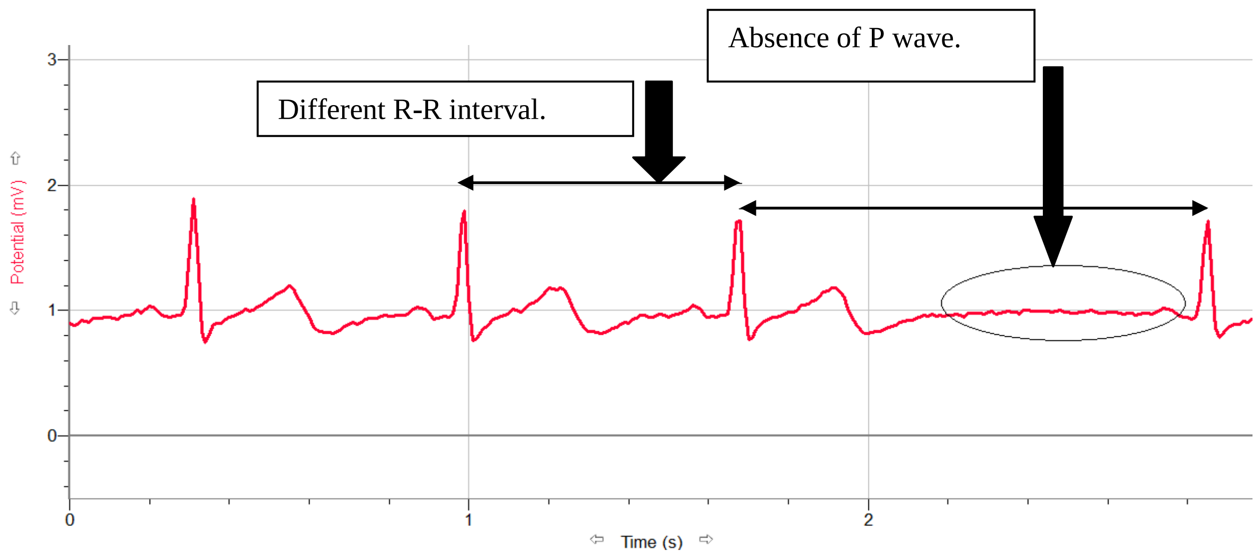
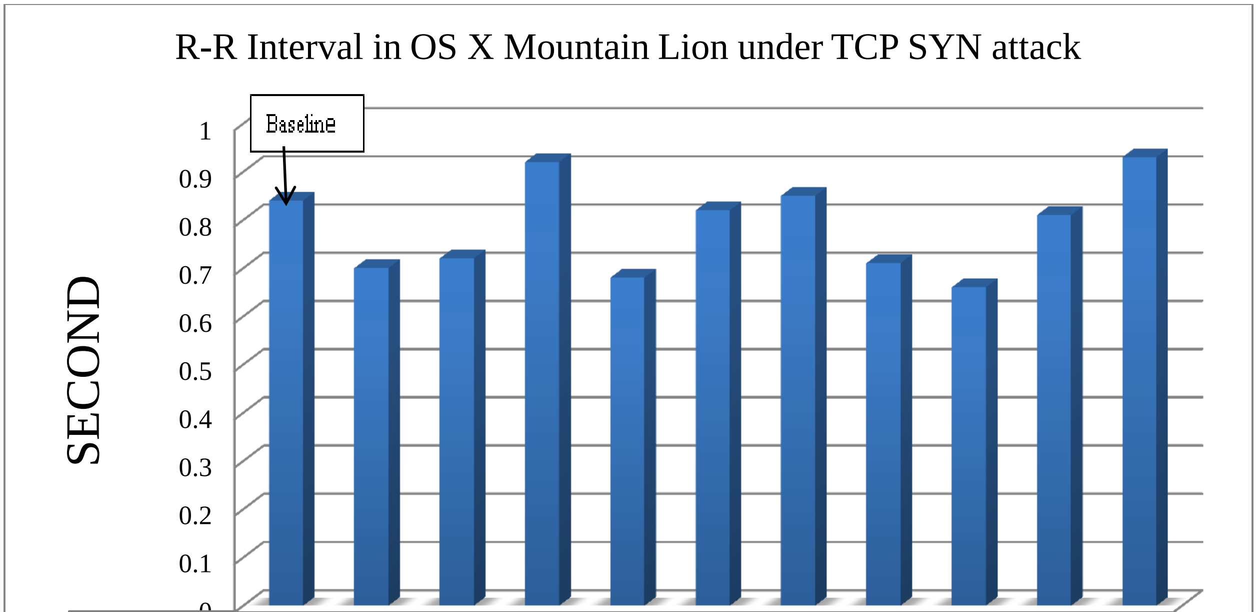
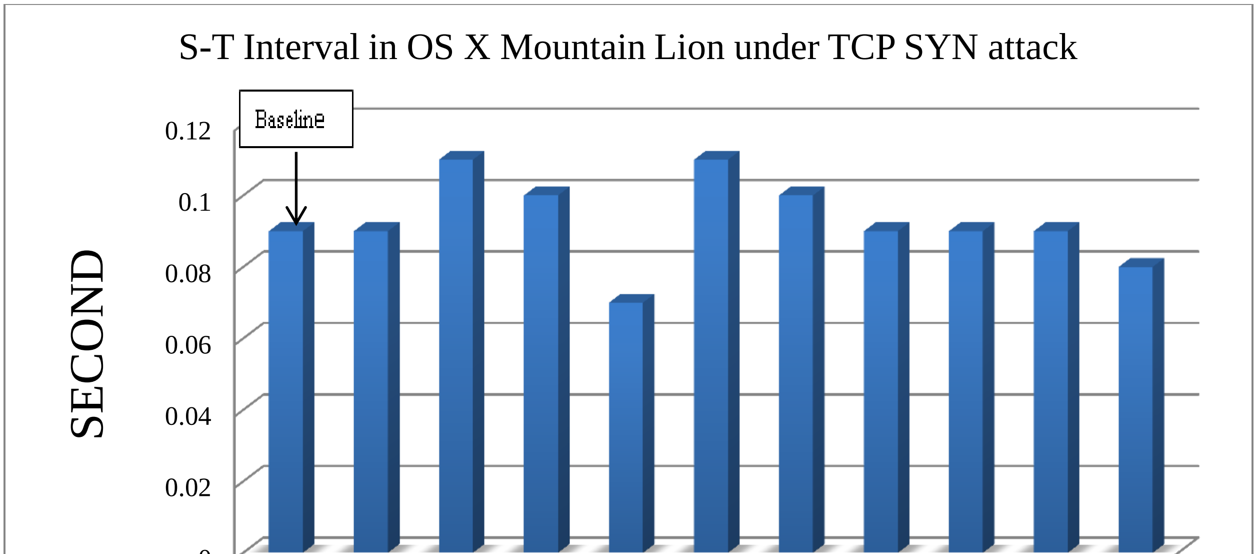


Figure 5.64 ECG signal under TCP SYN attack at the speed of 1Gbps in OS X Mountain Lion operating system



Mbps	0	100	200	300	400	500	600	700	800	900	1000
R-R interval	0.84	0.7	0.72	0.92	0.68	0.82	0.85	0.71	0.66	0.81	0.93

Figure 5.65 The values of R-R interval in OS X Mountain Lion under TCP SYN attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
S-T interval	0.09	0.09	0.11	0.1	0.07	0.11	0.1	0.09	0.09	0.09	0.08

Figure 5.66 The values of S-T interval in OS X Mountain Lion under TCP SYN attack

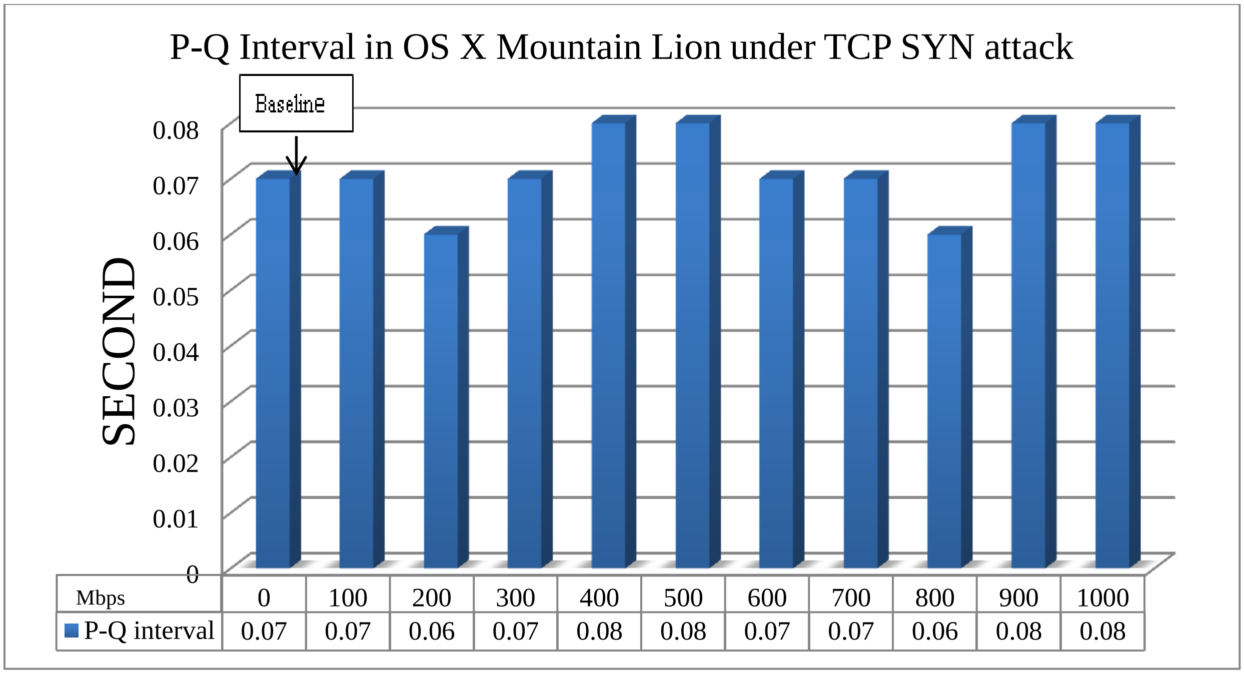


Figure 5.67 The values of P-Q interval in OS X Mountain Lion under TCP SYN attack

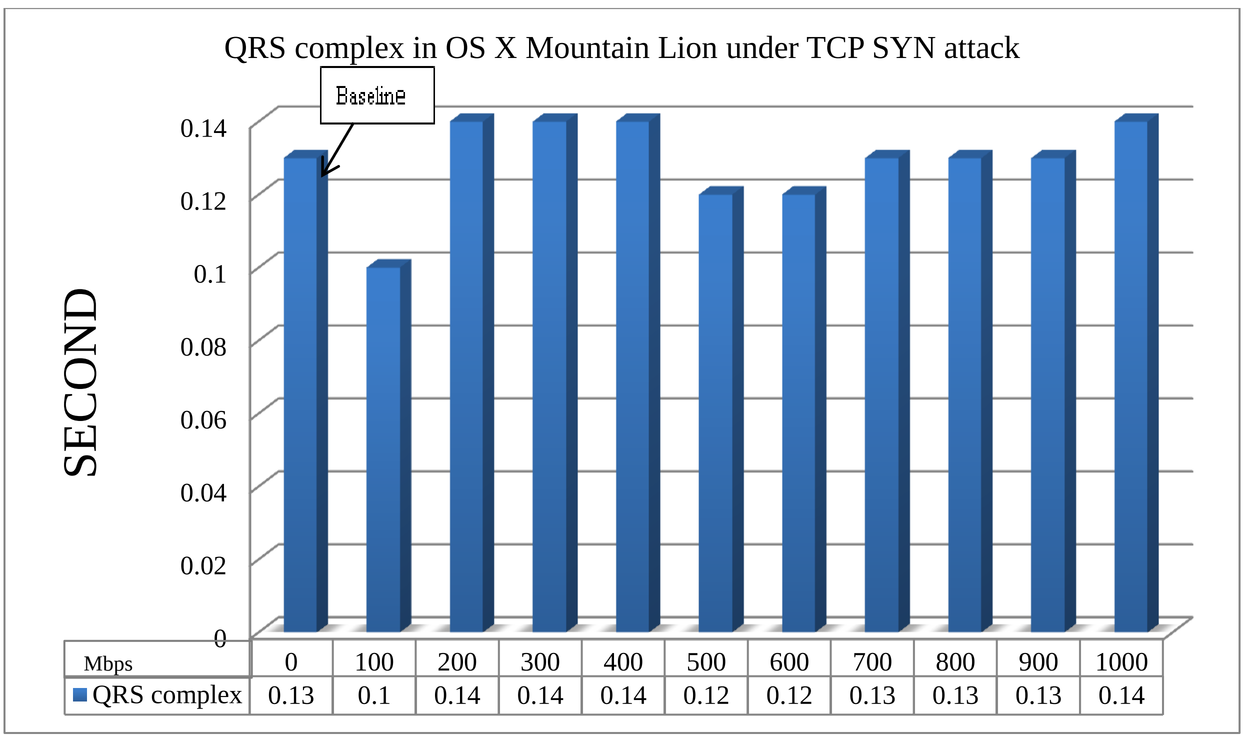


Figure 5.68 The values of QRS complex in OS X Mountain Lion under TCP SYN attack

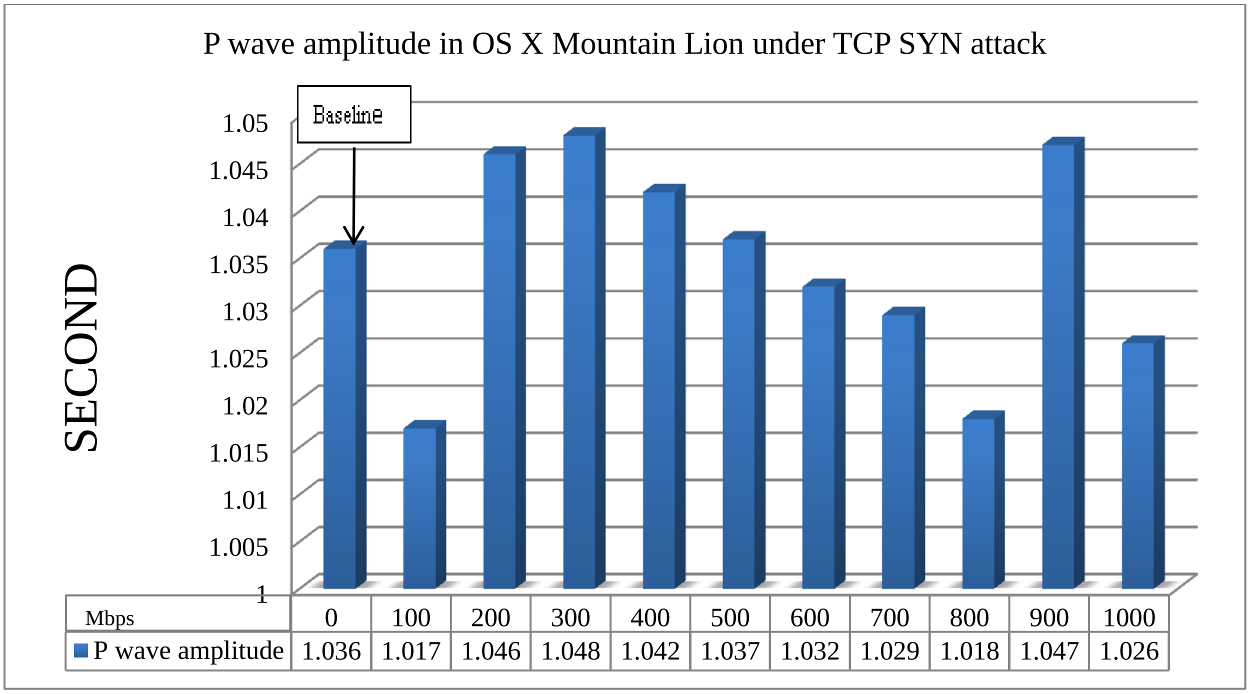


Figure 5.69 The values of P wave amplitude in OS X Mountain Lion under TCP SYN attack

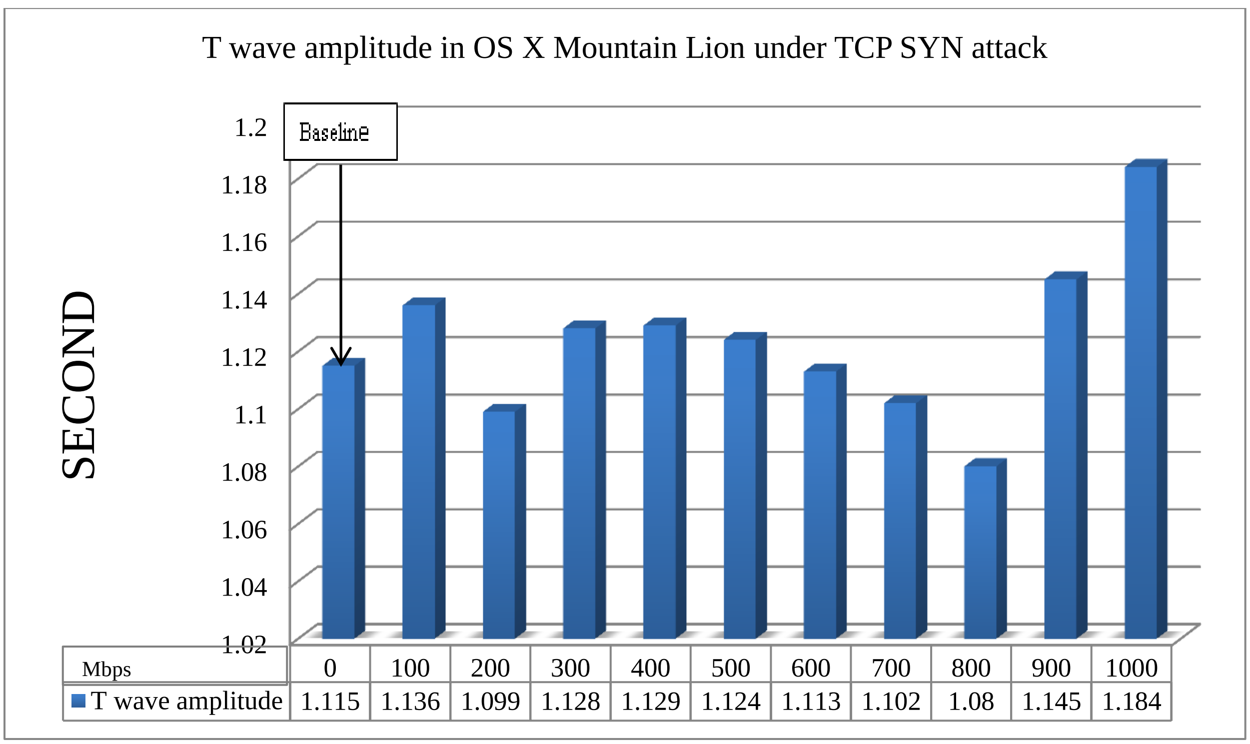


Figure 5.70 The values of T wave amplitude in OS X Mountain Lion under TCP SYN attack

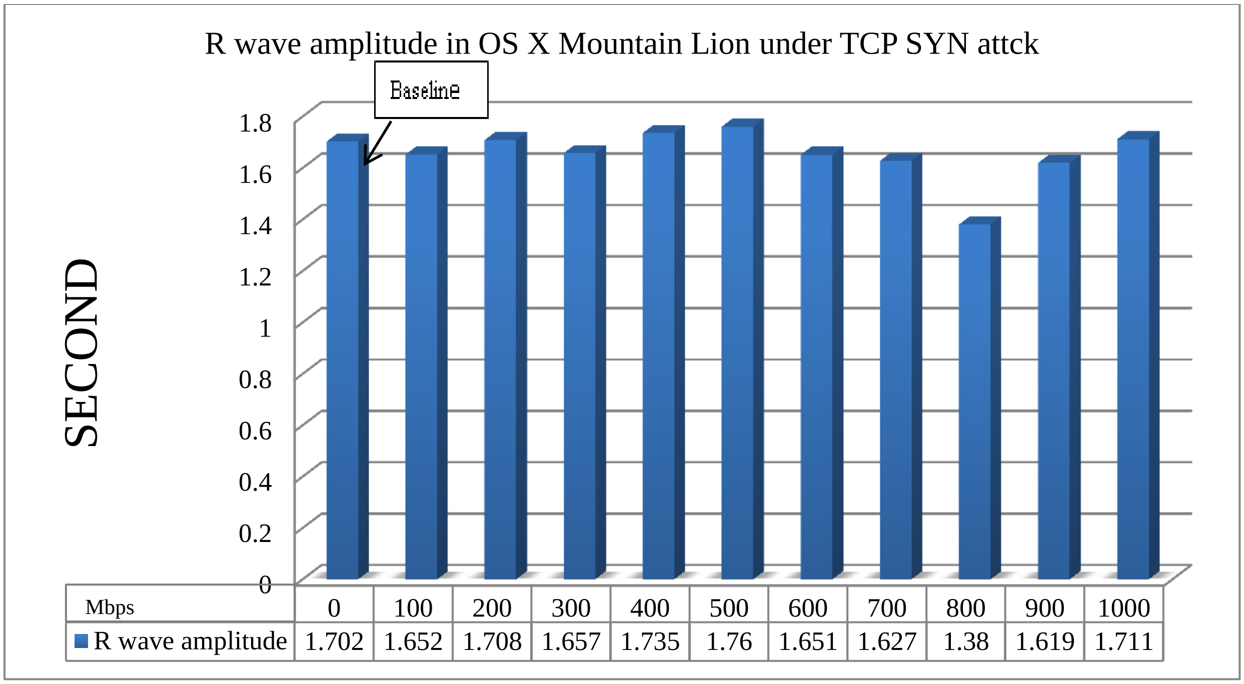


Figure 5.71 The values of R wave amplitude in OS X Mountain Lion under TCP SYN attack

5.4.3.3 ECG Data Collection Under Ping Attack. Ping attack in OS X Mountain Lion behaved as noise. According to the figure 5.72, all the ECG signal components but QRS complex distorted. It cannot be considered as a heart problem. It is similar to equipment disorder. Figure 5.73 to figure 5.79 illustrate the value of all components of the ECG signal under Ping attack in OS X Mountain Lion operating system. In figure 5.73 R-R interval is shown, it did not have a regular pattern under some attacks load R-R interval increases and under others, it decreases. In figures 5.76 to 5.79, deviation from baseline is not considerable so these ECG components can be considered as noisy condition because of the equipment disorder. As it is shown in figure 5.57 ECG under Ping attack of 300 Mbps the P-Q deviated from baseline and can be interpreted as atrial problem.

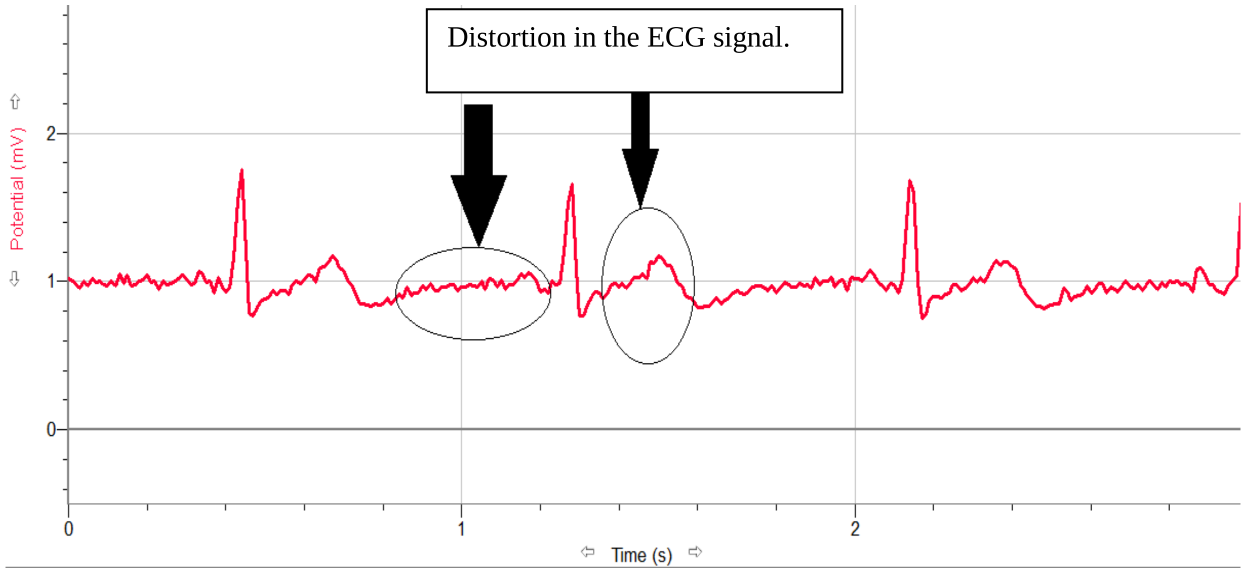


Figure 5.72 ECG signal under Ping attack at the speed of 1Gbps in OS X Mountain Lion operating system

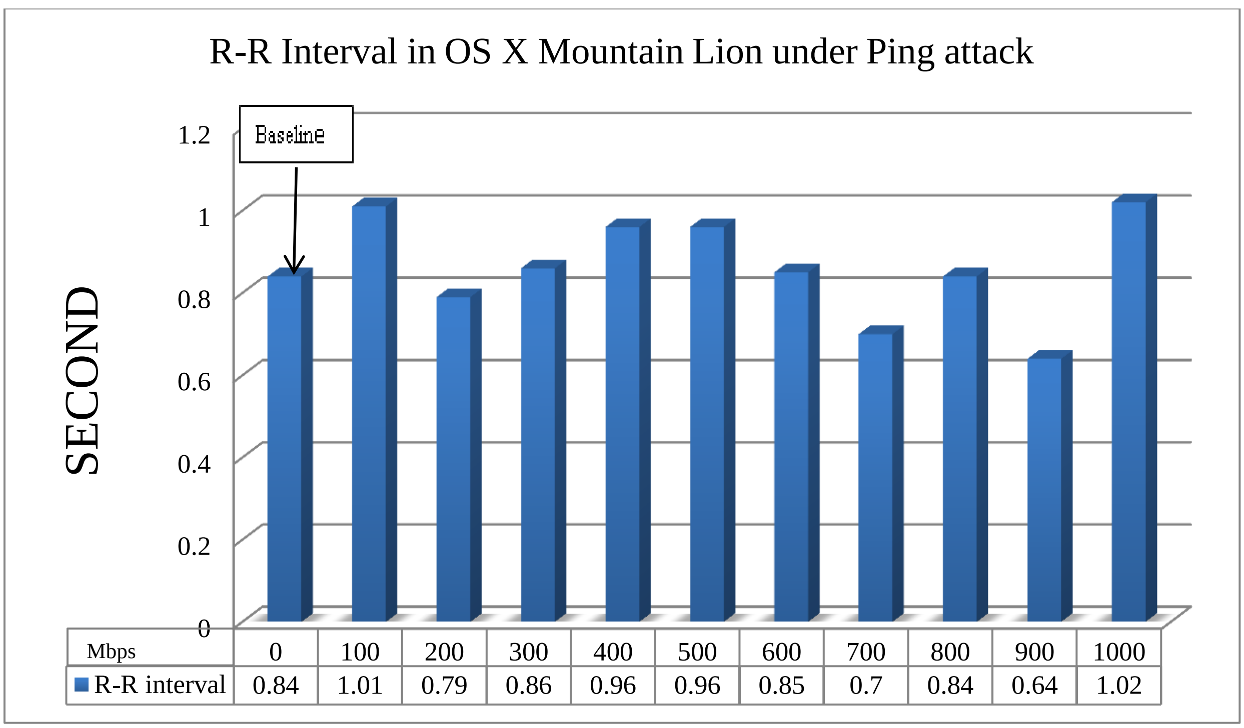


Figure 5.73 The values of R-R interval in OS X Mountain Lion under Ping attack

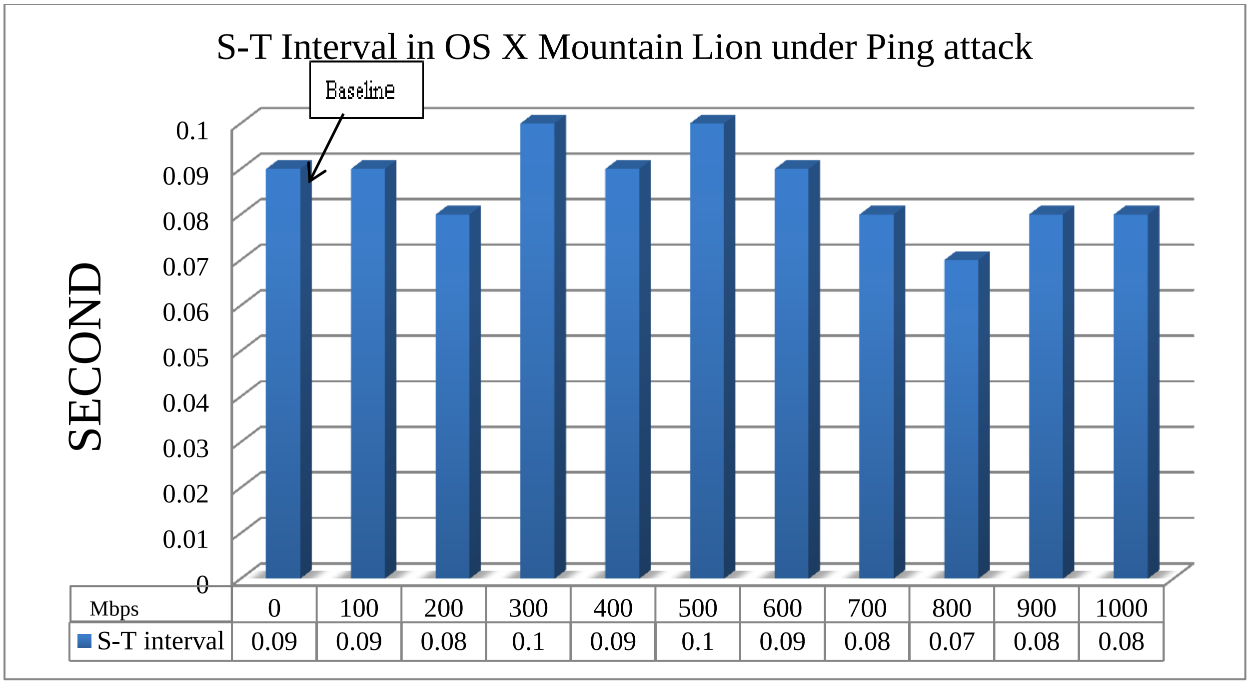


Figure 5.74 The values of S-T interval in OS X Mountain Lion under Ping attack

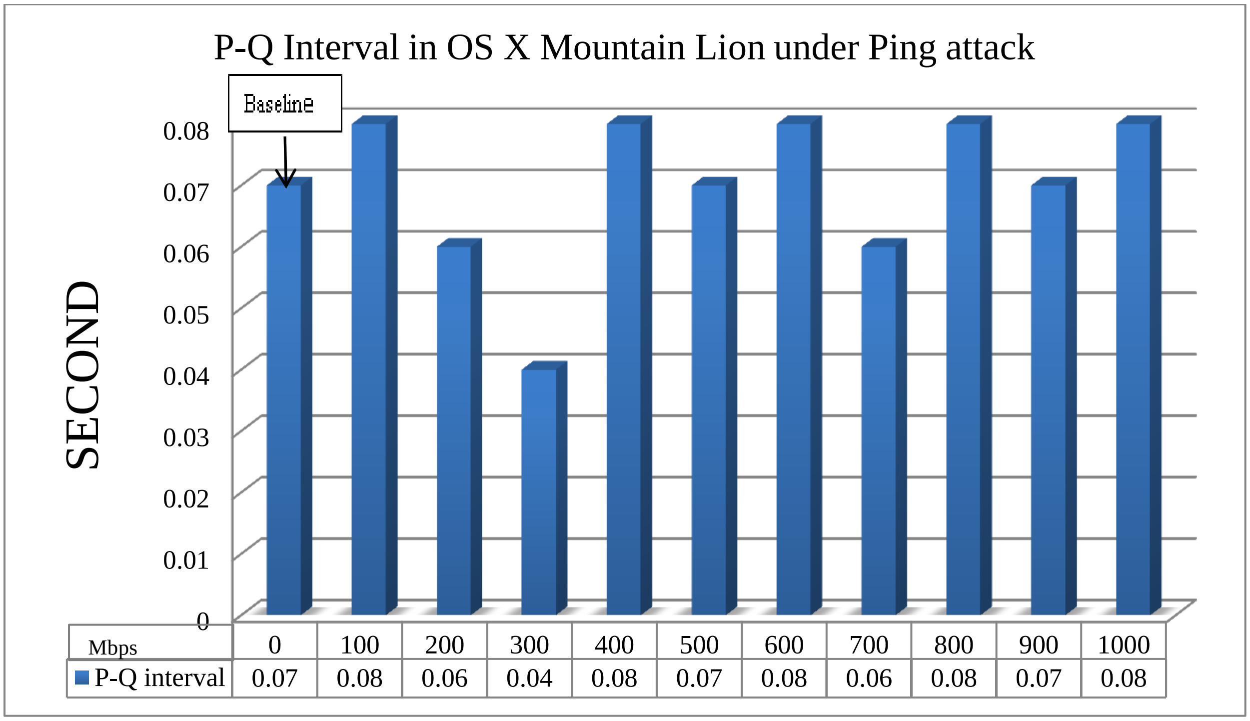


Figure 5.75 The values of P-Q interval in OS X Mountain Lion under Ping attack

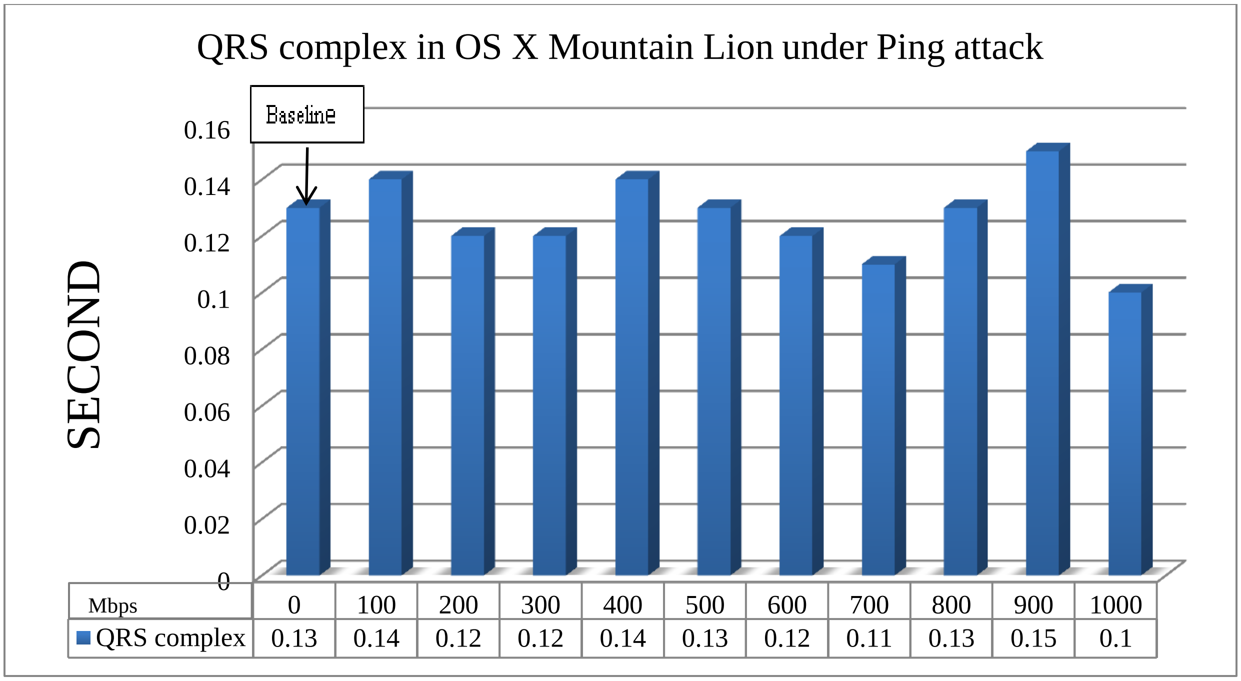


Figure 5.76 The values of QRS complex in OS X Mountain Lion under Ping attack

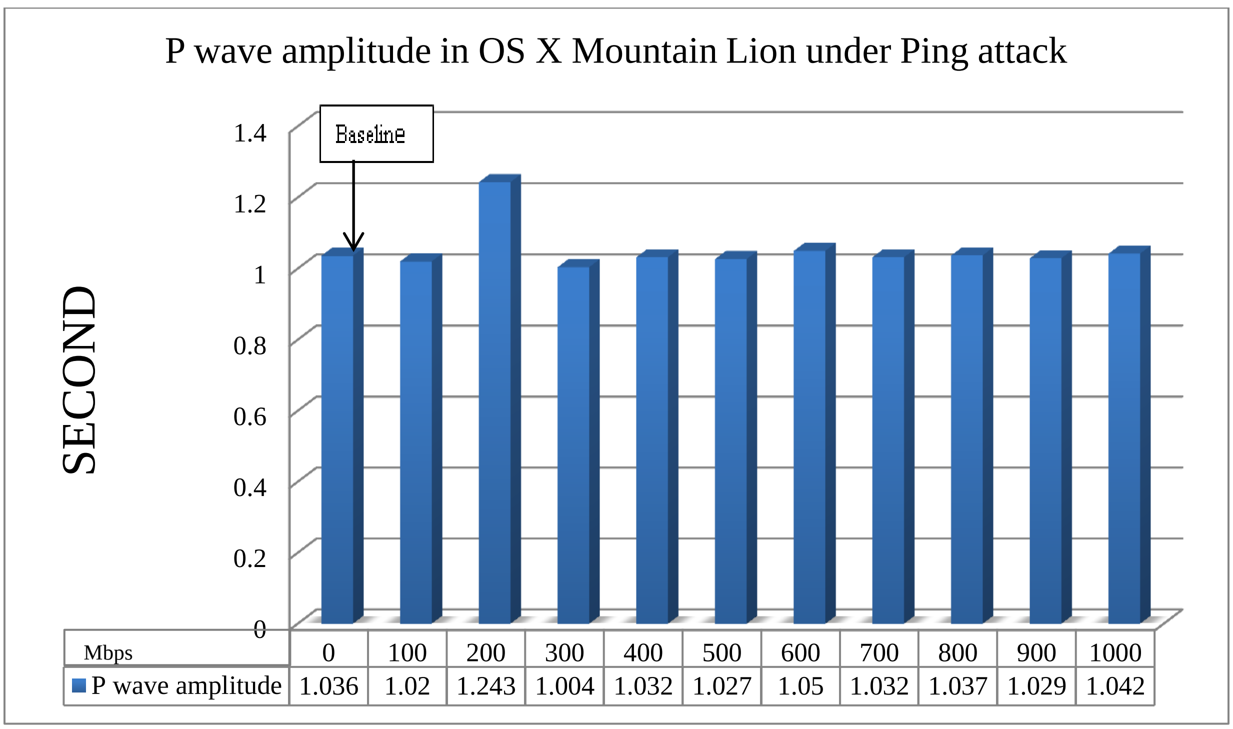


Figure 5.77 The values of P wave amplitude in OS X Mountain Lion under Ping attack

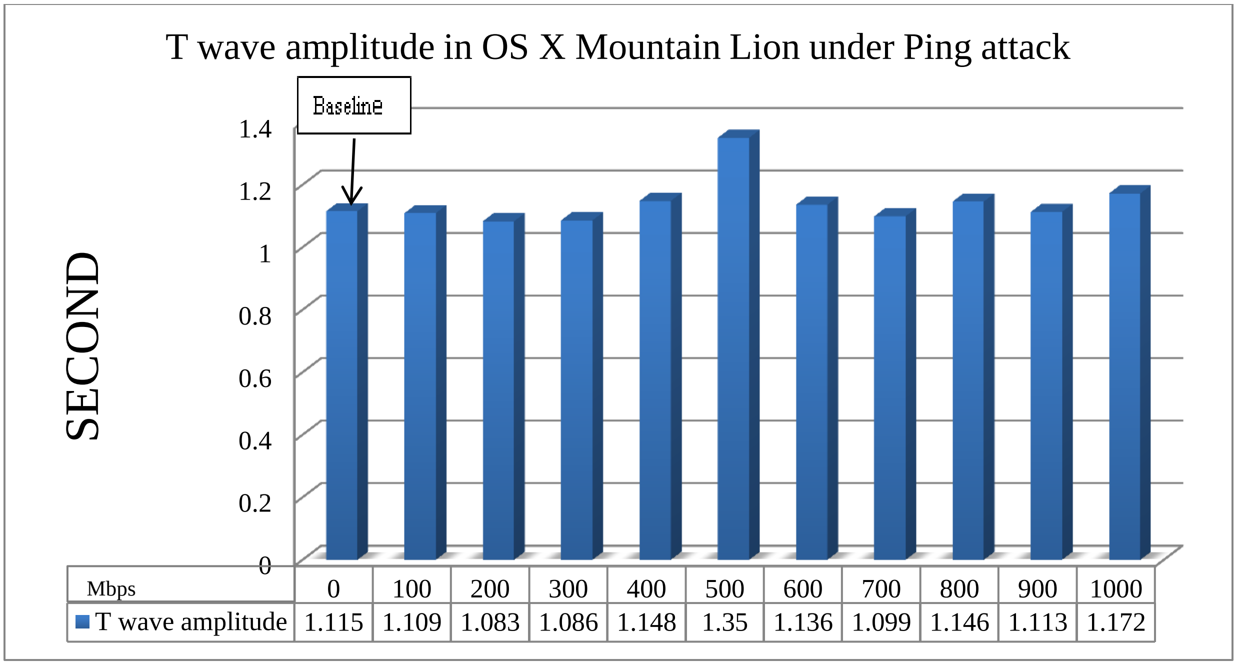


Figure 5.78 The values of T wave amplitude in OS X Mountain Lion under Ping attack

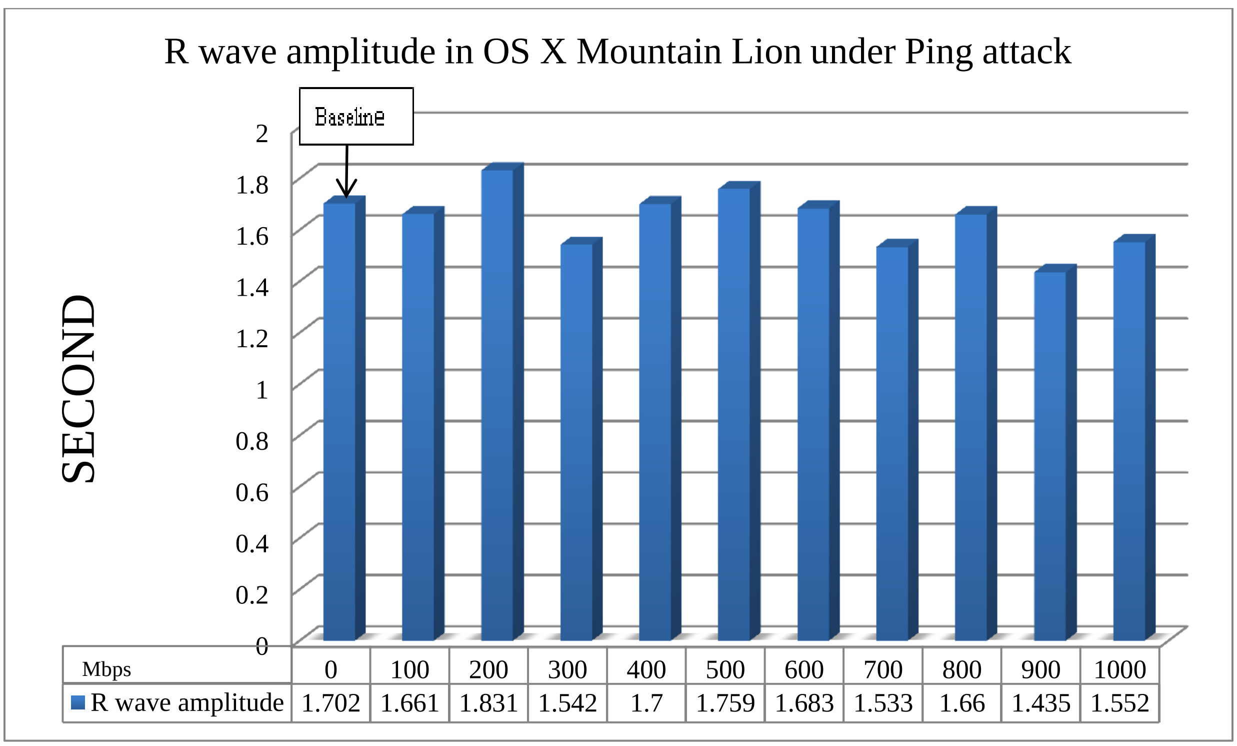


Figure 5.79 The values of R wave amplitude in OS X Mountain Lion under Ping attack

5.4.4 OS X Yosemite Results. Figure 5.80 and table 5.4 show the ECG signal in normal condition in OS X Yosemite operating system and the value of all components.

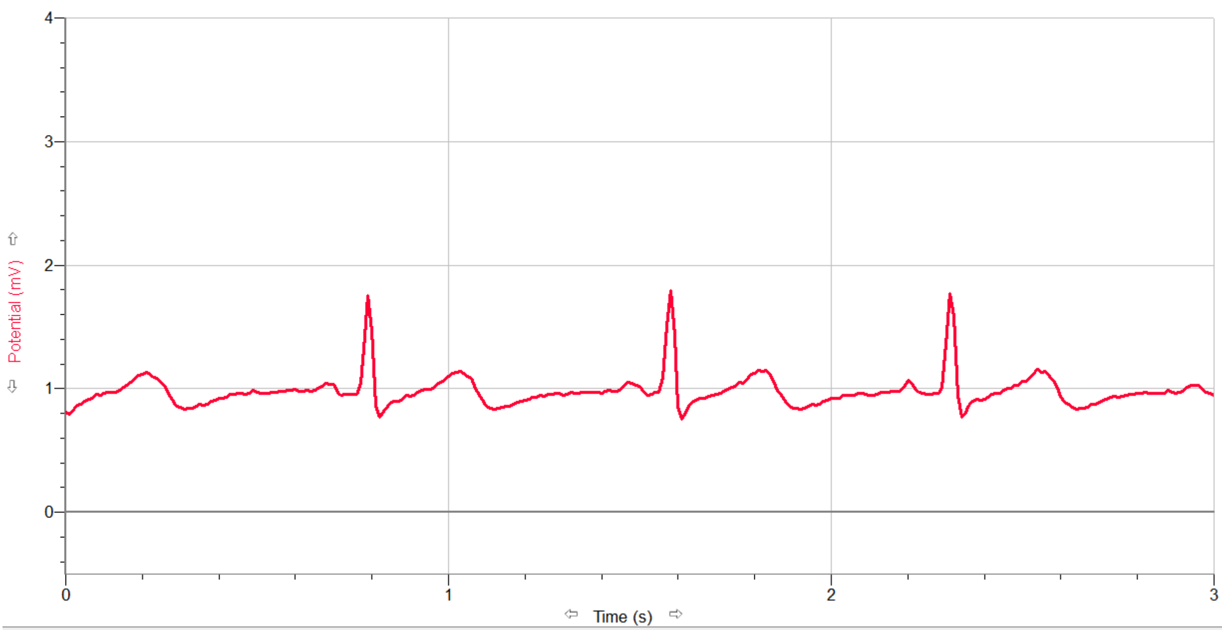


Figure 5.80 Baseline ECG collected by OS X Yosemite operating system under network condition

Table 5.4 Feature values of ECG signal in OS X Yosemite in the normal condition.

Feature	Value
R – R interval	0.79 s
S – T interval	0.10 s
P – Q interval	0.08 s
P wave amplitude	1.038 mV
T wave amplitude	1.142 mV
R wave amplitude	1.752 mV
QRS complex	0.13 s

5.4.4.1 ECG Data Collection Under ARP Attack. According to the figure 5.81 the T wave of ECG signals under ARP attack changed and the amplitudes of R waves change irregularly. Those two deviations from original signal can interpret as ischemia, as any change in the shape of T wave can be consider as ischemia. Figure 5.82 to figure 5.88 show all the components of the ECG signal under ARP attack. Figure 5.82 shows R-R intervals that can be interpreted as tachycardia for 100 Mbps to 300 Mbps attack load and can be considered as bradycardia from 400 Mbps to 1 Gbps attack load. Figures 5.83, 5.84, 5.86, and 5.87 show S-T interval, P-Q interval, P wave, and T wave respectively which are deviated from baseline several time in different attack loads and can be interpreted as ischemia. According to the figure 5.85 QRS complex, which relates to ventricular depolarization and depolarization can be considered as normal heart condition. Figure 5.88, which shows R wave amplitude, is observed as a normal R wave. Therfore ARP attack did not effect on QRS complex and R wave of the captured ECG signal.

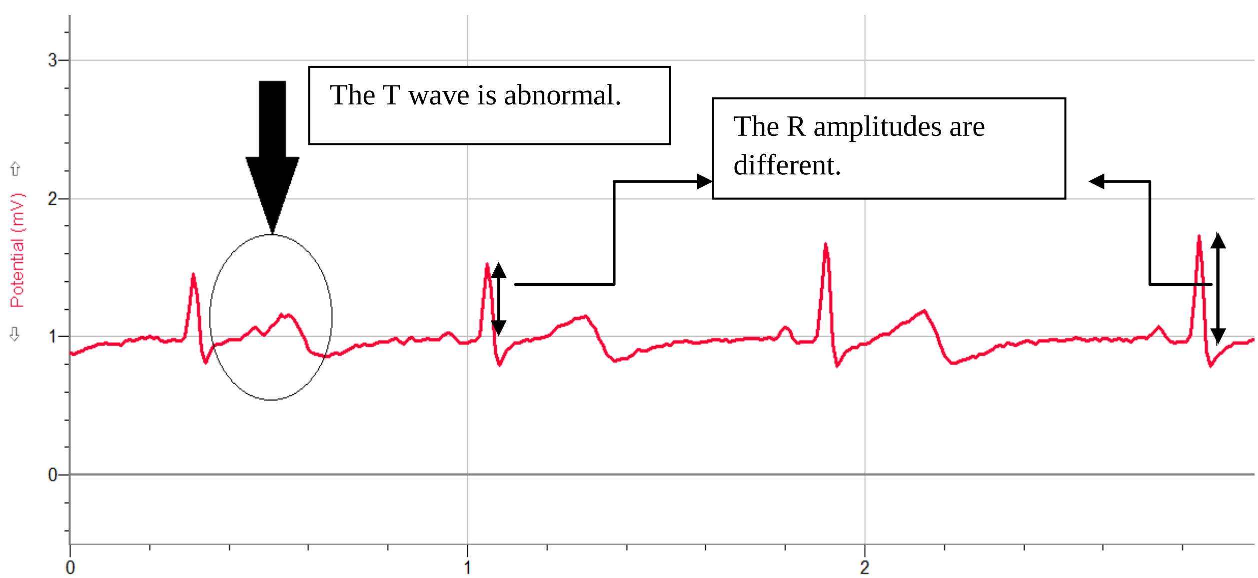


Figure 5.81 ECG signal under ARP attack at the speed of 1Gbps in OS X Yosemite operating system

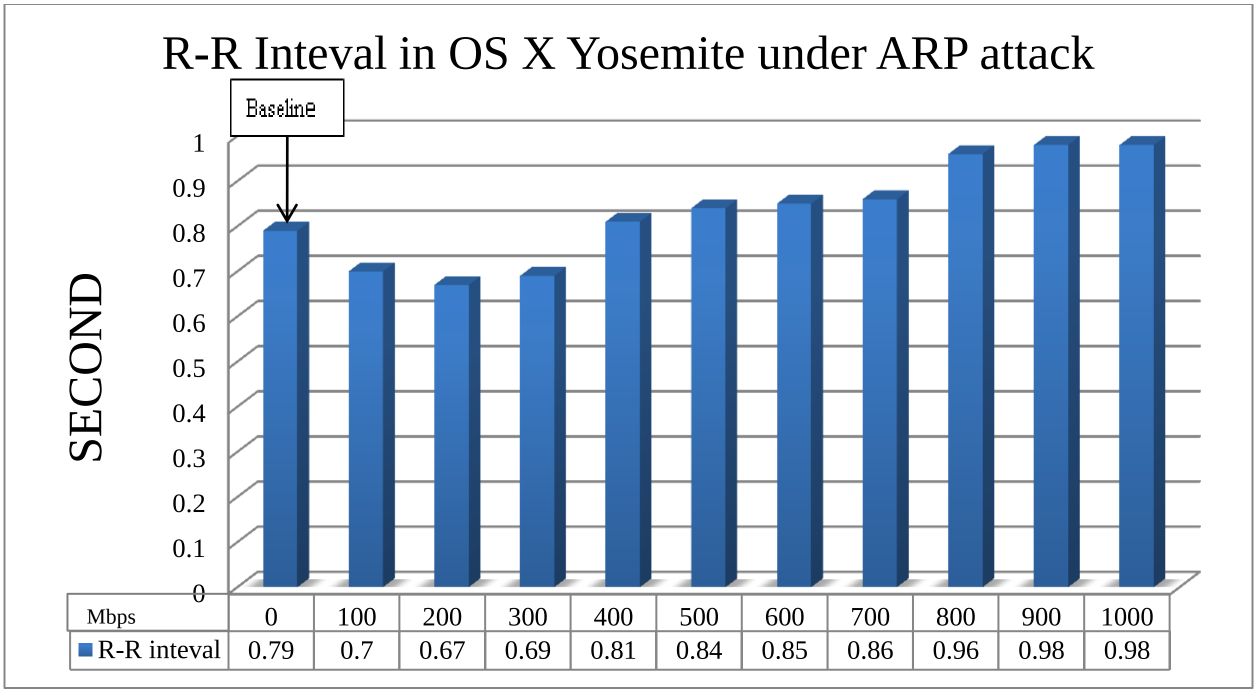


Figure 5.82 The values of R-R interval in OS X Yosemite under ARP attack

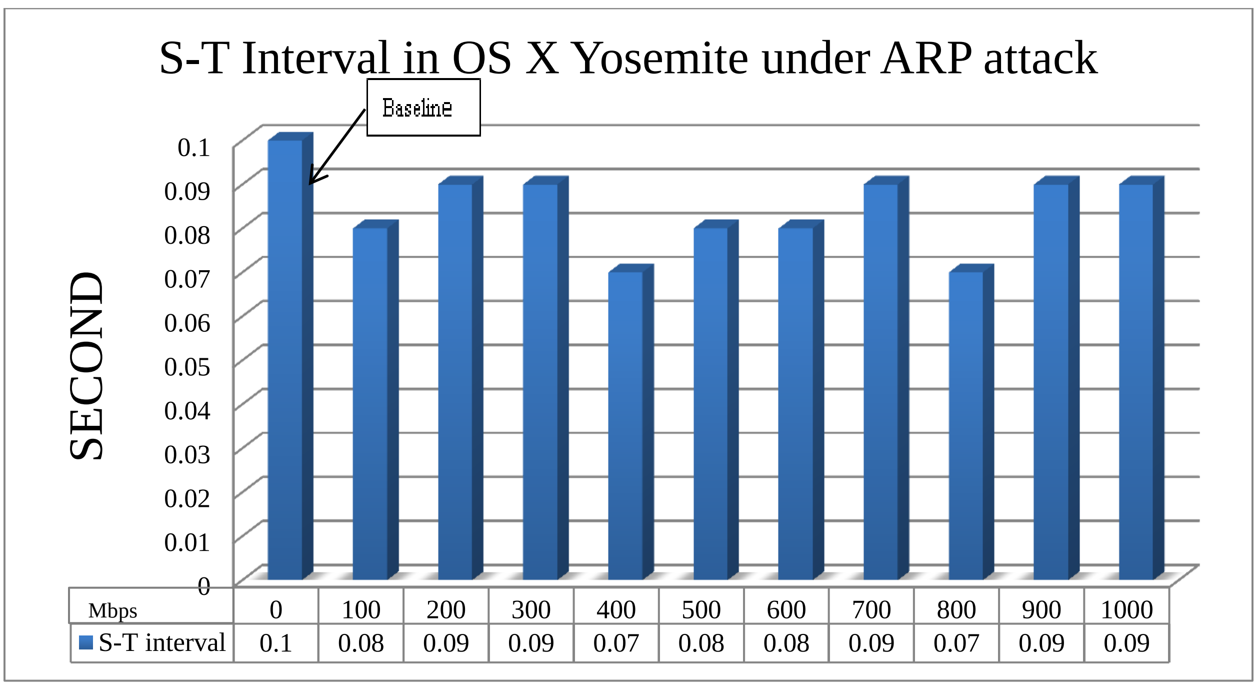
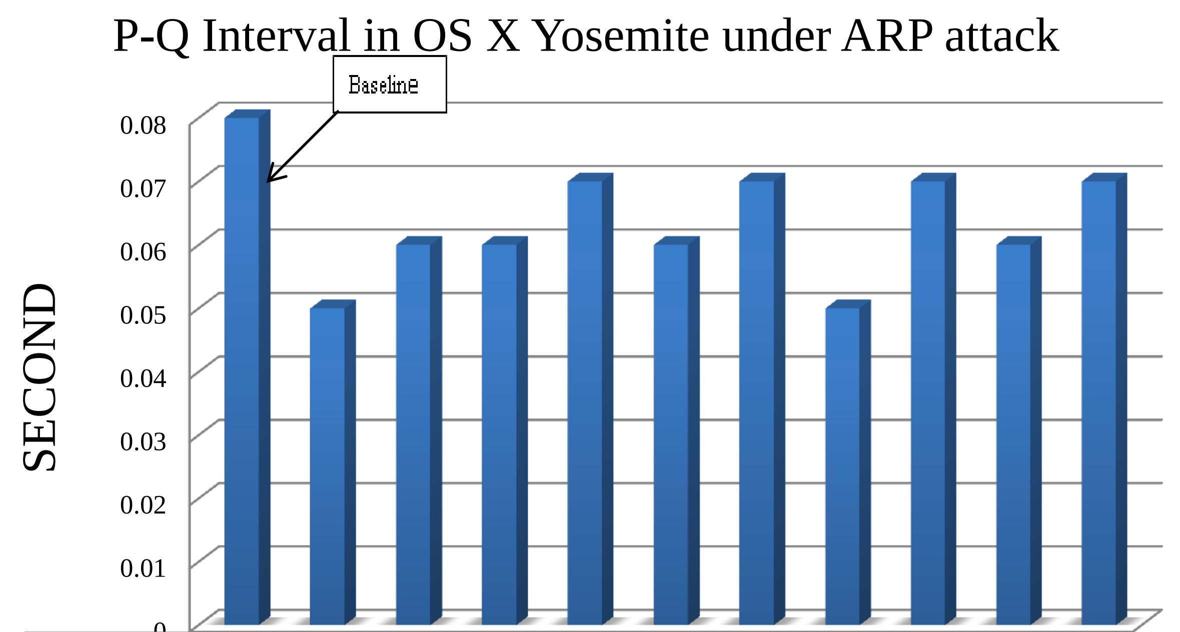
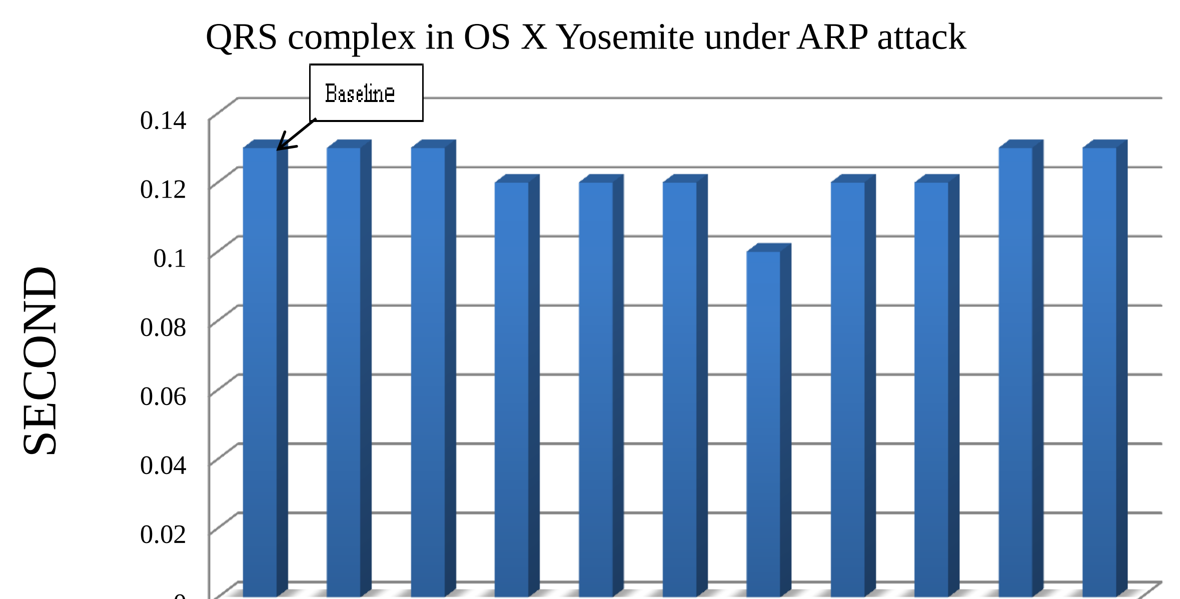


Figure 5.83 The values of S-T interval in OS X Yosemite under ARP attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
P-Q interval	0.08	0.05	0.06	0.06	0.07	0.06	0.07	0.05	0.07	0.06	0.07

Figure 5.84 The values of P-Q interval in OS X Yosemite under ARP attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
QRS complex	0.13	0.13	0.13	0.12	0.12	0.12	0.1	0.12	0.12	0.13	0.13

Figure 5.85 The values of QRS complex in OS X Yosemite under ARP attack

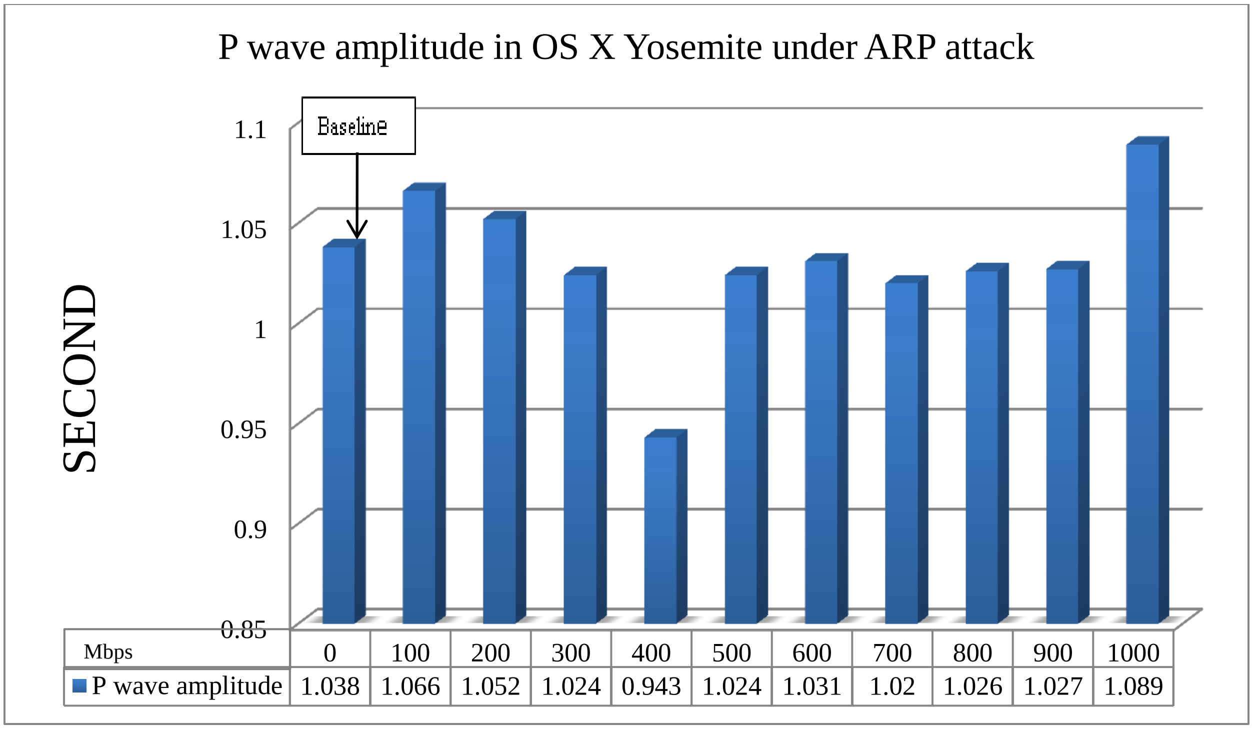


Figure 5.86 The values of P wave amplitude in OS X Yosemite under ARP attack

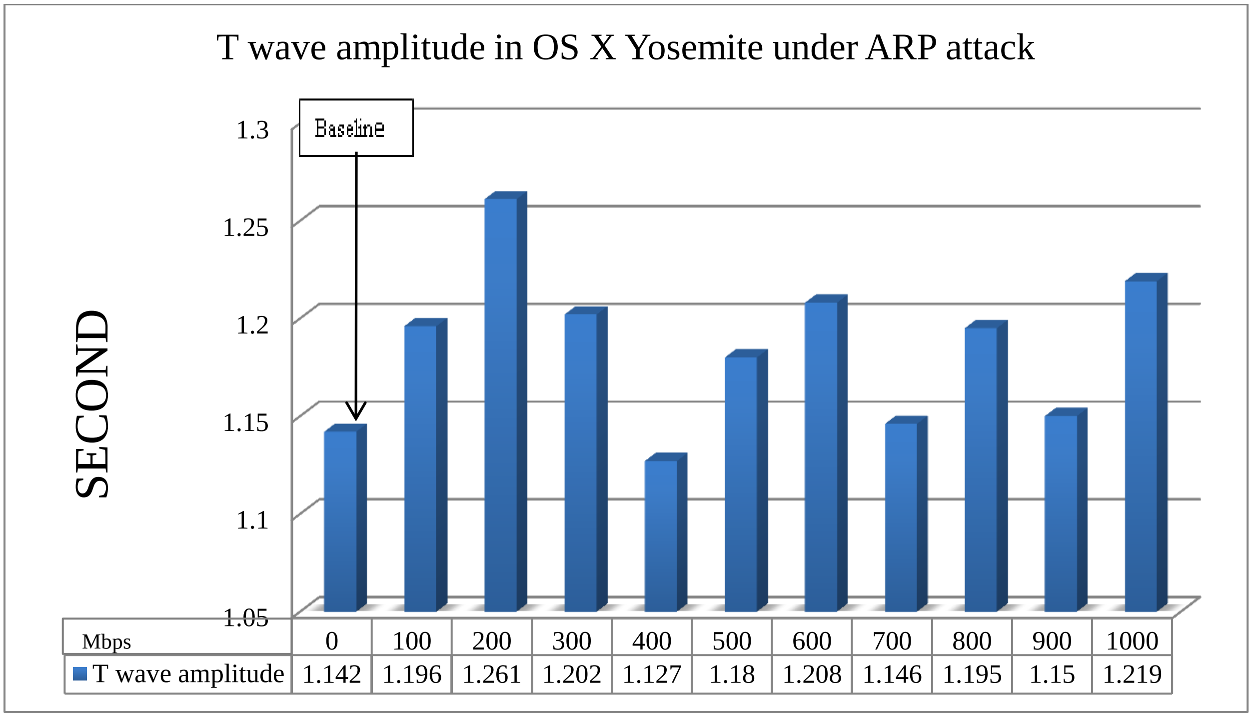


Figure 5.87 The values of T wave amplitude in OS X Yosemite under ARP attack

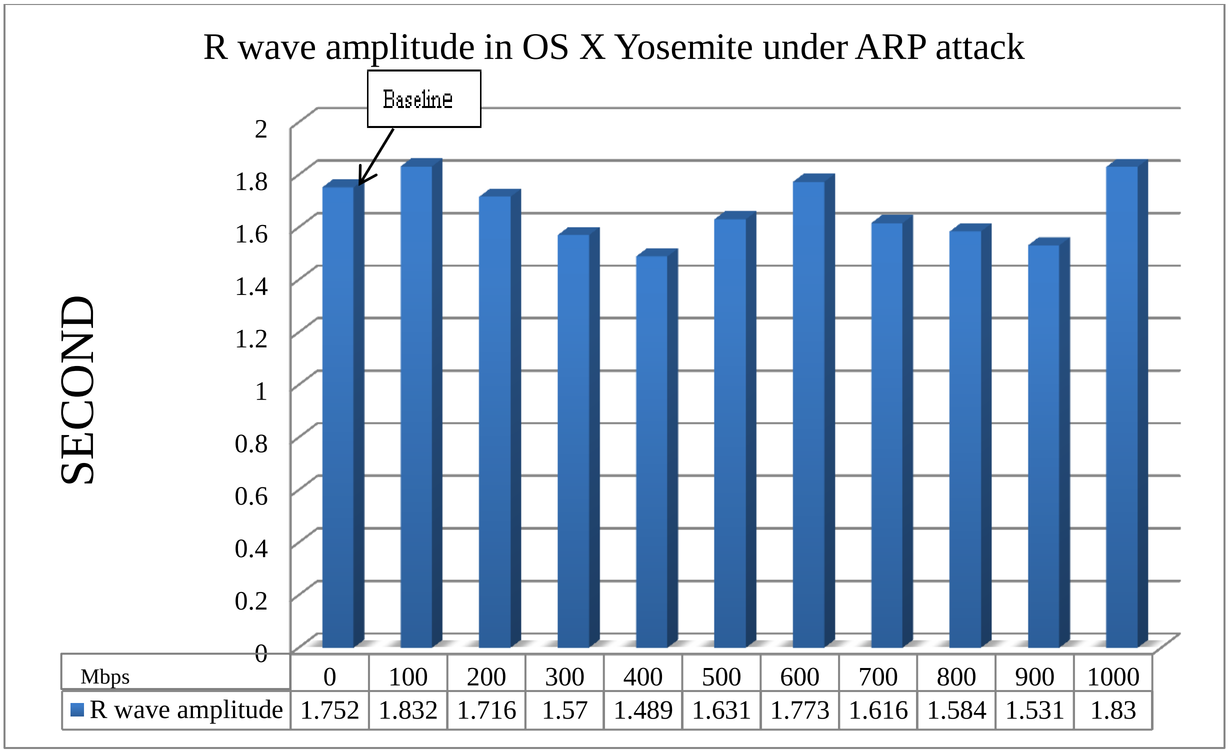


Figure 5.88 The values of R wave amplitude in OS X Yosemite under ARP attack

5.4.4.2 ECG Data Collection Under TCP SYN Attack. Captured ECG signal under TCP SYN attack at the speed of 1Gbps is illustrate in figure 5.89, which had no P wave and R-R intervals increased sharply and irregular rhythm, so these two factors can interpret as sinus bradycardia arrhythmia. This heart problem relates to slow heart beat rate. Figure 5.90 to figure 5.96 show the value of all components of the ECG signal under TCP SYN attack. QRS complex, which is shown in figure 5.93 almost, has a regular pattern and in figure 5.96 R wave has a constant pattern. According to figure 5.94 and 5.95, which are, represented P wave and T wave, the worst case is related to the attack load of 800 Mbps and generally they have irregular pattern.

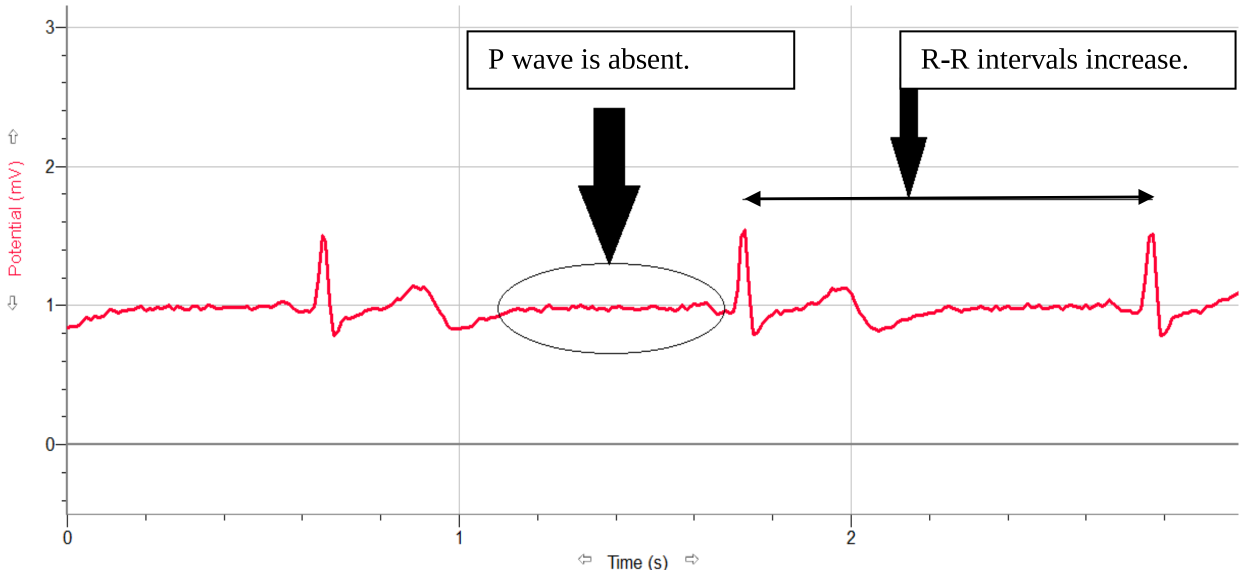
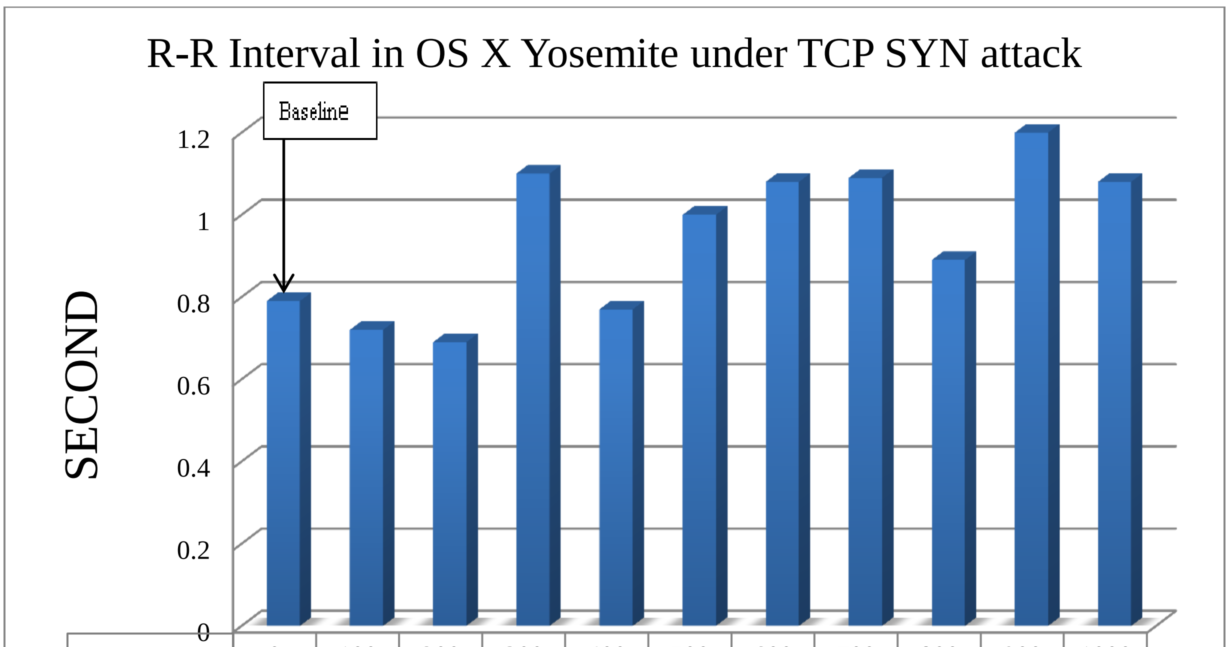


Figure 5.89 ECG signal under TCP SYN attack at the speed of 1Gbps in OS X Yosemite operating system



Mbps	0	100	200	300	400	500	600	700	800	900	1000
R-R interval	0.79	0.72	0.69	1.1	0.77	1	1.08	1.09	0.89	1.2	1.08

Figure 5.90 The values of R-R interval in OS X Yosemite under TCP SYN attack

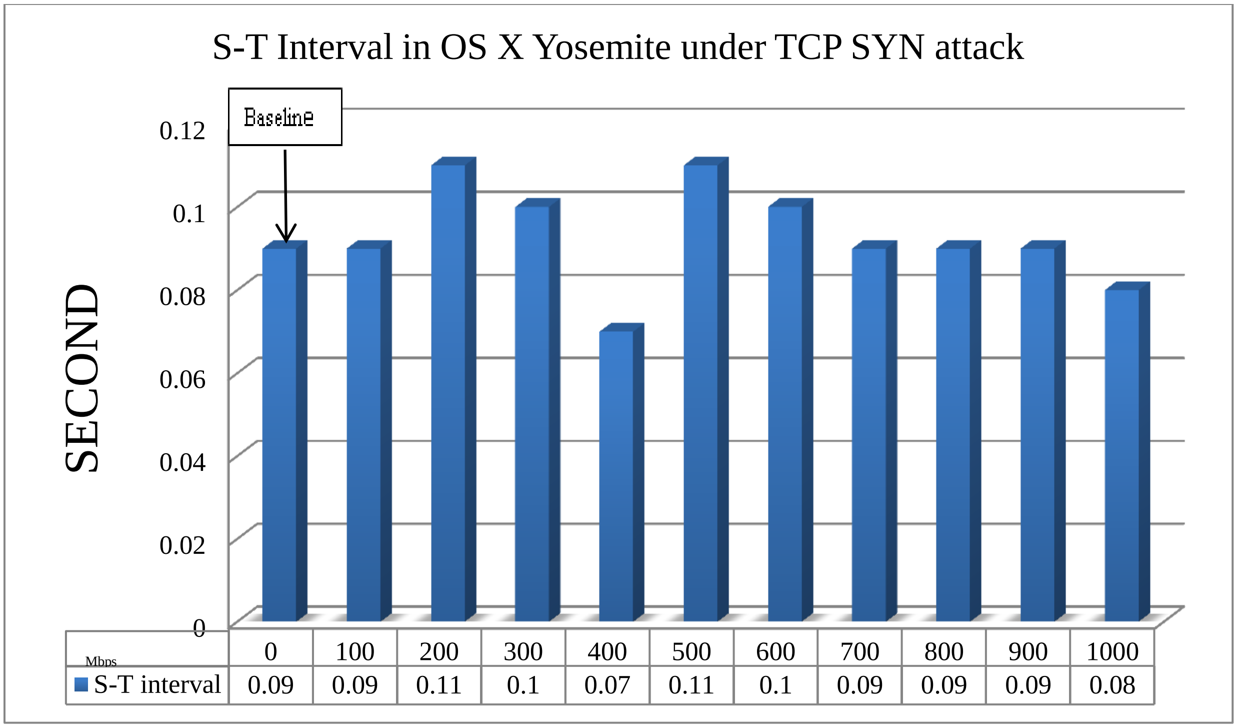


Figure 5.91 The values of S-T interval in OS X Yosemite under TCP SYN attack

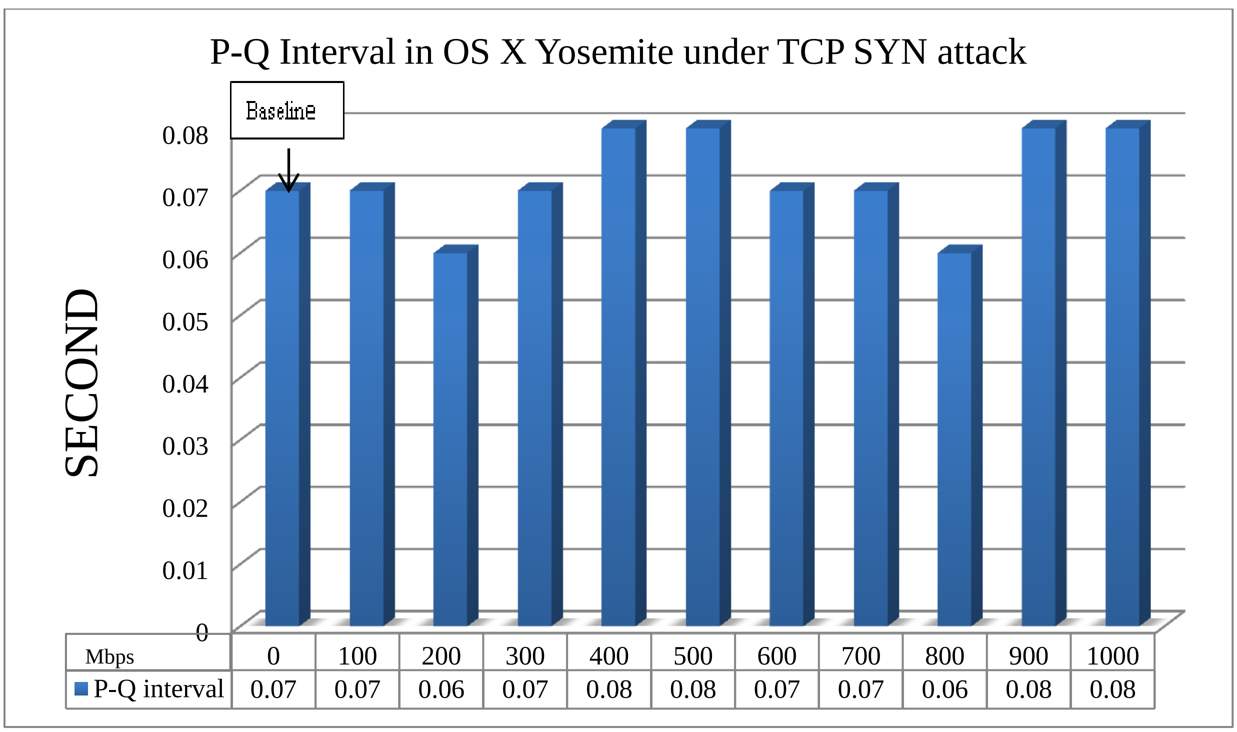


Figure 5.92 The values of P-Q interval in OS X Yosemite under TCP SYN attack

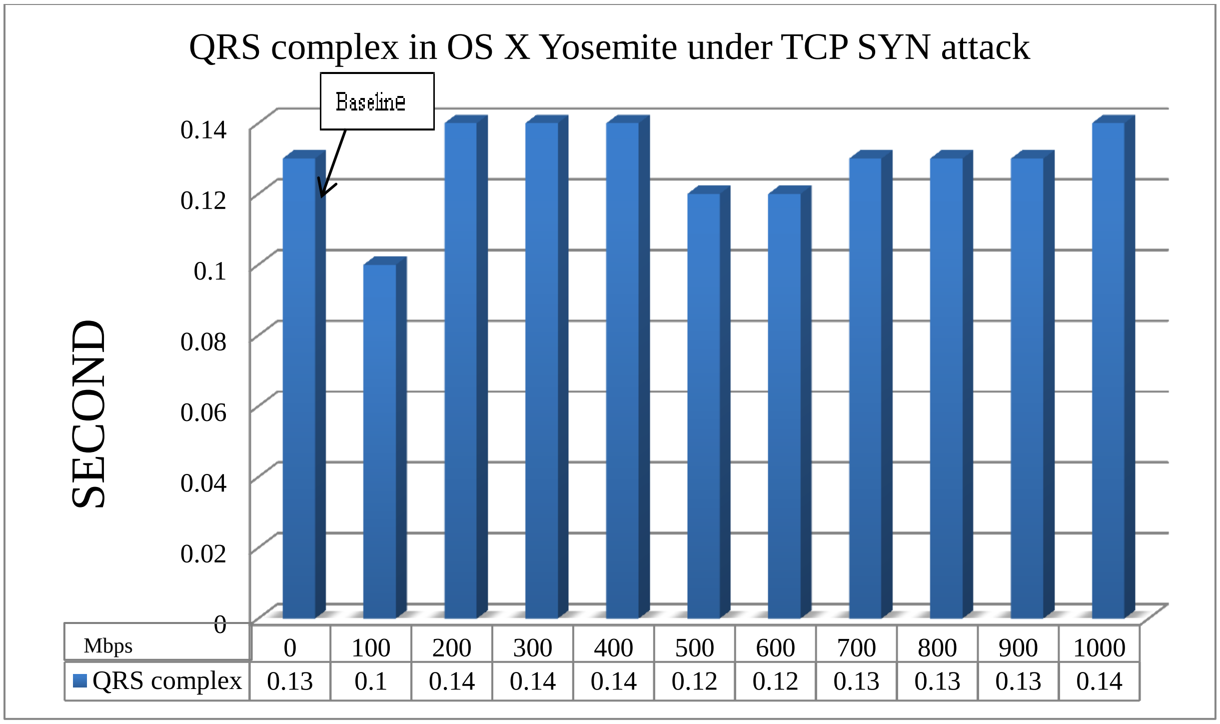


Figure 5.93 The values of QRS complex in OS X Yosemite under TCP SYN attack

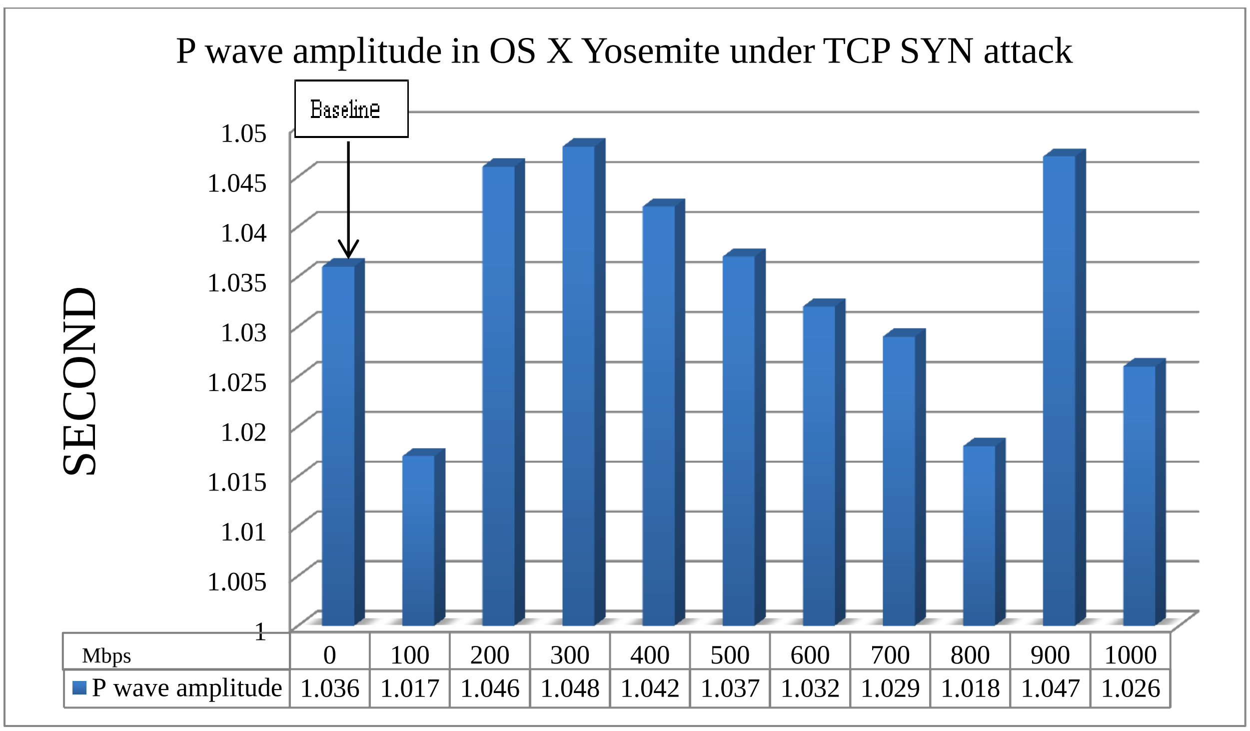
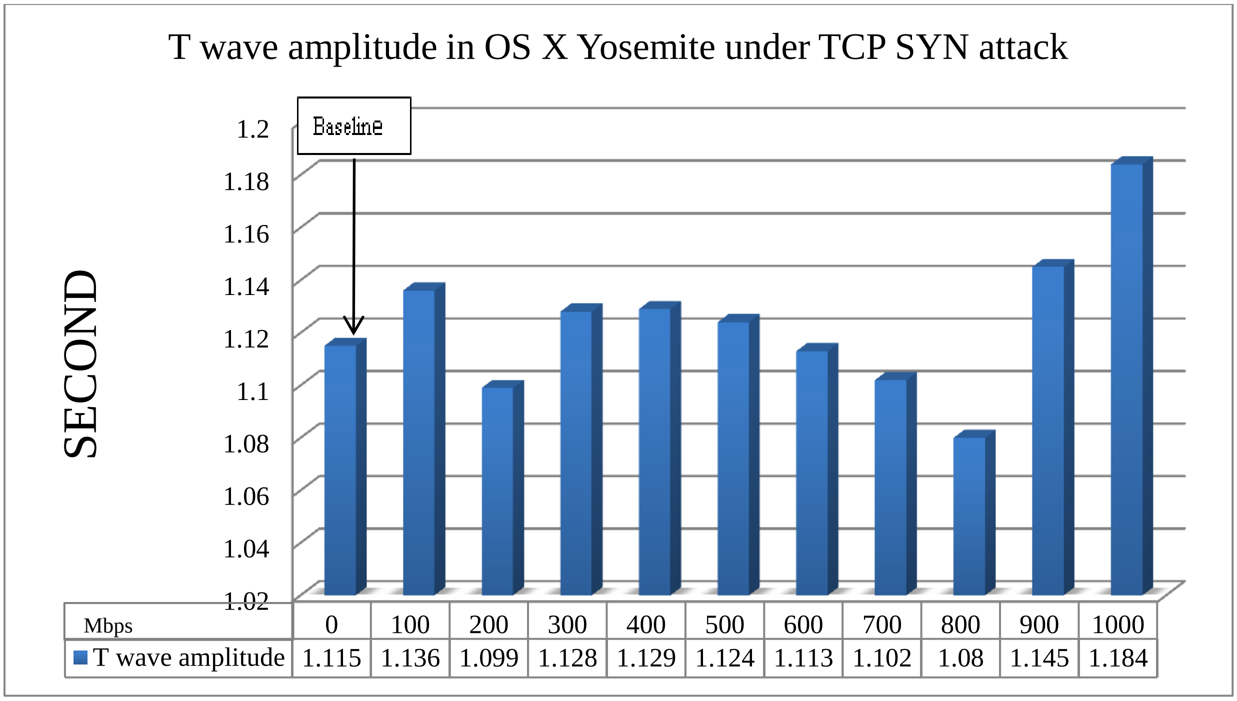
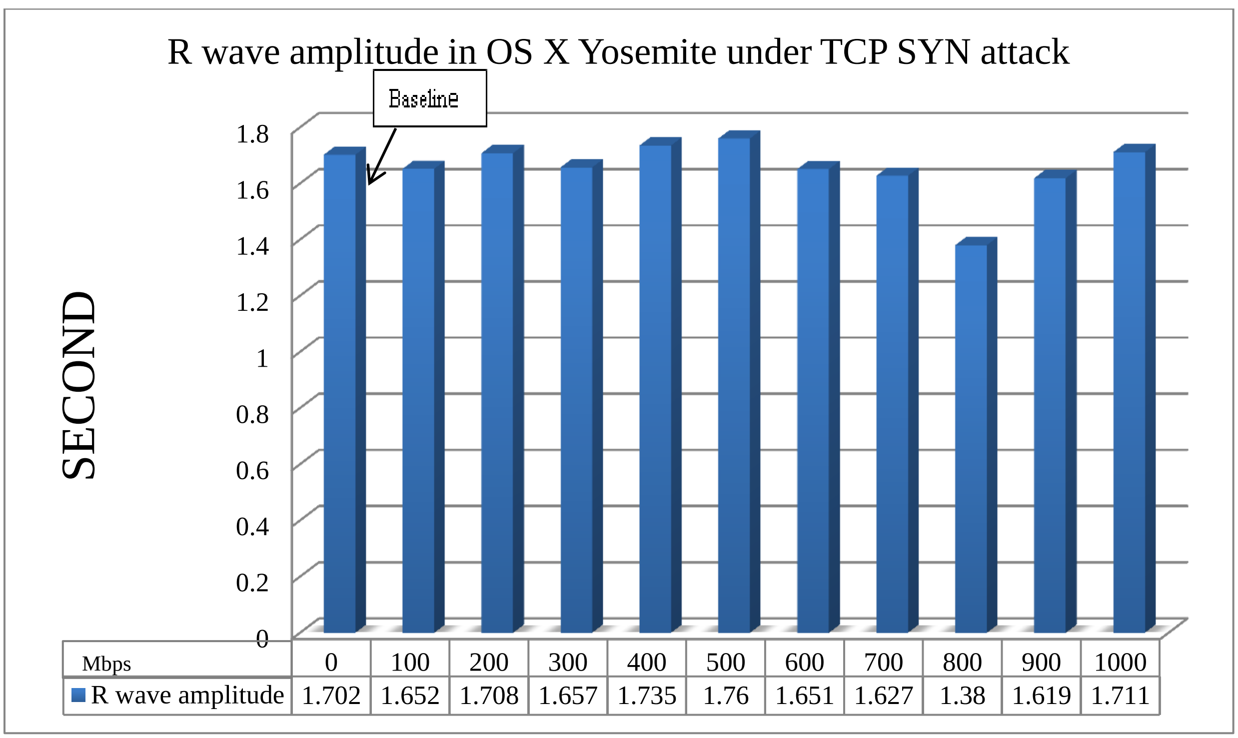


Figure 5.94 The values of P wave amplitude in OS X Yosemite under TCP SYN attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
T wave amplitude	1.115	1.136	1.099	1.128	1.129	1.124	1.113	1.102	1.08	1.145	1.184

Figure 5.95 The values of T wave amplitude in OS X Yosemite under TCP SYN attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
R wave amplitude	1.702	1.652	1.708	1.657	1.735	1.76	1.651	1.627	1.38	1.619	1.711

Figure 5.96 The values of R wave amplitude in OS X Yosemite under TCP SYN attack

5.4.4.3 ECG Data Collection Under Ping Attack. According to the figure 5.97 that shows the ECG signal under Ping attack in the worst case, T wave shape deviated from original signal. Absence of the P wave can be considered as atrial abnormality and abnormal T wave can be considered as ischemia. Figure 5.98 to figure 5.104 are illustrated the value of all components of ECG signal under Ping attack. According to the figure 5.98 R-R interval under Ping attack can represent both tachycardia and bradycardia heart problem. In figure, 5.102, which are, illustrated the P wave values there is a deviation from baseline in the attack load of 300 Mbps is observed that can be interpreted as abnormal P wave and atrial problem. In figure 5.103 T wave is deviated from baseline at the attack load of 100 Mbps that can be represent a problem in ventricular repolarization. Other components of ECG signal are normal.

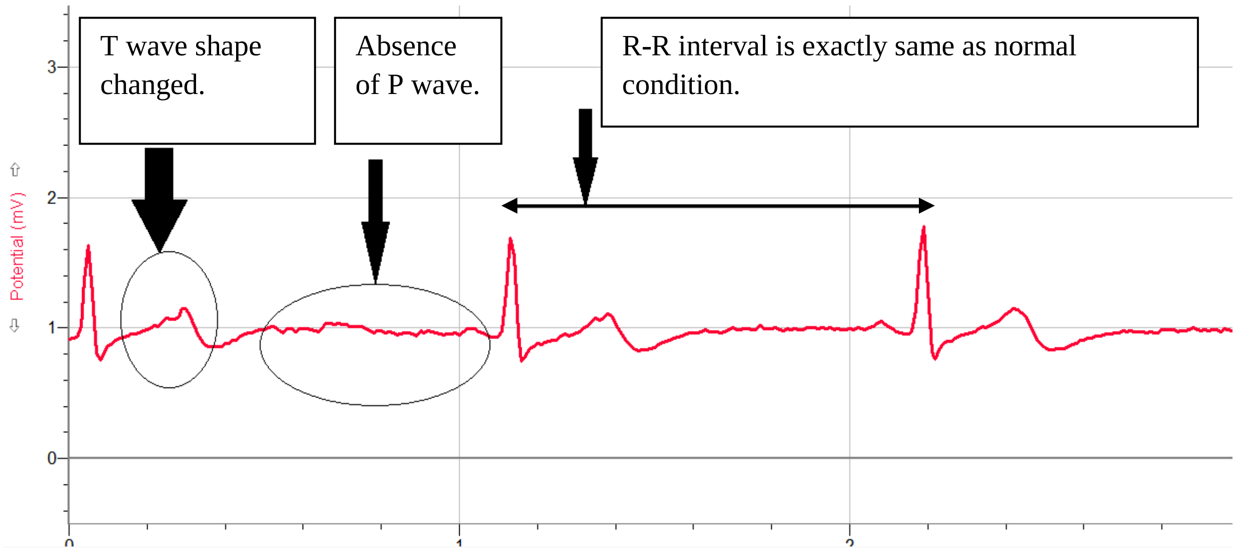
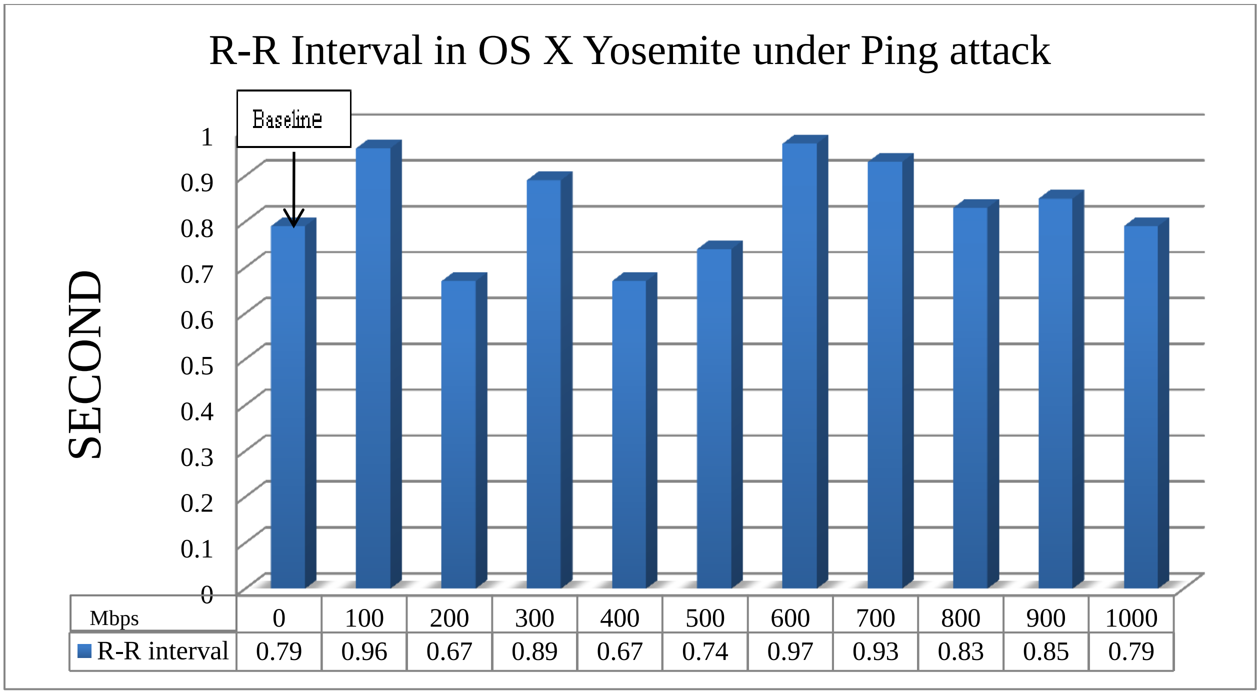
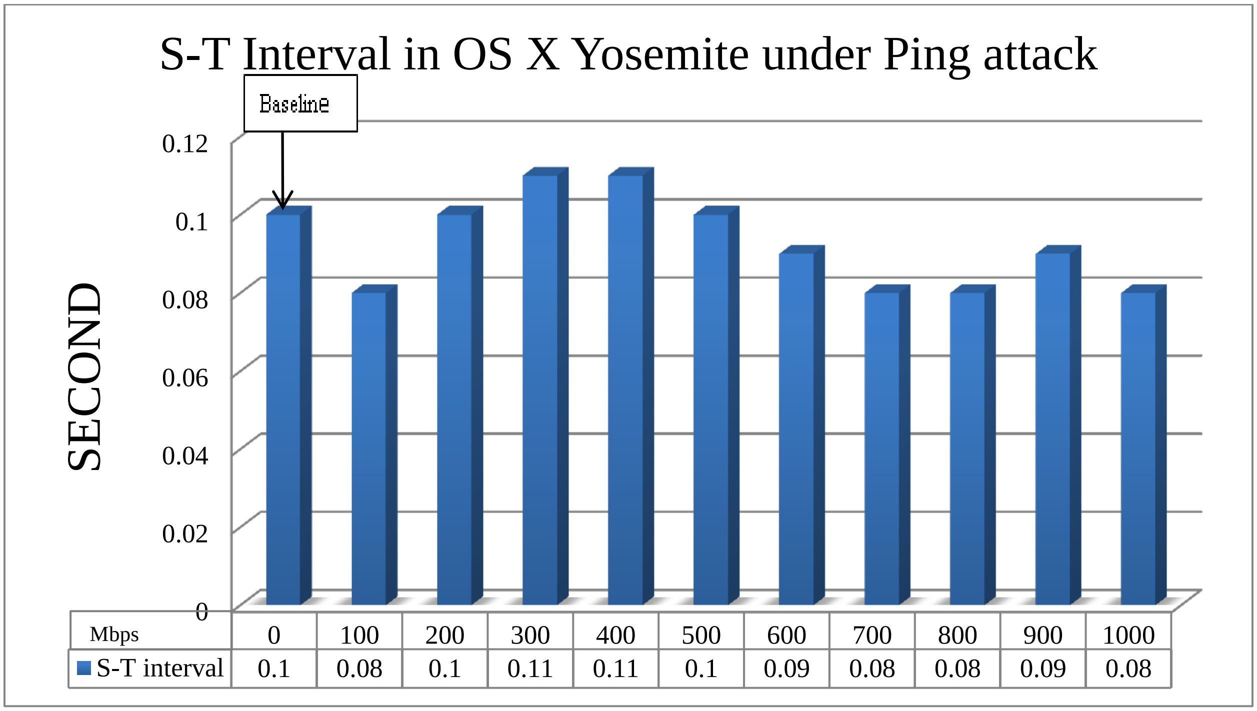


Figure 5.97 ECG signal under Ping attack at the speed of 1Gbps in OS X Yosemite operating system



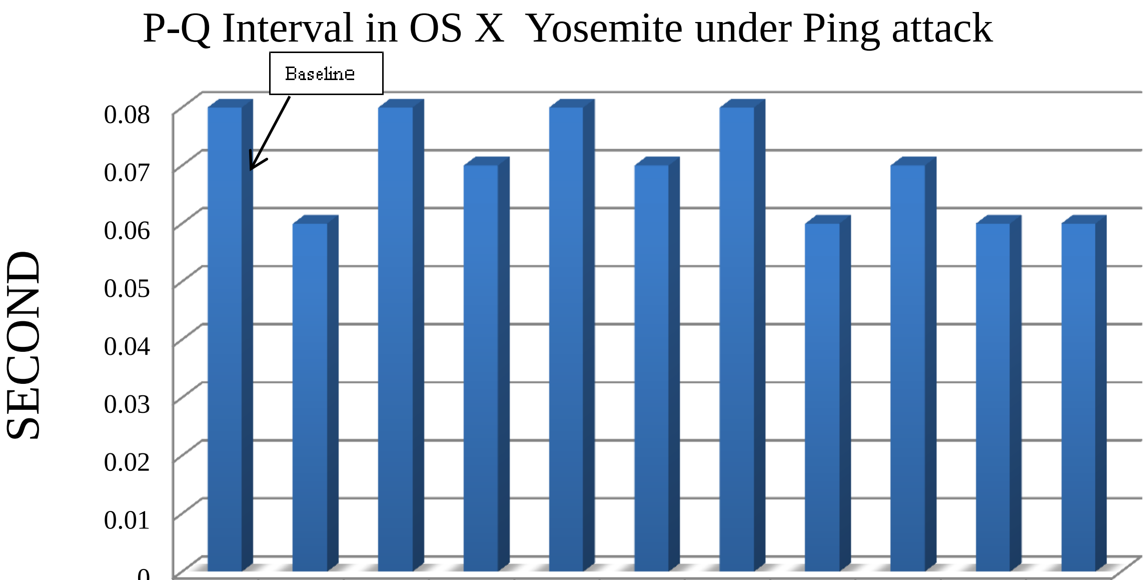
Mbps	0	100	200	300	400	500	600	700	800	900	1000
R-R interval	0.79	0.96	0.67	0.89	0.67	0.74	0.97	0.93	0.83	0.85	0.79

Figure 5.98 The values of R-R interval in OS X Yosemite under Ping attack



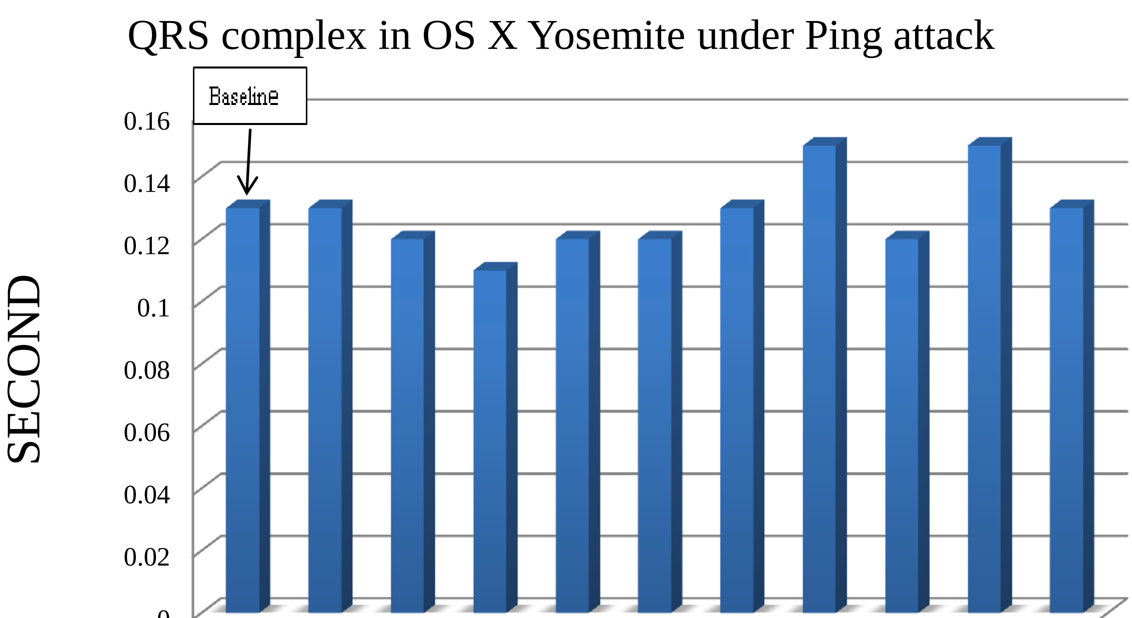
Mbps	0	100	200	300	400	500	600	700	800	900	1000
S-T interval	0.1	0.08	0.1	0.11	0.11	0.1	0.09	0.08	0.08	0.09	0.08

Figure 5.99 The values of S-T interval In OS X Yosemite under Ping attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
P-Q interval	0.08	0.06	0.08	0.07	0.08	0.07	0.08	0.06	0.07	0.06	0.06

Figure 5.100 The values of P-Q interval in OS X Yosemite under Ping attack



Mbps	0	100	200	300	400	500	600	700	800	900	1000
QRS complex	0.13	0.13	0.12	0.11	0.12	0.12	0.13	0.15	0.12	0.15	0.13

Figure 5.101 The values of QRS complex in OS X Yosemite under Ping attack

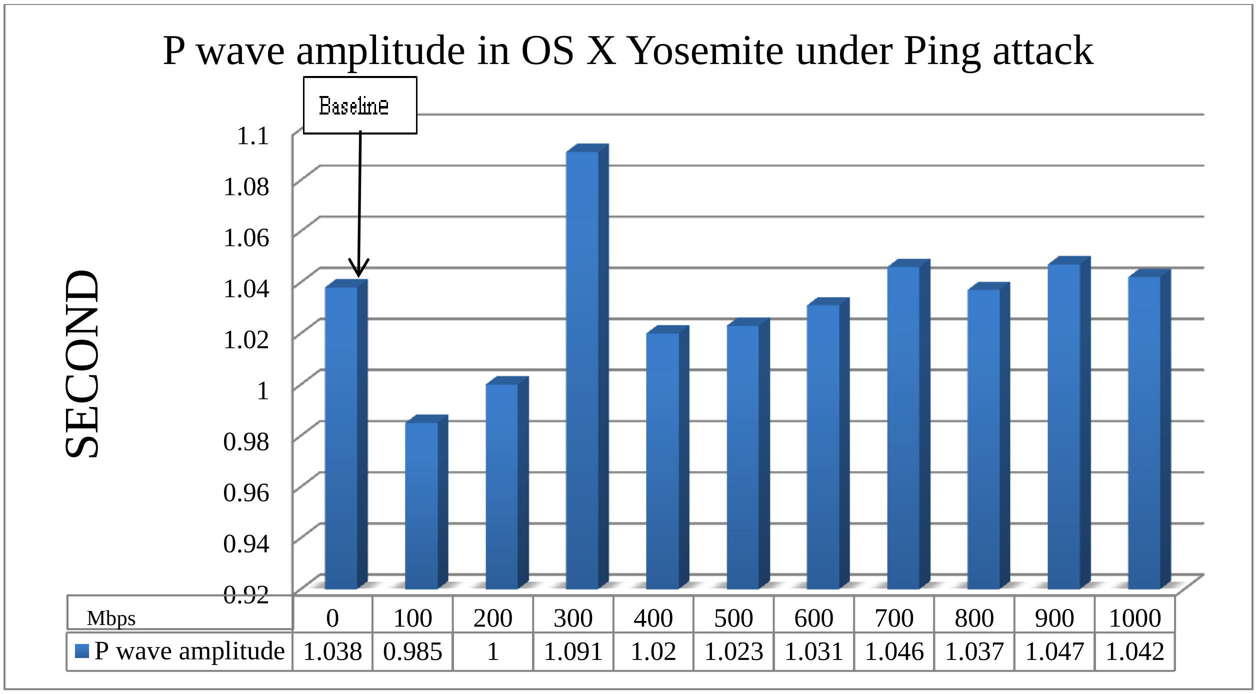


Figure 5.102 The values of P wave amplitude in OS X Yosemite under Ping attack

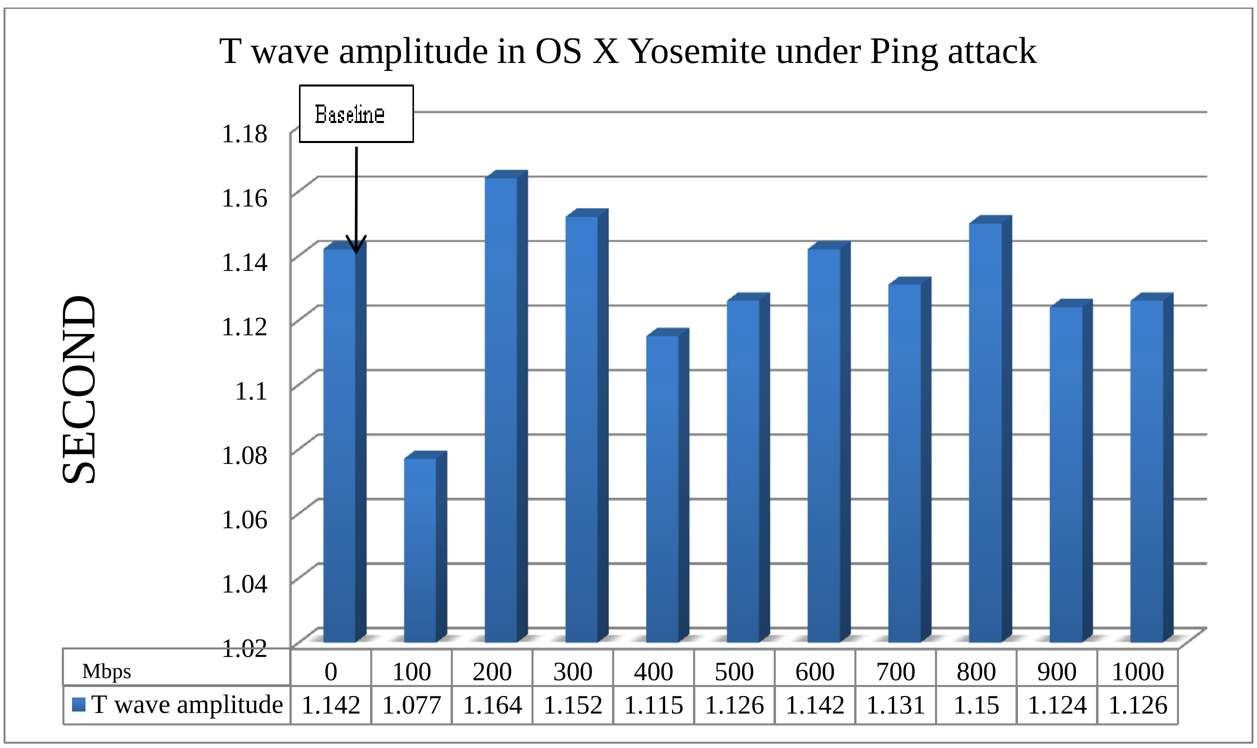


Figure 5.103 The values of T wave amplitude in OS X Yosemite under Ping attack

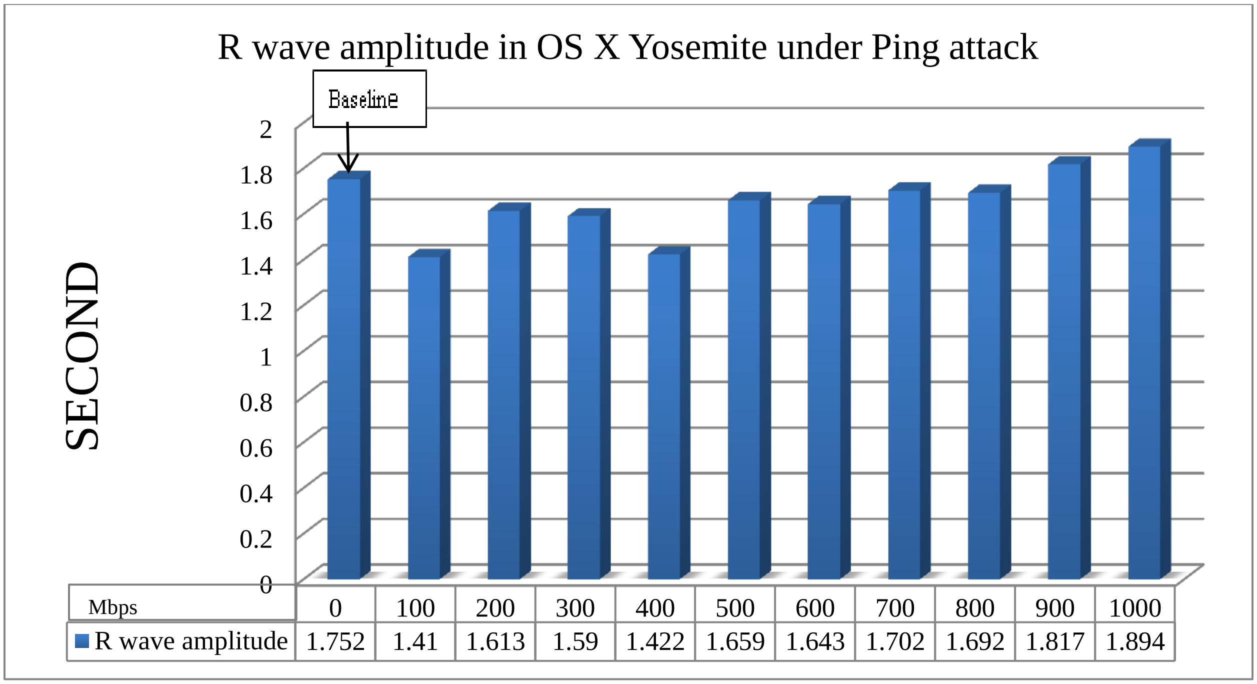


Figure 5.104 The values of R wave amplitude in OS X Yosemite under Ping attack

To compare the operating systems that were used in this experiment, Windows 8 Microsoft performed worse than other three operating systems. The OS X Lion and OS X Mountain Lion performed better than others did. None of these operating systems can quality for HIPAA certification completely. To compare three Cyber-attacks that were sent to the monitoring systems, TCP SYN attack affected the ECG signal more than other two attacks. Ping attack affected the ECG signal less than two other attacks in OS X Lion and OS X Mountain Lion operating systems. ARP attack affected the ECG signal in OS X Yosemite more than three others operating systems.

CHAPTER VI

CONCLUSION

The main purpose of this research is focused on the, Electrocardiogram monitoring on the Mac platform under network attack conditions. Nowadays, by increasing the number of Cyber-attacks, researchers and networking engineers try to recognize the effect of these attacks and remove them from original data to reach useful data. This issue becomes more important in ECG monitoring, because false ECG interpretation can raise false alarm for patient with cardiac problems and may result in wrong diagnosis and wrong treatment.

In this research human ECG was recorded at rest position on the Mac platform, separately four different operating systems, and three kinds of Cyber-attacks were simulated for the Mac platform during ECG collection. As the results were shown in chapter V the Windows 8 can be considered as the worst operating system for monitoring ECG signal under Cyber-attacks in the network. Three most important ECG components, which include R-R interval S-T interval and P wave under all three Cyber-attacks, deviated from ECG in normal condition. whereas in OS X Lion, OS X mountain Lion, and OS X Yosemite only in worst case with the traffic speed of 1Gbps.

Captured ECG signals under condition of ARP attack in Windows 8 Microsoft can be interpreted as junctional escape rhythm, in OS X Lion as premature atrial contractions or just an abnormality of heart function with the atrial problem, in OS X Mountain Lion as premature atrial contractions, and in OS X Yosemite as ischemia. In Windows 8 all the ECG components deviated from original ECG signal in normal condition so it can be considered as the worst operating system for monitoring ECG signal. Both OS X Lion and OS X Yosemite operating systems perform better than other two operating systems under ARP attack.

Windows 8 Microsoft had the worst performance among those four operating systems because after 700 Mbps attack traffic by consuming all computing resources the monitoring device got freeze so capturing ECG signal was impossible. In OS X Yosemite TCP SYN attack can be considered as ischemia whereas in other two operating systems, it did not affect ECG signals, and it only caused delay and abnormality, which is important here, is bradycardia.

The last cyber-attack, which was sent to the iMac platform, was Ping attack. Ping attack did not affect Windows 8 Microsoft OS X Lion and OS X Mountain Lion, it cased only delay on these operating systems and in worst case, it can be considered as bradycardia, which is not a serious heart problem. In OS X Yosemite Ping attack affected ECG signal a lot specially changed T wave amplitude and S-T interval that can be interpreted as ischemia.

This research is an advance approach to detect the abnormalities on the ECG signal and realize that these abnormalities are from heart problem or they are caused by Cyber-attack. Both OS X Lion and OS X Mountain Lion have the better performance under Cyber-attacks.

Nowadays wireless monitoring is improved in both aspects software and hardware. It can be useful for old patients who lives alone and cannot go to the clinic or hospital, all these experiments can be done with wireless devices and the effect of those cyber-attacks can be studied. To improve the study the effect of network security systems such as Firewall, IPS, and IDS can be investigated, also it is useful to evaluate systems and networks before deployment.

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BIOGRAPHICAL SKETCH

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