Palestine Polytechnic University

College of Engineering and Technology

"The Effect of Multiple wifi Technology on Throughput"

Prepared By :

Mahmoud naeem oda rajabee

Fadel mohammedfaten shaheen

Mahmoud Ajlouni

Supervisor

Eng.ahmad qudimat

2010-2011

ROJECT NAME

“The Effect of Multiple wifi Technology on Throughput"

Prepared By

Mahmoud naeem oda rajabee

Fadel mohammedfaten shaheen

Mahmoud Ajlouni

According to the directions of the project supervisor and by the agreement of all examination committee members, this project is presented to the department of Mechanical Engineering at College of Engineering and Technology, for partial fulfillment Bachelor of engineering degree requirements.

Supervisor Signature

....

Committee Member Signature

....

Department Head Signature

....

Abstract

This project attempts to measure the throughput of different Wi-Fi technologies by using Colasoft Capsa7 program. The measurements are carried out for 802.11b/g/n in 2.4GHz band. Thereafter, comparisons for the aforementioned Wi-Fi technologies have been done for different clients configurations.

During in this project there are many results and measurements are obtained, such as; in combinations that contain equal number of b and g clients; throughput of b client is higher than g client. In combinations that contain equal number of b and n clients, throughput of each n clients are higher than each b clients.

Although in Combinations that contain g and n clients, throughput of n clients are higher than g clients in all combination between them.

الإهداء

بسم الله الرحمن الرحيم

الهي لا يطيب الليل إلا بشكرك ولا يطيب النهار إلا بطاعتك ...ولا تطيب اللحظات إلا بذكرك ... ولا تطيب الآخرة إلا بعفوك.. ولا تطيب الجنة إلا برؤيتك الله جل جلالة

إلى من بلغ الرسالة وأدى الأمانة ... ونصح الأمة ... إلى نبي الرحمة والعالمين..

سيدنا محمد صلى الله عليه وسلم

إلى من كلله الله بالهيبة والوقار .. إلى من علمني العطاء بدون انتظار ... إلى من أحمل اسمه بكل افتخار أرجو من الله أن يمد في عمرك لترى ثمارا قد حان قطافها بعد طوال انتظار وستبقى كلماتك نجوم أهتدي بهذا اليوم وفي الغد والى الأبد ..

والدي العزيز

إلى ملاكي في الحياة ... إلى معنى الحب والى معنى الحنان والتفاني ... إلى بسمة الحياة وسر الوجود إلى من كان دعائها سر نجاحي وحنانها بلسم جراحي إلى أغلى الحبايب

أمي الحبيبة

ووداعهم ونحن نخطو خطوتنا الأولى في غمار الحياة فواجب علينا شكرهم

ونخص بالجزيل الشكر والعرفان إلى كل من أشعل شمعة في دروب عملنا و

وإلى من وقف على المنابر وأعطى من حصيلة فكره لينير دربنا

إلى الأساتذة الكرام في كلية الهندسة شكر الجزيل إلى

المهندس : أحمد قديمات

الذي تفضل بإشراف على هذا المشروع فجزاه الله عنا كل خير فله منا كل التقدير والاحترام

والمهندس : مهند العجلوني

الذي تفضل بمساعدتنا على تأمين مستلزمات المشروع من الخارج

"كن عالما ... فإن لم تستطع فكن متعلما، فإن لم تستطع فأحب العلماء، فإن لم تستطع فلا تبغضهم"

List OF Tables

List of figure

Content

Chapter one introduction

Chapter Two : Theoretical Background

Chapter Three : System Design and Implementation

Chapter four : designe detail

Chapter five : result and analysis

Chapter six : conclusion and future work

Chapter 1

Introduction

1.1. Overview.

1.2. Objectives.

1.3. Project Risk Management.

1.4. Project Schedule.

1.5. Estimated Cost.

1.6. Outline.

1.1. Overview.

Wireless networks refer to any type of computer and telecommunications network in which interconnections between nodes are implemented without the use of wires. Wireless telecommunications networks are generally implemented with some type of remote information transmission system that uses electromagnetic waves.

Wireless LAN (WLAN) is a networking technology that allows the connection of computers without wires or cables, mostly using radio and infrared frequency. It's called LAN because the range is limited within an office, building, store, or just house.

The WIFI technology is a short name for Wireless Fidelity and that is a standard for wireless local area networks (WLANs). It's like a common language that all the devices use to communicate to each other; it is known as IEEE 802.11, there are different versions of it, the main communications standards are 802.11, 802.11a, 802.11b, 802.11g, and 802.11n.

If there are a group of clients that are connecting to the AP and since there are many Wi-Fi technologies, this network may have combination of clients that uses different type of Wi-Fi technologies.

1.2. Objectives.

By our network we want to build, we want to satisfy a group of objectives that are:

1. Designing wireless network that consists of different combination of Wi-Fi technologies.
2. Measuring the throughput of each client in all client's cases.
3. Measuring the throughput of the AP in all its scenarios.

1.3. Project Risk Management.

During the implementation and executing of the project , many problems and risks may occur , we must solve this in early time of the project in order to operate the project in efficiently and effectively manner.

The project risks are:

- ❖ Latency of devices arrival.
- ❖ Supervisor change.

- ❖ Group meeting difficulties.
- ❖ The devices operate differently from what are expected.
- ❖ The results we obtained are not as we expected.

We can come over these risks by:

- ❖ Starting working on the implementation of our network at early time.
- ❖ Demanding devices at early time.
- ❖ Organizing our meeting.
- ❖ Taking many of values to approach to correct results.
- ❖ Starting to learn about simulation programs at earlier time.

1.4. Project Schedule.

The aim of the project is to measure the throughput of the network that is including of different types of WIFI technologies.

We change the WIFI technology used in network card and measured the throughput for each client in all cases. We will use one AP and four network cards that are supporting 802.11b\g\n.

To do this, we need to organize our time. There are two time estimation schedules; the first one shows what has been done in the first semester. And the other shows the scheduling of the second semester. The timing management divides the system hierarchy according to the actions to group of tasks as followling:

T1: Identifying the contents of project and discussing the initial information about it.

T2: Analyzing the project and put all possible problems that may focus on it during our work.

T3: Examining if our equipment we need in this project is available or not, and trying to get it in shortest time.

T4: Collecting information about WIFI technology and all standards about it and start writing our project.

T5: Investigating about programs that are used to measure the throughput value.

T6: Studying the property of AP and network cards and collecting some information about it to construct our first impression about what we would do.

T7: Write our documentation.

T8: Downloading the programs we want to use and starting to learn about it.

T9: Collecting our equipment we want in our project and starting to build all cases in our network.

T10: Testing all cases and measuring the throughput for each one.

T11: Comparing between the results obtained in this project.

T12: Organizing our all data and information to start writing our final documentation.

T13: Retesting the throughput more than one time for all cases to reduce the probability of error that may occur through measurement and to ensure the results.

T14: Writing our final documentation that includes all work in our project during two semesters.

Table 1.1: Time Planning.

week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
first semester															
T1															
T2															
T3															
T4															
T5															
T6															
T7															
second semester															
T8															
T9															
T10															
T11															
T12															
T13															
T14															

1.5. Estimated Cost.

In this section we listed overall cost of all components we need in this project.

The components of our project are:

- One gigabit AP.
- Four network cards that support 802.11b\g\n Wi-Fi technologies.
- Five Pc computers.
- Colasoft capsa 7 program.

The cost of each equipment is shown in table (1.2).

Table 1.2: Project Cost.

Number	Object	Cost($)
1	One Access Point	400
2	Four Network Cards+ one gigabit Ethernet card	350
3	five computers	3000
4	Printing	120
Total		3870

1.6. Outline.

Our documentation of this project is divided into seven chapters that describe the hardware and software implementation, the following explains the content of each chapter:

Chapter 1: Introduction

This chapter presents overview, objectives of the project, project scheduling, risks, and estimated cost.

Chapter 2: Theoretical Background

This chapter defines and discusses the WIFI technology and property of each standard, and much information about this technology.

Chapter 3: Project Design and Implementation

This chapter discuses the design of our network that consists of different combination of Wi-Fi technologies and describes the steps for construct networks.

Chapter 4: Project Design Details

This chapter gives all details about the design of our network and how to implement and measure the throughput for all clients' cases.

Chapter 5: System Implementation and Testing

In this chapter we listed all results we optioned by measurement of our network, and the analysis of the results.

Chapter 6: Conclusion and Future Work

This chapter provides the conclusions that will be concluded after making the project, and suggestion for future work.

Chapter 2

Theoretical Background

2.1. Definition.

Wireless networks refer to any type of computer and telecommunications network in which interconnections between nodes are implemented without the use of wires. Wireless telecommunications networks are generally implemented with some type of remote information transmission system that uses electromagnetic waves.

The growth of wireless networks has transformed our daily life into such a situation that we cannot think of a life without these devices like computers, mobile phones etc. The wireless networks that interconnect these devices with each other are adding more and more nodes into it each minute. These devices communicate with each other using many popular standards developed by IEEE and such other groups.

In wireless Internet, the wireless router or AP (Access Point) sends the signals to the remote server and the server bounces the signals back to the wireless router or AP so the connection can be made. Wireless LANs have become popular in the home due to ease of installation, and the increasing popularity of laptop computers. Public businesses such as coffee shops and malls have begun to offer wireless access to their customers. Large wireless network projects are being put up in many major cities.

Wireless networks have many uses. A common is the portable office. People on the road want to use their portable electronic equipment to send and receive telephone calls, faxes, and electronic mail, read remote files, login on remote machines, and does this from anywhere.

Wireless is rapidly gaining in popularity for both home and business networking. Wireless technology continues to improve, and the cost of wireless products continues to decrease. Popular wireless local area networking (WLAN) products conform to the 802.11 "Wi-Fi" standards. The wireless networks includes network adapters (NICs), APs, and routers.

2.2. Advantages & disadvantages of wireless network.

The wireless networks change the way of how to connect to the network, it provides number of advantages and disadvantages compared to the wired network.

2.2.1. Advantages of wireless network.

The wireless networks make our life easier by number of advantages:

- Mobility: one of the most advantages that can allow users can access to the network without cable, that mean the user can move within the covered region of it and keep the connection with this network, wired networks on the other hand can't provide this. For example, coffee shops, offer their customers a wireless connection to the internet.

- Deployment: Initial setup of a wireless network requires a single access point or more. Wired networks, on the other hand have the additional cost and complexity of actual physical cables being run to numerous locations (which can even be impossible for hard-to-reach locations within a building). And if one of the cable is down the maintenance operation is difficult.

- Cost: Wireless networks can serve a suddenly-increased number of clients with the existing equipment. But in wired network we need cable and additional hubs if the number of clients are increased that are added more cost and more complexity.

2.2.2. Disadvantage of wireless network.

Although of this advantages in wireless network there are number of disadvantages like:

- Security: Wireless networks can be accessed by any computer within range of the network's signal so information transmitted through the network (including encrypted information) may be intercepted by unauthorized users. It is a fairly simple setup. The Internet connection from your provider is connected to a wireless access point or router which broadcasts the signal. You connect wireless antenna network cards to your computers to receive that signal and sent back to the wireless access point. A hacker searching for insecure wireless connections can get into your systems and collect much information about you.

- Range: the range of wireless network is limited by the transmitted power which is normally limited; we can't increase the transmitted power as we want because interference may accrue by neighboring cells. After measuring the value of interference we can use repeaters or additional access points to increase the range and costs for this will increased. If you are near to wireless access point, you will get high and good network speed. However if another person joins the network sitting far from the wireless router/access point, the network speed of both computers will be dropped. The rule is that if the distance from the wireless router/access point increased the speed of wireless network is decreased.

- Reliability: Interference of cordless phone, or other electronic devices that operated in the same radio frequency band, so don't place the wireless network nears to these electronic devices or you can turn off these electronic devices. Also the interference between wireless networks will reduce the network throughput. In this case you can configure wireless router/access point to use different channel and test interference effect again. Interference reduces the capacity of network.

- Speed: The speed on most wireless networks is slow compared to the wired networks (100 Mbit/s up to several Gbit/s) .The bandwidth of wireless network is shared among wireless users, so the more users you have on the same network the slower network speed. The wireless network speed (throughput) will usually be affected by the following factors:

* Interference – reduced the network throughput.

* Signal Blocking – Signal blocking like by walls.

* Shared bandwidth – The bandwidth of wireless network is shared with other wireless system in the same geographical space and same frequency band.

* Wireless users –the more users you have on the same network the slower network speed.

* Distance – as distance increased the throughput of network is decreased.

2.3. Wireless Network types.

The widespread of this technology makes many applications as WIFI, WIMAX, GSM systems, and personal communication services more in use .These communication technique use tow types to communicate all station in this network with each other.

There are tow types of wireless network

1. Ad-Hoc
2. Infrastructure

2.3.1. Ad-Hoc network.

In Ad-Hoc network mode (Peer-to-peer) setup where clients can connect to each other directly (without AP).

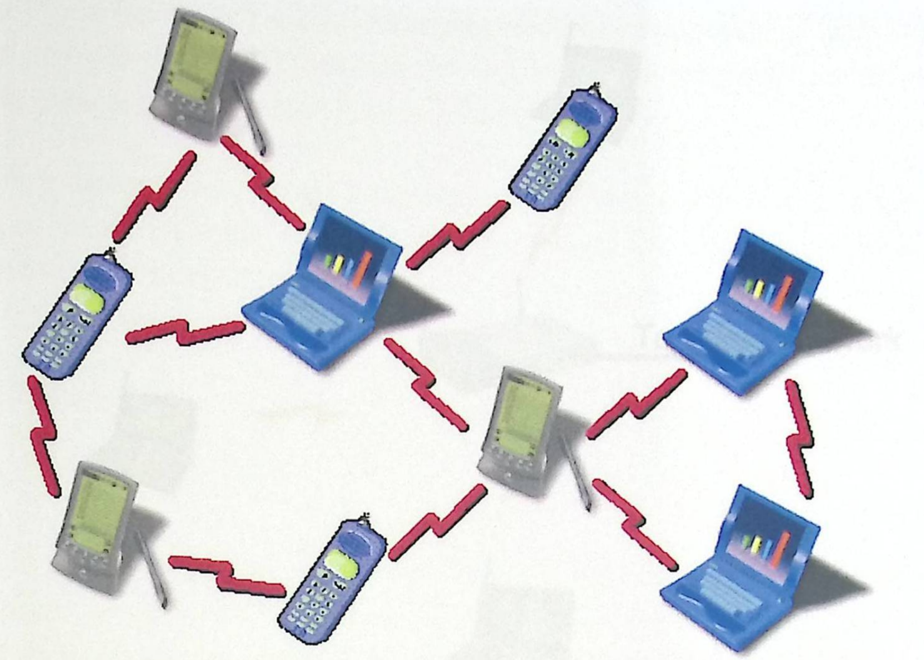


Figure 2.1: AD-Hoc Network.

Ad-Hoc mode is a method for wireless devices to communicate directly with each others. Operating in ad-hoc mode allows all wireless devices within range of each other to discover and communicate in peer-to-peer without involving access points.

To set up an ad-hoc wireless network, each wireless station must be configured for ad-hoc mode. In addition, all wireless station on the ad-hoc network must use the same SSID and the same channel number to establish the connection. In Ad-Hoc network the distance of each station to another is small and having a little number of station, if a large ad-hoc network it is becomes difficult to manage.

2.3.2. Infrastructure network.

In an infrastructure network there is an Access Point (AP), which becomes the hub of a "star topology". Any communication has to go through it. If a Mobile Station (MS), like a computer, a PDA, or a phone, wants to communicate with another MS, it needs to send the information to AP and then AP sends it to the destination MS , Multiple APs can be connected together and handle a large number of clients (more complexity of network).

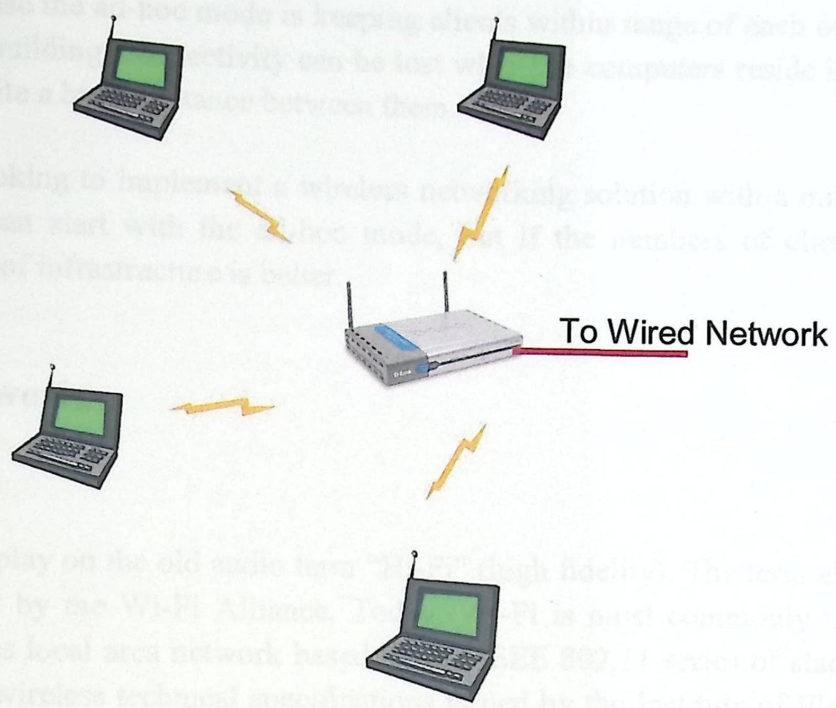


Figure 2.2: Infrastructure Network.

A wireless access point (AP) is required for infrastructure mode wireless networking. To join the WLAN, the AP and all wireless clients have to use the same SSID. The AP is then cabled to distribution system to allow wireless clients access to internet connections or printers or any application installed.

2.3.3. Ad-Hoc Mode vs. Infrastructure Mode.

Devices in a wireless network are set up to either communicate Infrastructure Mode or Ad Hoc" mode (it's also called peer-to-peer).

Here are key differences between the two modes.

- Ad Hoc Mode does not require an access point; it's easier to set up, especially in a small or temporary network.
- Infrastructure takes advantage of coverage wide areas when compared to Ad Hoc.

In an ad-hoc mode, which is comprised of wireless network adapters that are able to automatically locate and communicate with each other. This is the cheapest method of setting up a wireless network and acceptable for a network that consists of two to three computers. However, there are some disadvantages to travel through this route, especially when it comes to a medium to large-sized network. Many of the functionalities are lost when the designated computer is turned off. The other disadvantage to use the ad-hoc mode is keeping clients within range of each other. In a large home or building, connectivity can be lost when the computers reside in areas where there is quite a bit of distance between them.

If you're looking to implement a wireless networking solution with a minimum cost level, you can start with the ad-hoc mode, but if the numbers of clients are increased the use of infrastructure is better.

2.4. WIFI Network.

"Wi-Fi" is a play on the old audio term "Hi-Fi" (high fidelity). The term also has been trademarked by the Wi-Fi Alliance. Today, Wi-Fi is most commonly used to describe a wireless local area network based on the IEEE 802.11 series of standards, which is a set of wireless technical specifications issued by the Institute of Electrical and Electronic Engineers (IEEE). The IEEE is an international professional organization for electrical and electronics engineers, with formal links with the International Organization for Standardization (more commonly known as the "ISO"). [1]

The first wireless LAN (WLAN) standard (designated 802.11 by the IEEE) was ratified in 1997 for data rates up to 2Mbps in the 2.4Ghz unlicensed frequency band. And the first IEEE standard of Wi-Fi was 802.11b which added support 11Mbps maximum data rate by using Direct Sequence Spread Spectrum (DSSS) modulation technique within the same 2.4GHz band. Concurrently, 802.11a, added support for data rates up to 54Mbps within the 5GHz band using Orthogonal Frequency Division Multiplexing (OFDM).

IEEE ratified the 802.11g amendment in 2001 adding the same 802.11a data rates and operated in the same 802.11b frequency band. 802.11g is used OFDM modulation and compatible to 802.11b.

A wireless local area network (WLAN) is a shared-medium communications network that broadcasts information over wireless links to be received by all stations. Most of today's WLANs are built upon the IEEE 802.11 standards. These standards define technical specifications by specific organizations in order to establish consistency in hardware and/or software development.

Because radio signals move through the air, you can set up a network connection from any place within range of the network base station's transmitter; it's not necessary to use a telephone line, or some other dedicated wiring to connect your computer to the network. Just turn on the radio connected to the computer and it will find the network signal.

All 802.11 standards technologies are commonly referred to as 'Wi-Fi'. There are several specifications in the 802.11 family:

- 802.11 — applies to wireless LANs and provides 1 or 2 Mbps transmission in the 2.4 GHz band using either frequency hopping spread spectrum (FHSS) or direct sequence spread spectrum (DSSS).
- 802.11a — an extension to 802.11 that applies to wireless LANs and provides up to 54-Mbps in the 5GHz band. 802.11a uses an orthogonal frequency division multiplexing encoding scheme rather than FHSS or DSSS.
- 802.11b (also referred to as 802.11 High Rate or Wi-Fi) — an extension to 802.11 that applies to wireless LANS and provides 11 Mbps transmission (with a fallback to 5.5, 2 and 1-Mbps) in the 2.4 GHz band. 802.11b uses only DSSS. 802.11b was 1999 ratification to the original 802.11 standard, allowing wireless functionality comparable to Ethernet.
- 802.11e — a wireless draft standard that defines the Quality of Service (QoS) support for LANs, and is an enhancement to the 802.11a and 802.11b wireless LAN (WLAN) specifications. 802.11e adds QoS features and multimedia support to the existing IEEE 802.11b and IEEE 802.11a wireless standards, while maintaining full backward compatibility with these standards.
- 802.11g — applies to wireless LANs and is used for transmission over short distances at up to 54-Mbps in the 2.4 GHz bands.
- 802.11n — 802.11n builds upon previous 802.11 standards by adding multiple-input multiple-output (MIMO). The additional transmitter and receiver antennas allow for increased data throughput through spatial multiplexing and increased range. The real speed would be 100 Mbit/s (even 250 Mbit/s in PHY level), and so up to 4-5 times faster than 802.11g.
- 802.11r - 802.11r, also called Fast Basic Service Set (BSS) Transition, supports VoWi-Fi handoff between access points to enable VoIP roaming on a Wi-Fi network with 802.1X authentication.
- 802.1X — Not to be confused with 802.11x (which is the term used to describe the family of 802.11 standards) 802.1X is an IEEE standard for port-based Network Access Control that allows network administrators to restricted use of IEEE 802 LAN service access points to secure communication between authenticated and authorized devices. [2]

2.4.1 WI-FI Operating Frequencies.

Each type of wireless data network operates on a specific set of radio frequencies. Most Wi-Fi networks operate in a special band of unlicensed radio frequencies in 2.4 GHz band. Other Wi-Fi systems use a different unlicensed band in 5 GHz. [3]

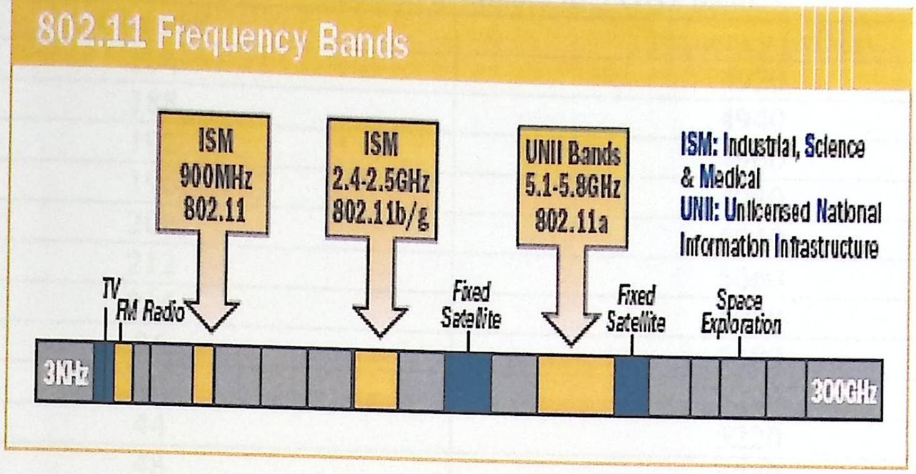


Figure 2.3: Wi-Fi frequency bands.

An Unlicensed means that anybody using equipment that complies with the technical requirements can send & receive radio signals on these frequencies without a radio station license. Unlike mobile company, which require licenses to use of that frequency to a specific type of service. The 802.11b and 802.11g Wi-Fi services all operate in a frequency range at or slightly above 2.4 GHz. The 802.11a signal uses a band close to 5.3 GHz and 802.11n operated in the tow bands.

Table 2.1: Channels available in 2.4 GHz band.

channel	Frequency band (GHZ)	Channel center band (GHZ)
1	2.401 - 2.423	2.412
2	2.406 2.428	2.417
3	2.411 2.433	2.422
4	2.416 2.438	2.427
5	2.421 2.443	2.432
6	2.426 2.448	2.437
7	2.431 2.453	2.442
8	2.436 2.458	2.447
9	2.441 2.463	2.452
10	2.446 2.468	2.457
11	2.451 2.473	2.462
12	2.456 2.478	2.467
13	2.461 2.483	2.472
14	2.473 2.495	2.484

Table 2.2: Channels available in 5 GHz band.

Channel	Frequency (MHz)
184	4920
188	4940
192	4960
196	4980
208	5040
212	5060
216	5080
36	5180
40	5200
44	5220
48	5240
52	5260
56	5280
60	5300
64	5320
100	5500
104	5520
108	5540
112	5560
116	5580
120	5600
124	5620
128	5640
132	5660
136	5680
140	5700
149	5745
153	5765
157	5785
161	5805

The bandwidth of each channel is 20 MHz in 2.4 GHz and in 5 GHz bands, The Wi-Fi 802.11n can use channel band 20MHz or 40MHz (by combining two adjacent channels).

2.4.2. WI-FI 802.11 a.

The Wi-Fi 802.11a is lunched at July 1999 to provide maximum data rate 54Mbps by using OFDM as a modulation technology in 5 GHz unlicensed frequency band.
Physical Layer
5 GHZ Frequency Band

Wi-Fi 802.11a utilizes 300 MHz of bandwidth in the 5 GHz Unlicensed band (U-NII). Though the lower 200 MHz is physically contiguous, the FCC has divided the total 300 MHz into three distinct 100 MHz domains, each with a different legal maximum power output. [4]

The "low" band operates from 5.15 – 5.25 GHz, and has a maximum of 50 mW. The "middle" band is located from 5.25 – 5.35 GHz, with a max. of 250 mW. The "high" band utilizes 5.725 – 5.825 GHz, with a maximum of 1 W. Because of the high power output, devices transmitting in the high band will tend to be building-to-building products. The low and medium bands are more suited to in-building wireless products. [4]

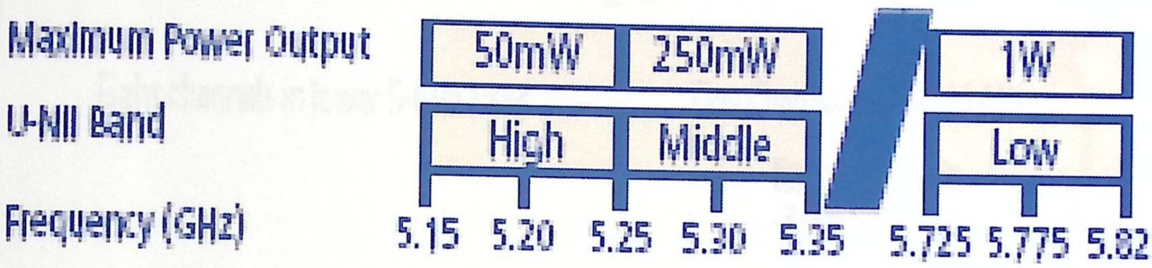


Figure 2.4: 5 GHz Unlicensed band (U-NII).

Operation in the 5 GHz UNII band poses challenges to 802.11a radio design that include multipath and additional path loss, since path loss is increased by increasing the frequency and that cased decreasing the coverage range of wi-fi 802.11a network .

802.11a supports bandwidth up to 54 Mbps and signals in a regulated frequency spectrum around 5 GHz. This higher frequency compared to 802.11b shortens the range of 802.11a networks. The higher frequency also means 802.11a signals have more difficulty penetrating walls and other obstructions. Because 802.11a and 802.11b utilize different frequencies, the two technologies are incompatible with each other. [4]

OFDM Modulation Scheme

802.11a uses Orthogonal Frequency Division Multiplexing (OFDM), a new encoding scheme that offers benefits over spread spectrum in channel availability and data rate. Channel availability is significant because the more independent channels that are available, the more scalable the wireless network becomes .The high data rate are accomplished by combining many lower-speed subcarriers to create one high-speed channel.

802.11a uses OFDM to define a total of 8 nonoverlapping 20 MHz channels across the 2 lower bands ; each of these channels is divided into 52 subcarriers , each approximately 300 KHz wide .the 802.11b\g uses 3 non-overlapping channels. [4]

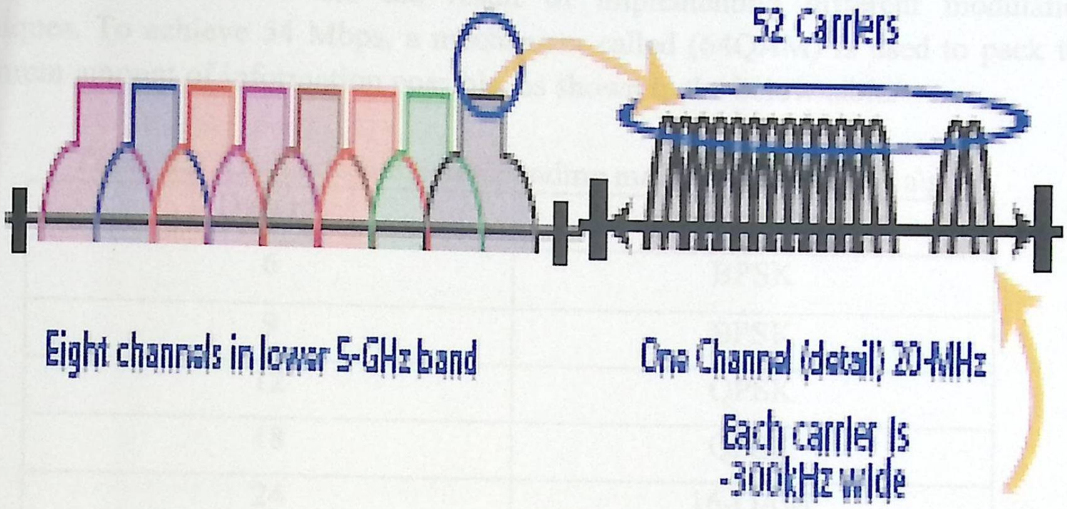


Figure 2.5: Subcarriers of the channel.

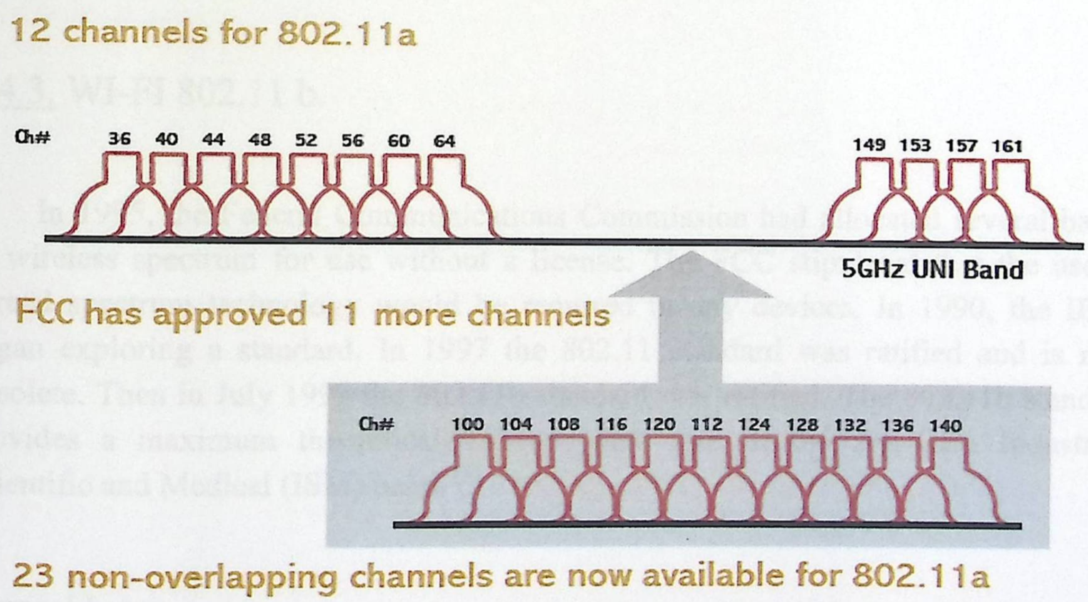


Figure 2.6: 802.11a non-overlapping channels.

Data Rates

Signal blocking by thick wall or other physical barriers. If you sit near wireless router/access point, you will get high and good network speed. However if another person joins the network sitting far from the wireless AP, the network speed of both computers will be dropped. The rule is the further your location from the wireless AP, the slower your connection will be, and the distance will affect the network speed of other users also.

Devices utilizing 802.11a are required to support speeds of 6, 12, and 24 Mbps. Optional speeds go up to 54 Mbps, but will also typically include 48, 36, 18, and 9 Mbps. These differences are the result of implementing different modulation techniques. To achieve 54 Mbps, a mechanism called (64QAM) is used to pack the maximum amount of information possible, as shown in the below table.

Table 2.3: Data rate and corresponding modulation in 802.11a\g.

Data rat	modulation
6	BPSK
9	BPSK
12	QPSK
18	QPSK
24	16-QAM
36	16-QAM
48	64-QAM
54	64-QAM

2.4.3. WI-FI 802.11 b.

In 1995, the Federal Communications Commission had allocated several bands of wireless spectrum for use without a license. The FCC stipulated that the use of spread spectrum technology would be required in any devices. In 1990, the IEEE began exploring a standard. In 1997 the 802.11 standard was ratified and is now obsolete. Then in July 1999 the 802.11b standard was ratified. The 802.11b standard provides a maximum theoretical 11Mbps data rate in the 2.4 GHz Industrial, Scientific and Medical (ISM) band. [5]

Physical Layer
2.4 GHZ Frequency Band

Both 802.11b and 802.11g operate in the 2.4GHz bands divided into 13 channels with 20 MHz for each one, most of them overlap with each other, leaving only three non-overlapping channels [channels 1, 6 and 11] .

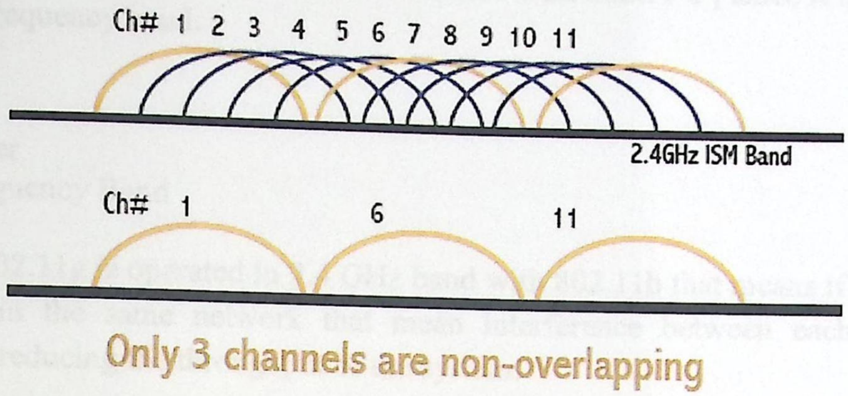


Figure 2.7: 802.11b/g channels and non-overlapping channels.

Data Rates

The original standard released in 1997 defined a CSMA/CA based MAC, two PHY layers in the 2.4 GHz band, and a third PHY based on Infrared (IR). The 2.4 GHz PHY employs Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS) respectively to achieve between 1 and 2 Mbit/s. Two years later the task group 802.11b ratified a new standard for the PHY layer operating at 2.4 GHz. It is used modulation types that are CCK and DSSS to provide maximum data rate 11Mbps.

Table 2.4: Data rate and corresponding modulation in 802.11b.

Data rat	modlation
11	CCK
5.5	CCK
2	DQPSK
1	DQPSK

2.4.4. WI-FI 802.11 g.

In 2002 and 2003, WLAN products supporting a newer standard called 802.11g emerged on the market. 802.11g attempts to combine the best of both 802.11a and 802.11b. 802.11g supports bandwidth up to 54 Mbps, and it uses the 2.4 GHz frequency for greater range. 802.11g is backwards compatible with 802.11b, meaning that 802.11g access points will work with 802.11b wireless network adapters and vice versa. [6]

It is used OFDM as a modulation technique to provide 54 Mbps maximum data rate in 2.4 GHz band , that means it is combatable with 802.11 b , since it is operated in the same frequency band.

Physical Layer
2.4 GHZ Frequency Band

Wi-Fi 802.11g is operated in 2.4 GHz band with 802.11b that means if these tow stations are in the same network that mean interference between each other is occurred and reducing the throughput of the system.

Data Rates

The Wi-Fi 802.11g operates on 2.4 GHz band like 802.11b , but since it is used OFDM as a modulation technique the affect of interference is less comparing with 802.11b so it have more data rate up to 54Mbps

802.11g uses OFDM, CCK, DSSS as a modulation technique so it is compatible with 802.11b (since it is operated in same frequency range) and not compatible with 802.11a since they are operated in different frequency bands.

2.4.5. WI-FI 802.11 n.

It is the newest Wi-Fi technology applied in 2006 it is used MIMO (Multiple Input Multiple Output) technology to increase the data rate up to 600 Mbps.

Unfortunately, every increase in rate came at the expense of a loss in range. In the IEEE 802.11a/g standards, for instance, the highest data rate of 54 Mbps is achieved through the use of 64-QAM. The use of such highly spectral efficient higher order modulations requires a significant larger SNR than the simple BPSK modulation used for the lowest 1 Mbps rate, resulting in a significant loss in range. In addition, the link becomes more vulnerable to co-channel interference, which reduces the total system capacity. [7]

Physical Layer
2.4 & 5 GHZ Frequency Band

802.11n is operates in ISM (2.4 GHz) and UNII(5 GHz) bands so it is combatable with all others Wi-Fi standards that means it is used 14 non-overlapping channels in tow bands (3+11) with 20 MHz for each one and can used 40MHz by combining tow adjacent channels in any bands to proved more bandwidth so more throughput .

Data Rates

The Wi-Fi 802.11n is trying to provide maximum possible data rate to obtain this goal, it is used more bandwidth 40MHz By bonding two adjacent 20 MHz channels and used enhanced MIMO technology by using beam forming and diversity to increase transmitted speed.

The 802.11n standard defines a range of mandatory and optional data rates in both 20 and 40MHz channels there are several optional rates. One optional feature is to use a reduced guard interval of 400 ns instead of 800 ns, which increases the maximum data rate for 2 spatial streams in a 40MHz channel to 300 Mbps. Other optional rates use 3 or even 4 spatial streams. The highest optional data rate defined by 802.11n is 600 Mbps, which is achieved by using 4 spatial streams in a 40MHz channel with a 400 ns guard interval. [7]

While 802.11 a/b/g networks operate in a 20 MHz channel, 802.11n defines the use of 20 and 40 MHz channels. 40 MHz channels allow doubling of the data rate to 150 Mbps. All 802.11 devices send a packet over the air as a sequence of symbols. Devices using 40 MHz channels can encode and transmit more data in each symbol. Depending on the degree of complexity that the environment can support, 802.11 devices choose an appropriate data rate for use over the air. For example, the IEEE 802.11b standard supports data rates of 1, 2, 5.5 and 11 Mbps. [8]

Much of the throughput improvement in 802.11n comes from aggregation techniques. Frame aggregation improves the efficiency of 802.11n systems by reducing the protocol overhead required for transmitting protocol frames. Video traffic can benefit from being transported using maximum size aggregate frames since video traffic sends many frames to the same destination. The Aggregated Medium Access Control Service Data Unit (A-MSDU) mechanism increases the frame size used in transmitting Medium Access Control (MAC) protocol frames. The Aggregated MAC Protocol Data Unit (A-MPDU) mechanism increases the maximum size of the 802.11 frames transported on the air from the legacy 2304 bytes to 64k bytes. [8]

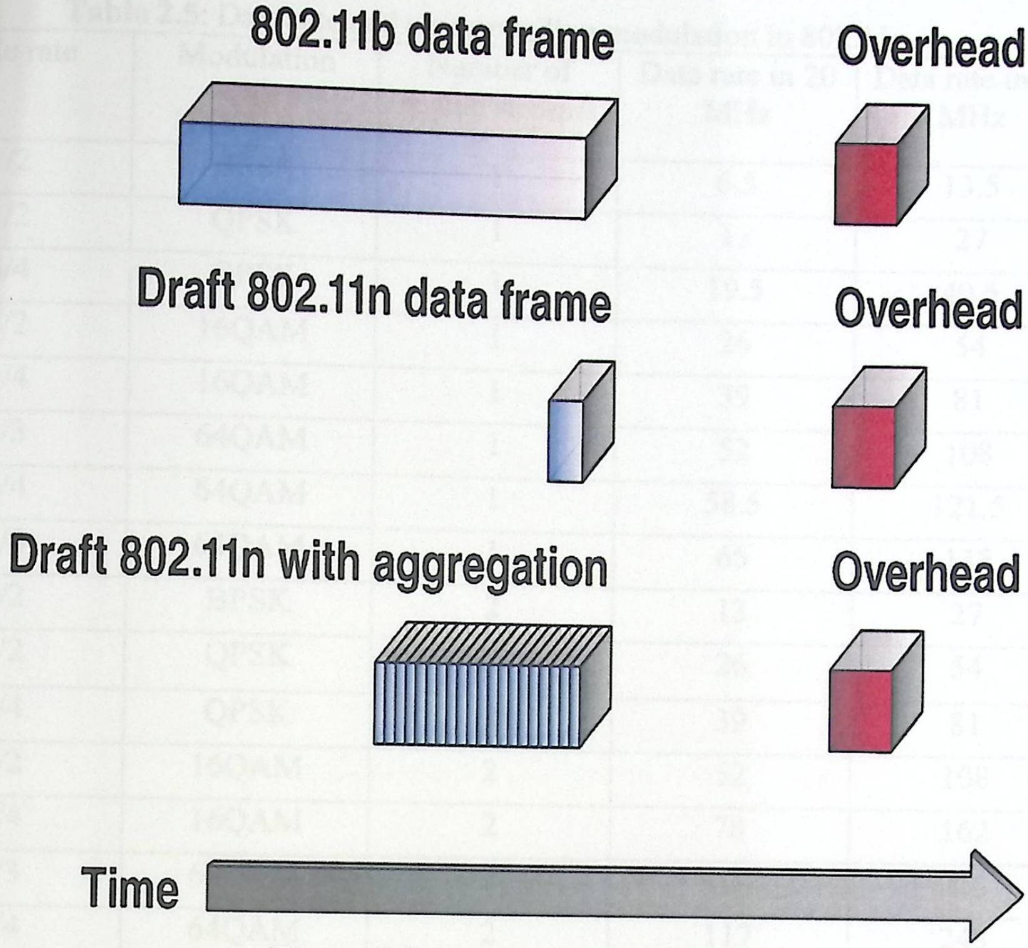


Figure 2.8: Aggregation in 802.11n.

Another efficiency improvement is in the area of streamlined acknowledgements. The block acknowledgement mechanism – a protocol for sending a single block acknowledgement (ACK) frame to acknowledge several received frames – can significantly improve protocol efficiency and throughput by reducing the amount of overhead dedicated to acknowledgements. While the block ACK protocol was also defined for legacy systems, it was not extensively deployed. The 802.11n standard has reduced the size of the block ACK frame from the legacy 128 bytes to eight bytes, which also yields a significant improvement in efficiency. [8]

Table 2.5: Data rate and corresponding modulation in 802.11n.

Code rate	Modulation	Number of spatial streams	Data rate in 20 MHz	Data rate in 40 MHz
1/2	BPSK	1	6.5	13.5
1/2	QPSK	1	13	27
3/4	QPSK	1	19.5	40.5
1/2	16QAM	1	26	54
3/4	16QAM	1	39	81
2/3	64QAM	1	52	108
3/4	64QAM	1	58.5	121.5
5/6	64QAM	1	65	135
1/2	BPSK	2	13	27
1/2	QPSK	2	26	54
3/4	QPSK	2	39	81
1/2	16QAM	2	52	108
3/4	16QAM	2	78	162
2/3	64QAM	2	104	216
3/4	64QAM	2	117	243
5/6	64QAM	2	130	270

With only one spatial stream these data rate of 802.11n is 65 Mbps comparing with 54Mbps in 802.11a\g; since n technology uses higher maximum code rate. By using 40MHz channel the data of 802.11n is doubles to 135Mbps.

When 802.11n uses 64QAM as a modulation technology it reach the maximum data rate that is 270Mbps by using two spatial streames.

Table 2.6: Major Components of 802.11n.

Feature	Definition	Specifiation status
Better OFDM	Support wder bandwidth & higher code rate to bring maximmum data rate to 65Mbps	mandatory
Space-Division Multiplixing	Improves performance by parsing data into multiple streams transmited through multple antennas	Optional for up to four spatial streams
Diversity	Exploits the existence of multiple anttenas to improve rang and reliability.Typically Employed when the number of anttenas on the receiving end is higher than the number of streams being transmitted	Optinal for up to four anttenas
MIMO power save	Limit power consumption penaity of MIMO by utilizing multiple antennas only on as-needed basis	Required
40MHz Channels	Effectively doubles data rates by doubling channel width from 20MHz to 40MHz	optional
Aggregation	Improves efficiency by allowing transmission bursts of multiple data packets between overhead communication	Required
Reduced Inter-Fram Spacing(RIFS)	One of several draft n features designed to improve efficiency provides a shorter delay between OFDM transmissions than in 802.11a or g	Required
Greenfield Mode	Improves efficiency by eleminating support for 802.11a/b/g devices in an all draft-n network	Currently optional

2.4.6. MIMO Enhancement.

There are two features in the draft-n specification that focus on improving MIMO performance, called beam-forming and diversity. Beam-forming is a technique that focuses radio signals directly on the target antenna, thereby improving range and performance by limiting interference.[9]

Diversity exploits multiple antennas by combining the outputs of or selecting the best subset of a larger number of antennas than required to receive a number of spatial streams. This is important because the draft n specification supports up to four antennas, so devices will probably encounter others built with a different number of antennas. A notebook computer with two antennas, for example, might connect to an access point with three antennas. In this case, only two spatial streams can be used even though the access point itself may be capable of three spatial streams. [9]

With diversity, surplus antennas are put to good use. The device with more antennas uses the extra ones to operate at longer range. For example, the outputs of two antennas may be combined to receive one spatial stream to achieve a longer link range. The concept may be extended to combine the outputs of three antennas to receive two spatial streams for higher data rate and range and so on. [9]

Table 2.7: Data rate in all Wi-Fi technologies.

	20 MHz channel				40 MHz channel			
	1 stream	2 streams	3 streams	4 streams	1 stream	2 streams	3 streams	4 streams
	Data Rate,in Mbps							
802.11b 2.4GHz	1,2, 5.5,11							
80211a 5GHz	6,9, 12,18, 24,36, 48,54							
802.11g 2.4GHz	1,2,6, 9,12, 18,24, 36,48, 54							
802.11n 2.4GHz 5GHz	6.5, 13, 19.5, 26,39, 52, 58.5, 65	13,26, 39,52, 78,104, 117, 130	19.5, 39, 58.5, 78,117, 156, 175.5, 195	26,52, 78,104, 156, 208, 234, 260	13.5, 27, 40.5, 54,81, 108, 121.5, 135	27,54, 81,108, 162, 216, 243, 270	40.5, 81, 121.5, 162, 243, 324, 364.5 405	54,108, 162, 216, 324, 432, 486, 540

802.11n is uses MIMO technology for transmitting and receiving data, this technology allowed it to transmit and receives four spatial streams; this technology is known as spatial multiplexing, unlike other Wi-Fi technologies that are using only one spatial stream.

2.5. Effect of interference on Wi-Fi.

802.11b/g uses the 2.4 GHz ISM band. Many other devices operated in the same band that is sharing with 802.11b/g clients. Interference causes packets to be re-transmitted. This causes reduced end-user throughput and increased latency of data traversing the Wi-Fi network.

Other Devices in the 2.4GHz ISM Band:
• Bluetooth Devices
• Home RF
• Cordless Phones
• X10 wireless video cameras

Since 802.11a is operating in 5GHz band the effect of interference is low comparing in 802.11b\g , since there are not many wireless technologies used this band expect Radar & Satellite.

IEEE 802.11b/g and Bluetooth, these two operating in the unlicensed 2.4 GHz frequency band. The number of devices equipped with IEEE 802.11 and Bluetooth is growing. Result is the number of co-located devices, say within 10 meters, grown to a limit, so that it may causes interference issues in the 2.4 GHz band.

The Bluetooth operates in 2.4GHz ISM band. Unfortunately, IEEE 802.11b/g and 802.11n can also operated in the same band that causes significant interference. When a node using IEEE 802.11g for example as a wireless standard wants to send a packet to the AP, it uses the carrier sense protocol running at the medium access control (MAC) layer to determine if the medium is free from traffic or not. [10]

If it finds the medium idle (i.e., none of the other stations sensing any RF energy in the channel), it issues Clear to Send (CTS) request packet to the destination node. If destination node wants to communicate, it sends back a small Ready to Send (RTS) packet to the sending node. When a sending node receives a positive acknowledgement from the destination node (i.e., RTS packet), both sending and receiving nodes can start communicating with each other by exchanging the regular data packets. Using the same technique, while another co-located IEEE 802.11b network tries to send the packet, it will postpone the transmission. [10]

This technique provides a good resolution for mutual interference between co-located IEEE 802.11 networks. However, when it comes to a co-located Bluetooth and IEEE 802.11 network, they just do not communicate with each other. There is a definite chance of collision when they use the same channel at a particular time. A

Bluetooth device may haphazardly begin transmitting packets while an IEEE 802.11 device is sending a frame. This may results in interference which forces the IEEE 802.11 station to retransmit the frame when it realizes that the destination station is not going to send back an acknowledgment. This lack of coordination is the basis for interference between Bluetooth and 802.11. [10]

The retransmission of frame is reducing the data rate of the stations in the network but since Bluetooth is transmitted at low power and different transmission protocols, Bluetooth does not cause much interference for 802.11b/g/n systems. The interference is occurred by other Wi-Fi or other wireless devices transmitted at high power with the same frequency band.

2.5.1. IEEE 802.11 DCF Protocol.

This section summarizes the operation of the IEEE 802.11 Distributed Coordination Function (DCF) protocol.

In the network, it may happen that two or more stations start transmitting simultaneously in the network and a collision occurs. In the CSMA/CA scheme, stations are not able to detect a collision by hearing their own transmission (as in the CSMA/CD protocol used in wired LANs). Therefore, an immediate positive acknowledgement scheme is employed to ascertain the successful reception of a frame. Specifically, upon reception of a data frame, the destination station initiates the transmission of an ACK (acknowledgement frame) after a time interval called Short InterFrame Space (SIFS). The SIFS is shorter than the DIFS in order to give priority to the receiving station over other possible stations waiting for transmission. If the ACK is not received by the source station, the data frame is presumed to have been lost, and a retransmission is scheduled. The ACK is not transmitted if the received frame is corrupted. A Cyclic Redundancy Check (CRC) algorithm is used for error detection. [11]

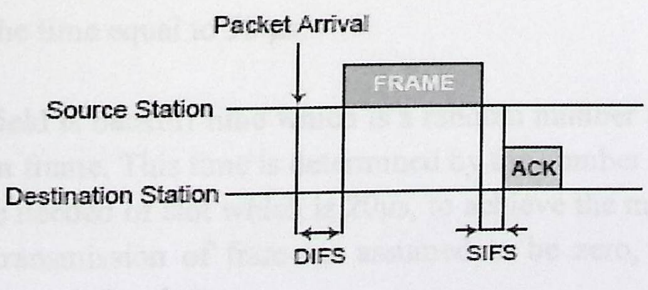


Figure 2.9: CSMA/CA scheme.

The IEEE 802.11 DCF protocol is designed to manage and reduce contention in the wireless communication medium in a fair manner. The algorithm used by the protocol is known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). According to the algorithm, when a node wants to transmit a frame, the station is required to first sense if the communication medium is busy. If it is, the station waits for a specific period of time known as the Backoff Interval (BO) and then tries to sense the medium again. If the channel is not busy, the station transmits the frame to the intended destination. The destination sends an acknowledgment message to the source of the frame upon successful reception of the frame. If the source does not receive an acknowledgment within a specific period of time, it tries to re-send the frame. Broadcast messages do not require the destination to send an acknowledgment of reception. [12]

The maximum data rate of IEEE 802.11g/a are 54Mbps for each one, and 802.11b has 11Mbps. however this speed is not true in practical and it is affected by a number of factors such as; the distance separation between access point and the client, the affect of protection methods that protect the networks of the collection problems such as CSMA\CA and RTS\CTS methods. Assuming the client is located in distance about 10 meters from the AP and without nearby AP operating in the same channel, we want to calculate the theoretical throughput of it as shown in different scenarios

First if we have an 802.11b client connected to the AP and this client is uses CSMA\CA protection method of collection the time sequence of this frame is

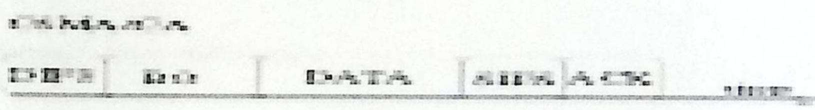


Figure 2.10: CSMA/CA timing diagram.

The first field is DCF interframe space (DIFS) which is a fixed number the station uses it to determined if the field is free from traffic with other devices or not, if the medium is free to send; the station can send its frame without colleted with other frames this takes the time equal to 50 μs.

The second field is backoff time which is a random number that the station must wait to sent its own frame. This time is determined by the number of retransmission of frame and the time needed of slot which is 20μs, to achieve the maximum throughput the number of retransmission of frame is assumed to be zero, and minimum CW (Contention Windows) is 31, then

$$t_{backoff} = CW_{min} * SLOT\,[\mu s]/2 \quad (2.1)$$

$$t_{backoff} = \frac{31 * 20 * 10^{(-6)}}{2}$$

$$= 310\ \mu s$$

The third field is the data field which is consists of three sections that are PLCP-p, PLCP-h and Mac frame. The first one is PLCP preamble that is 144 μs and the second is PLCP header which is 48 μs which are used to make the 802.11b is combatable with 802.11 or 802.11g is combatable with 802.11b this are added more over head to the network so reducing the throughput . the third section is Mac frame of the data that contains 28 control bytes and MAC Serves Date Unit (MSDU) which is typically 1500 bytes

$$tframe = (MSDU + 28) * 8 / max\ data\ rate$$ ....(2.2)

$$= (1500 + 28) * 8/11Mbps$$
$$= 1111\ \mu s$$

The fourth field is short Interframe space (SIFS) which is used for highest priority information such as acknowledgement and that is used when the destination station was received the frame from the sender station this field takes time of 10 μs.

The fifth field is acknowledgement field which is consists of three sections that are PLCP-p , PLCP-h and Mac frame the first two are used for preamble which take 192 μs as mentioned before and the third section is Mac frame of the acknowledgement, that has 14 control bytes.

$$tack = 14\ bytes\ /\ max\ data\ rate$$ ....(2.3)

$$= 14 * 8\ /\ 11Mbps$$
$$= 10.2\ \mu s$$

$$ttotal = tbackoff + t\,DIFS + tPLCP - p + tPLCP - h + tframe + tSIFS + tPLCP - p + tPLCP - h + tack$$ ......(2.4)

$$= 310\ \mu s + 50\ \mu s + 2(144\ \mu s + 48\ \mu s) + 1111\ \mu s + 10.2\ \mu s$$
$$= 1865\ \mu s$$

$$tMSDU = 1040\ \mu s\ \text{at size 1500byte}$$

$$Efficiency = tMSDU\ /\ ttotal = 1040\ \mu s\ /\ 1865\ \mu s = 0.557 = 55.7\%$$

The theoretical data rate of Wi-Fi 802.11b is
$$TMT = 0.557 * 11Mbps = 6.14\ Mpbs$$

The theoretical data rate of Wi-Fi 802.11g\a is
$$TMT = 0.557 * 54Mbps = 27Mbps$$

So the theoretical maximum throughput for Wi-Fi 802.11b is not exceeds 6.14 Mbps and for Wi-Fi 802.11g\a since they are used same modulation technique which is equal only 27 Mbps.

Contention in the communication medium can be further reduced using Request-To-Send (RTS) and Clear-To-Send (CTS) messages between sender-receiver pairs. A sender transmits an RTS with information about the size of the data frame to come and the channel time to be consumed by the data frame. If the receiver is free to receive the data frame, it sends CTS back to the sender. At the same instant, other stations in the vicinity of the sender-receiver pair record the estimated time for data transmission and backoff until the channel becomes free again. [12]

Figure below shows the timing and sequence of frames and delays used by the 802.11 protocol. The delays that precede and follow the transmission of control frames (RTS, CTS or ACK) or data frames are called Inter-Frame Spacings (IFS). Before the transmission of an RTS, stations are required to wait for a time equal to the Distributed IFS (DIFS). On the other hand, a destination station is required to send a CTS or an ACK frame within a Short IFS (SIFS) amount of time after the reception of RTS and DATA frames from the source, respectively. If the sending station senses the medium busy during the DIFS interval, it chooses a BO from a range and then an associated timer starts counting down to zero. If the channel is sensed busy during the BO, the sending station stops the countdown and resumes the countdown when the channel is idle again. When the timer counts down to zero, the sending station attempts to transmit the frame if the channel is idle for a period of DIFS. If the channel is busy, another BO is chosen from an exponentially increased range and the process repeats. [12]

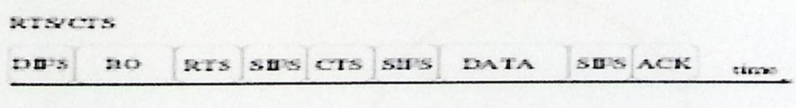


Figure 2.11: RTS\CTS timing diagram.

2.5.2 Hidden Node problem.

This problem occurs when different clients connected to the same access point can't see each other, decide that the channel is free, and transmit at the same time. The frames collide with each other when they reach the access point and all of them are discarded. Sometimes the CSMA/CA mechanism may be insufficient.

This problem accrued when client A tests the medium by CSMA\CA finds it free and begins to transmit frame to the AP. At the same time Client B begun to transmit own frame to AP. The access point will discard tow frames that have collided as shown below.

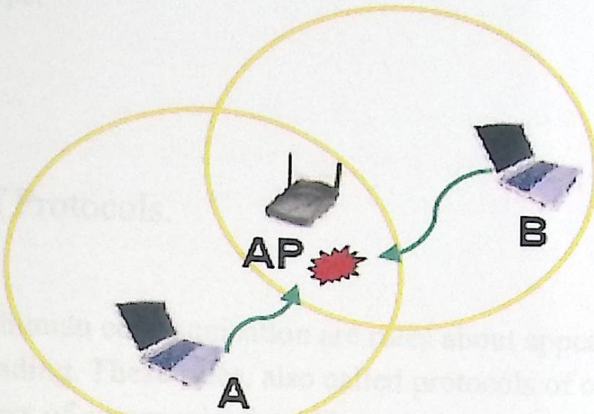


Figure 2.12: Hidden node problem.

To solve this problem, both IEEE 802.11 standards use the RTS/CTS (Request To Send / Clear To Send) protection mechanism thus ensuring that all the clients can transmit data without colliding. Clients sent RTS requests to the access point and the access point broadcasts a CTS response giving the slot time unit values during only the client that is making the RTS request can transmit frames. In this case, the benefit of reducing collisions is achieved at the cost of increasing the overhead even more, and reducing user data throughput. [13]

Fig below shows the RTS/CTS protection mechanism. Client A sends an RTS request to the access point to notify that it wishes to transmit data. The access point broadcasts a CTS message indicating for how long the channel will be occupied and which client can begin to transmit its own frames. The rest of the clients must wait during the time interval defined in the CTS message before they can transmit. [13]

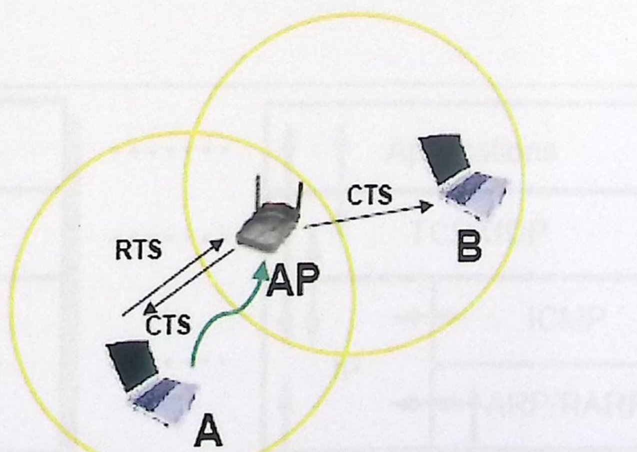


Figure 2.13: RTS/CTS protection mechanism.

This protection mechanism added more overhead to the network comparing with CSMA\CA and reduced the theoretical maximum throughput of the AP that supports 802.11g to only 18Mbps.

2.6. TCP/IP.

2.6.1. Definition of Protocols.

The protocols in human communication are rules about appearance, speaking, listening and understanding. These rules, also called protocols of conversation, represent different layers of communication. They work together to help people communicate successfully. The need for protocols also applies to computing systems. Network engineers have written rules for communication that must be strictly followed for successful host-to-host communication. These rules apply to different layers of sophistication such as which physical connections to use, how hosts listen, how to interrupt, how to terminate communications, which language to use and many others. These rules, or protocols, that work together to ensure successful communication are grouped into what is known as a protocol suite or family. Some of the best known protocol suit include: IPX/SPX, X.25, AX.25, AppleTalk and TCP/IP. [14]

2.6.2. The TCP/IP protocol layers.

Like most networking software, TCP/IP is modeled in layers, such as Systems Network Architecture (SNA) and the Open System Interconnection (OSI) model. TCP/IP is consists of four layers; these layers include:

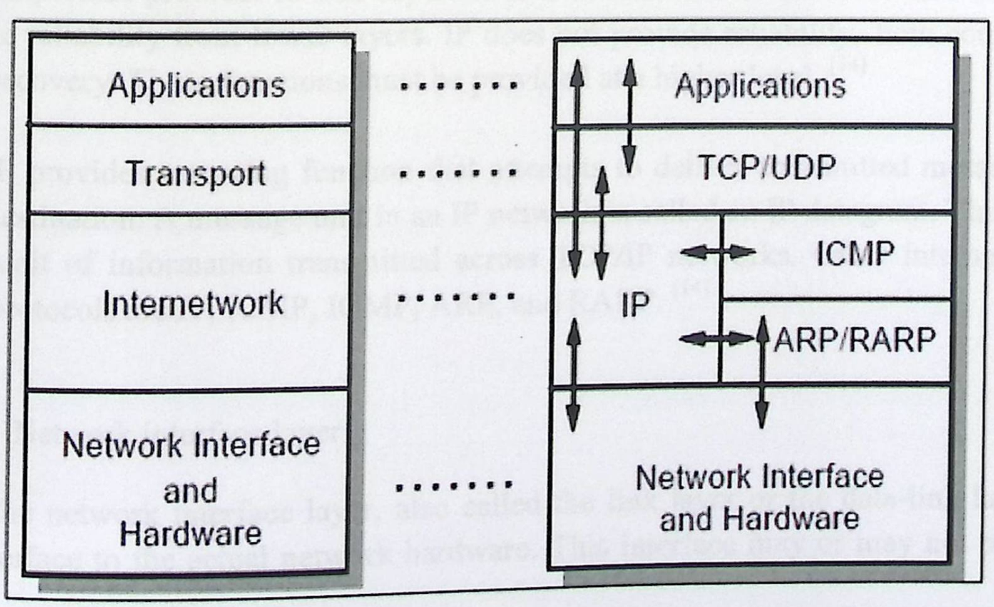


Figure 2.14: TCP\IP layers.

- Application layer

The application layer is provided by the program that uses TCP/IP for communication. An application is a user process cooperating with another process usually on a different host (there is also a benefit to application communication within a single host). Examples of applications include Telnet and the File Transfer Protocol (FTP). The interface between the application and transport layers is defined by port numbers and sockets. [14]

- Transport layer

The transport layer provides the end-to-end data transfer by delivering data from an application to its remote peer. Multiple applications can be supported simultaneously. The most-used transport layer protocol is the Transmission Control Protocol (TCP), which provides connection-oriented reliable data delivery, duplicate data suppression, congestion control, and flow control. [14]

Another transport layer protocol is the User Datagram the internetwork layer. It provides connectionless, unreliable, best-effort service. As a result, applications using UDP as the transport protocol have to provide their own end-to-end integrity, flow control, and congestion control, if desired. Usually, UDP is used by applications that need a fast transport mechanism and can tolerate the loss of some data. [14]

- Internetwork layer

The internetwork layer, also called the internet layer or the network layer, provides the "virtual network" image of an internet (this layer shields the higher levels from the physical network architecture below it). Internet Protocol (IP) is the most important protocol in this layer. It is a connectionless protocol that does not assume reliability from lower layers. IP does not provide reliability, flow control, or error recovery. These functions must be provided at a higher level. [14]

IP provides a routing function that attempts to deliver transmitted messages to their destination. A message unit in an IP network is called an IP datagram. This is the basic unit of information transmitted across TCP/IP networks. Other internetwork-layer protocols are IP, ICMP, IGMP, ARP, and RARP. [14]

- Network interface layer

The network interface layer, also called the link layer or the data-link layer, is the interface to the actual network hardware. This interface may or may not provide reliable delivery, and may be packet or stream oriented. In fact, TCP/IP does not specify any protocol here, but can use almost any network interface available, which illustrates the flexibility of the IP layer. Examples are X.25, ATM, FDDI, and even SNA. [14]

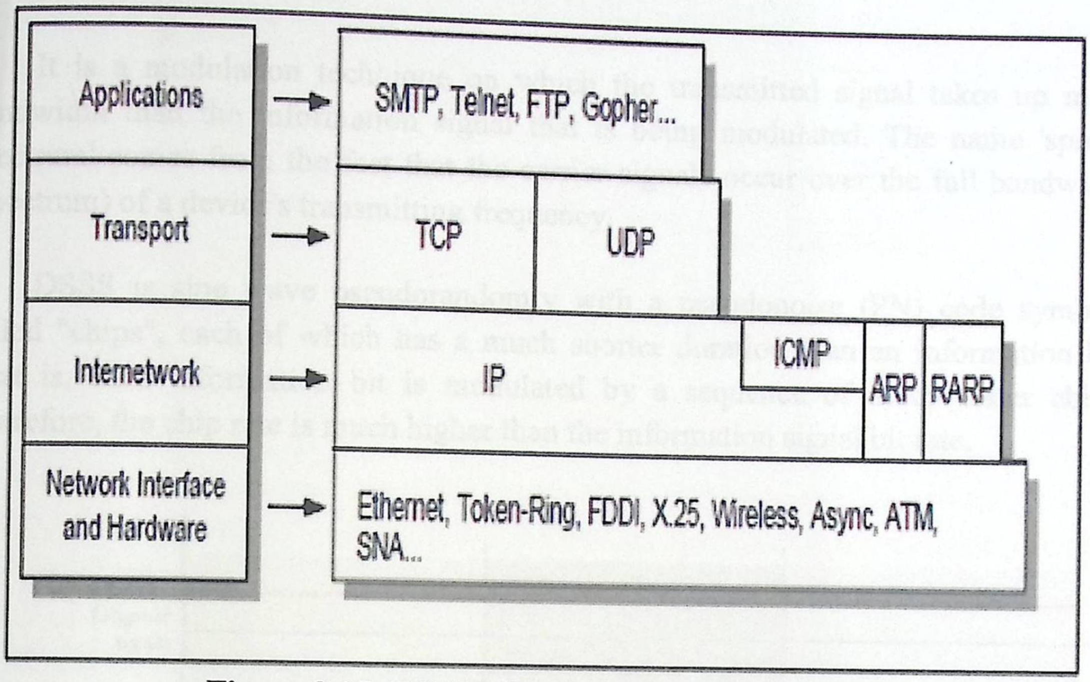


Figure 2.15: TCP\IP detailed architectural model.

2.7. Spread spectrum.

Spread spectrum is a technology used in wireless communications in which the signal generated in a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth. These techniques increase resistance to interference and jamming.

The signal whose frequency is constant is subject of interference. This occurs when another signal is transmitted on the same frequency that used it.

The frequency of the transmitted signal can be deliberately varied over a comparatively large segment of the electromagnetic radiation spectrum. This variation is done according to a specific, but complicated mathematical function. In order to intercept the signal, a receiver must be tuned to frequencies that vary precisely according to this function. The receiver must "know" the frequency-versus-time function employed by the transmitter, and must also "know" the starting-time point at which the function begins. If someone wants to jam a spread-spectrum signal, that person must have a transmitter that "knows" the function and its starting-time point. The spread-spectrum function must be kept out of the hands of unauthorized people or entities. [15]

The two main types of spread spectrum systems are Frequency Hopped Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS).

2.7.1. Direct sequence spread spectrum (DSSS).

It is a modulation technique on which the transmitted signal takes up more bandwidth than the information signal that is being modulated. The name 'spread spectrum' comes from the fact that the carrier signals occur over the full bandwidth (spectrum) of a device's transmitting frequency.

DSSS is sine wave pseudorandomly with a pseudonoise (PN) code symbols called "chips", each of which has a much shorter duration than an information bit. That is, each information bit is modulated by a sequence of much faster chips. Therefore, the chip rate is much higher than the information signal bit rate.

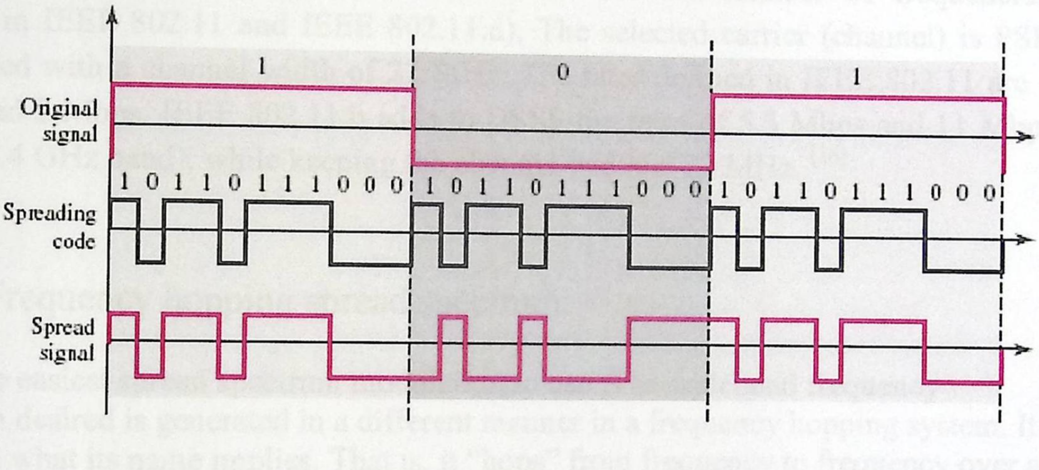


Figure 2.16: DSSS Encoding.

Direct-sequence spread-spectrum transmissions multiply the data being transmitted by a "noise" signal. This noise signal is a pseudorandom sequence of 1 and - 1 values, this noise-like signal can be used to exactly reconstruct the original data at the receiving end, by multiplying it by the same pseudorandom sequence (because $1 \times 1 = 1$, and $-1 \times -1 = 1$). This process known as despreading the principle of it is to correlate of the transmitted PN sequence with the PN sequence that the receiver believes the transmitter is using it. With longer PN sequence and more chips per bit enhance signal to noise ratio on the channel and that is called process gain

DSSS uses a signal structure in which the sequence of chips produced by the transmitter is known a priori by the receiver. The receiver can then use the same PN sequence to counteract the effect of the PN sequence on the received signal in order to reconstruct the information signal.

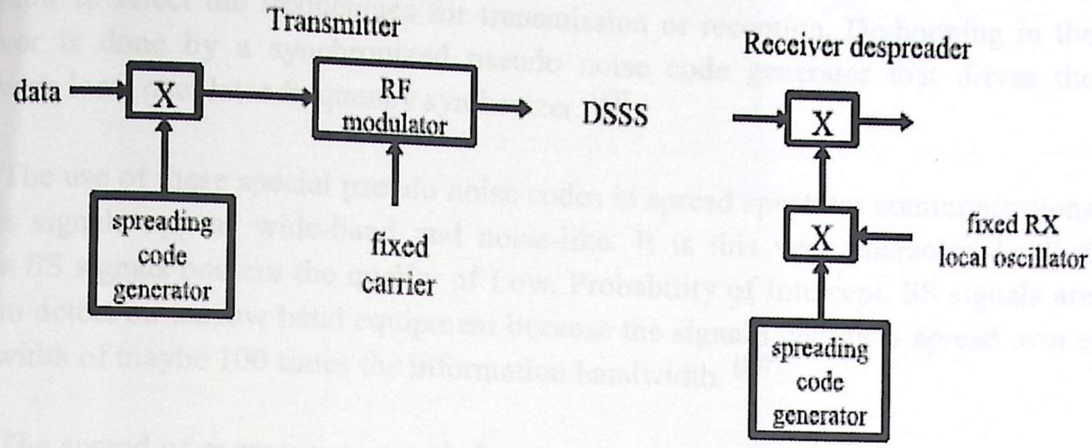


Figure 2.17: DSSS transmitter and receiver.

DSSS is defined (in IEEE 802.11) in the 2.4 GHz band as operating on one of 14 possible carriers (country specific bands have different number of frequencies, defined in IEEE 802.11 and IEEE 802.11.d). The selected carrier (channel) is PSK modulated with a channel width of 22 MHz. The rates defined in IEEE 802.11 are 1 Mbps and 2 Mbps. IEEE 802.11.b adds to DSSS the rates of 5.5 Mbps and 11 Mbps (in the 2.4 GHz band), while keeping the channel width at 22 MHz. [16]

2.7.2. Frequency hopping spread spectrum.

Is the easiest spread spectrum modulation to use. The wideband frequency spectrum desired is generated in a different manner in a frequency hopping system. It does just what its name implies. That is, it "hops" from frequency to frequency over a wide band. The specific order in which frequencies are occupied is a function of a code sequence, and the rate of hopping from one frequency to another is a function of the information rate. [17]

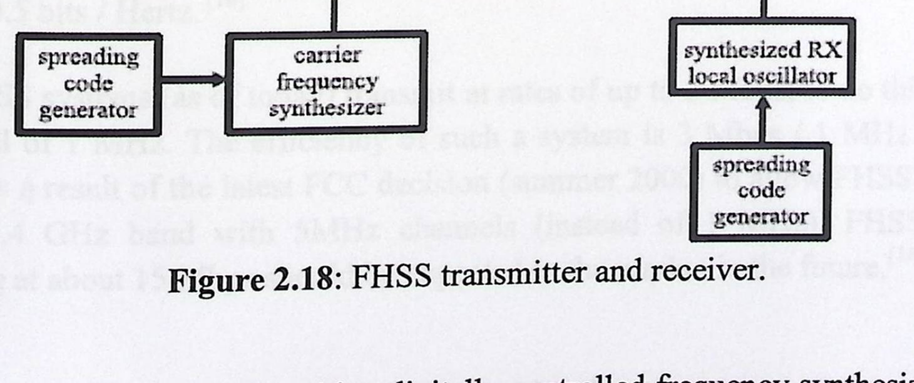


Figure 2.18: FHSS transmitter and receiver.

Theoretically, any radio with a digitally controlled frequency synthesizer can be converted into a frequency-hopped radio. All that is needed is to add a PN code generator to select the frequencies for transmission or reception. De-hopping in the receiver is done by a synchronized pseudo noise code generator that drives the receiver's local oscillator frequency synthesizer. [18]

The use of these special pseudo noise codes in spread spectrum communications makes signals appear wide-band and noise-like. It is this very characteristic that makes SS signals possess the quality of Low. Probability of Intercept. SS signals are hard to detect on narrow band equipment because the signal's energy is spread over a bandwidth of maybe 100 times the information bandwidth. [18]

The spread of energy over a wide band, or lower power spectral density, makes SS signals less likely to interfere with narrowband communications. Narrow band communications, conversely, cause little to no interference to SS systems because the correlation receiver effectively integrates over a very wide bandwidth to recover an SS signal. The correlator hence "spreads" out a narrow band interferer over the receiver's total detection bandwidth. Since the total integrated signal density or SNR at the correlator's input determines whether there will be interference or not, an SS receiver is immune to narrow band interference. [18]

The FHSS and DSSS technologies are described as well as different types of spread coding. DSSS systems can provide higher access data rates (up to 11Mbit/s) than FHSS systems (up to 3Mbit/s). More FHSS systems can operate simultaneously in the same area than DSSS systems. DSSS systems have higher interference susceptibility tolerance levels. However, if there is a strong broadband interferer in the operational spectrum, FHSS systems will suffer less due to frequency hopping. Assuming equal transmit powers, DSSS systems have lower power spectral density due to wider operating spectrum. Monte Carlo analysis results show that DSSS systems are more likely to cause interference than FHSS systems. The worst case interference levels are higher when the interferer is FHSS system. It was shown that this case has a very low probability of occurring. [19]

DSSS systems transmit at rates of up to 11 Mbps; to do this they use a contiguous sub-band of 22 MHz. The efficiency of such a system is 11 Mbps / 22 MHz = 0.5 bits / Hertz. [16]

FHSS systems (as of today) transmit at rates of up to 3 Mbps; to do this they use a channel of 1 MHz. The efficiency of such a system is 3 Mbps / 1 MHz = 3 bits / Hertz. As a result of the latest FCC decision (summer 2000) to allow FHSS operation in the 2.4 GHz band with 5MHz channels (instead of 1 MHz), FHSS systems operating at about 15 Mbps should be expected in the market in the future.[16]

2.8. Orthogonal frequency division multiplexing.

2.8.1. The single-carrier modulation system.

A single carrier system modulates information onto one carrier using frequency, phase, or amplitude adjustment of the carrier. For digital signals, the information is in the form of bits, or collections of bits called symbols, that are modulated onto the carrier. As higher bandwidths (data rates) are used, the duration of one bit or symbol of information becomes smaller, and that is cases an inter symbol interference (ISI); the system becomes more susceptible to loss of information from impulse noise, signal reflections and other impairments. These impairments can impede the ability to recover the information sent. In addition, as the bandwidth used by a single carrier system increases, the susceptibility to interference from other continuous signal sources becomes greater. This type of interference is commonly labeled as carrier wave (CW) or frequency interference. [20]

2.8.2. Frequency division multiplexing modulation system.

Frequency division multiplexing (FDM) extends the concept of single carrier modulation by using multiple subcarriers within the same single channel. The total data rate to be sent in the channel is divided between the various subcarriers.

Current national television systems committee (NTSC) television and FM stereo multiplex are good examples of FDM. FDM offers an advantage over single-carrier modulation in terms of narrowband frequency interference since this interference will only affect one of the frequency subbands. The other subcarriers will not be affected by the interference. Since each subcarrier has a lower information rate, the data symbol periods in a digital system will be longer, adding some additional immunity to impulse noise and reflections FDM systems usually require a guard band between modulated subcarriers to prevent the spectrum of one subcarrier from interfering with another. These guard bands lower the system's effective information rate when compared to a single carrier system with similar modulation. [20]

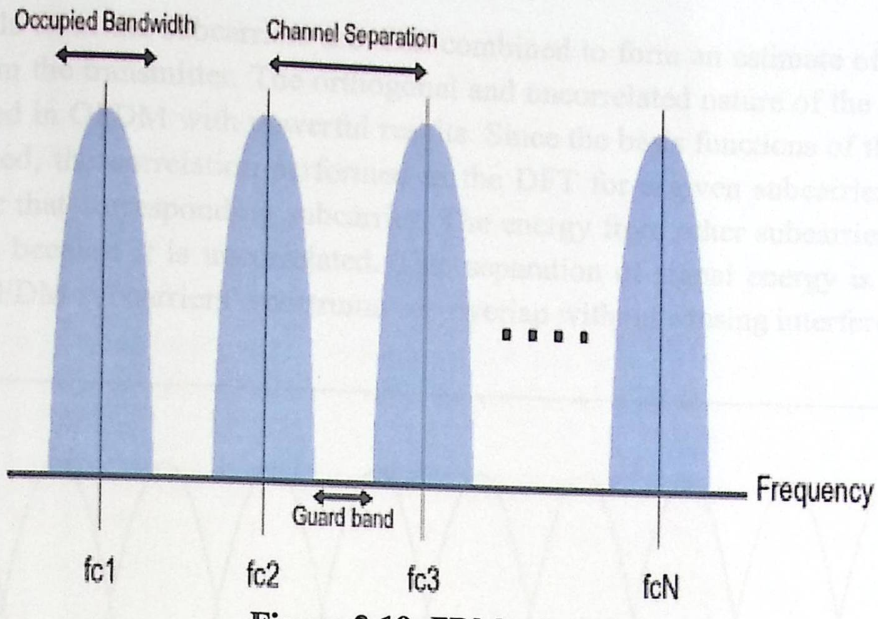


Figure 2.19: FDM principle.

2.8.3. Orthogonality and OFDM.

A higher level of spectral efficiency could have been achieved, if the FDM system above had been able to use a set of subcarriers that were orthogonal to each other.

The use of orthogonal subcarriers would allow the subcarrier's spectra to overlap, thus increasing the spectral efficiency. As long as orthogonality is maintained, it is still possible to recover the individual subcarrier's signals despite their overlapping spectrums. If the dot product of two deterministic signals is equal to zero, these signals are said to be orthogonal to each other. Orthogonality can also be viewed from the standpoint of stochastic processes. If two random processes are uncorrelated, then they are orthogonal. Given the random nature of signals in a communications system, this probabilistic view of orthogonality provides an intuitive understanding of the implications of orthogonality in OFDM. Recall from signals and systems theory that the sinusoids of the DFT form an orthogonal basis set, and a signal in the vector space of the DFT can be represented as a linear combination of the orthogonal sinusoids. One view of the DFT is that the transform essentially correlates its input signal with each of the sinusoidal basis functions. If the input signal has some energy at a certain frequency, there will be a peak in the correlation of the input signal and the basis sinusoid that is at that corresponding frequency. [20]

This transform is used at the OFDM transmitter to map an input signal onto a set of orthogonal subcarriers, i.e., the orthogonal basis functions of the DFT. Similarly, the transform is used again at the OFDM receiver to process the received subcarriers.

The signals from the subcarriers are then combined to form an estimate of the source signal from the transmitter. The orthogonal and uncorrelated nature of the subcarriers is exploited in OFDM with powerful results. Since the basis functions of the DFT are uncorrelated, the correlation performed in the DFT for a given subcarrier only sees energy for that corresponding subcarrier. The energy from other subcarriers does not contribute because it is uncorrelated. This separation of signal energy is the reason that the OFDM subcarriers' spectrums can overlap without causing interference. [20]

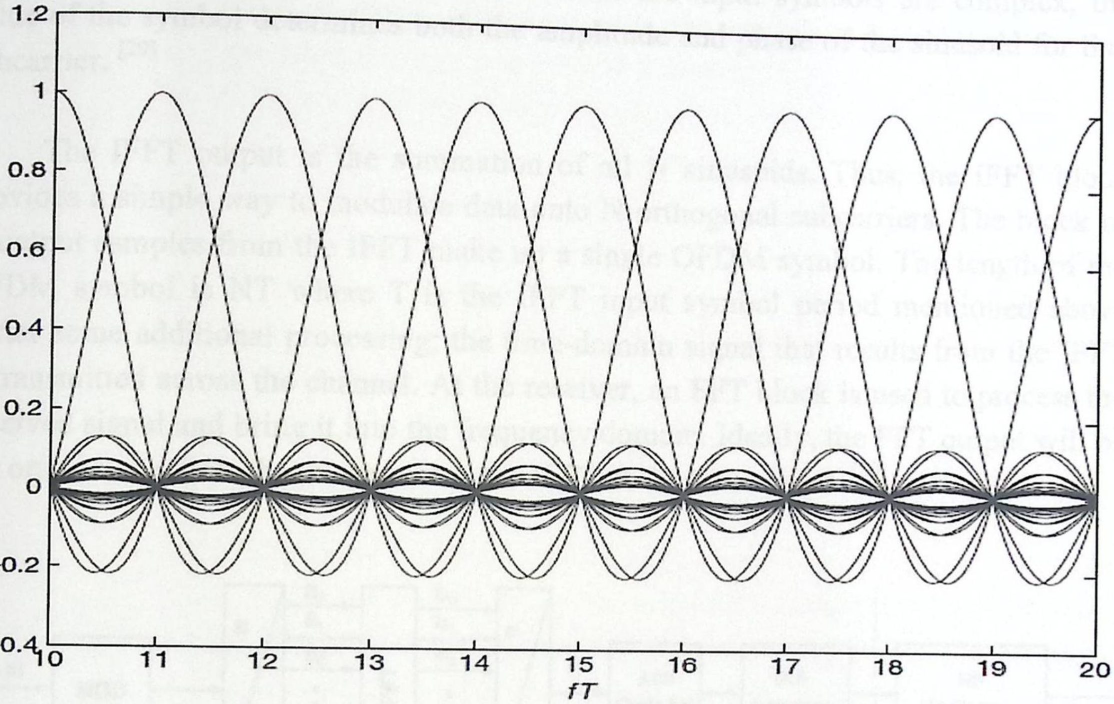


Figure 2.20: OFDM principle.

2.8.4. Implementation of an OFDM system.

The idea behind the analog implementation of OFDM can be extended to the digital domain by using the discrete Fourier Transform (DFT) and its counterpart, the inverse discrete Fourier Transform (IDFT). These mathematical operations are widely used for transforming data between the time-domain and frequency-domain. These transforms are interesting from the OFDM perspective because they can be viewed as mapping data onto orthogonal subcarriers. For example, the IDFT is used to take in frequency-domain data and convert it to time-domain data. In order to perform that operation, the IDFT correlates the frequency-domain input data with its orthogonal basis functions, which are sinusoids at certain frequencies. This correlation is equivalent to mapping the input data onto the sinusoidal basis functions. [20]

In practice, OFDM systems are implemented using a combination of fast Fourier Transform (FFT) and inverse fast Fourier Transform (IFFT) blocks that are mathematically equivalent versions of the DFT and IDFT, respectively, but more efficient to implement. An OFDM system treats the source symbols (e.g., the QPSK or QAM symbols that would be present in a single carrier system) at the transmitter as though they are in the frequency-domain. These symbols are used as the inputs to an IFFT block that brings the signal into the time domain. The IFFT takes in N symbols at a time where N is the number of subcarriers in the system. Each of these N input symbols has a symbol period of T seconds. Recall that the basis functions for an IFFT are N orthogonal sinusoids. These sinusoids each have a different frequency and the lowest frequency is DC. Each input symbol acts like a complex weight for the corresponding sinusoidal basis function. Since the input symbols are complex, the value of the symbol determines both the amplitude and phase of the sinusoid for that subcarrier. [20]

The IFFT output is the summation of all N sinusoids. Thus, the IFFT block provides a simple way to modulate data onto N orthogonal subcarriers. The block of N output samples from the IFFT make up a single OFDM symbol. The length of the OFDM symbol is NT where T is the IFFT input symbol period mentioned above .After some additional processing; the time-domain signal that results from the IFFT is transmitted across the channel. At the receiver, an FFT block is used to process the received signal and bring it into the frequency domain. Ideally, the FFT output will be the original symbols that were sent to the IFFT at the transmitter. [20]

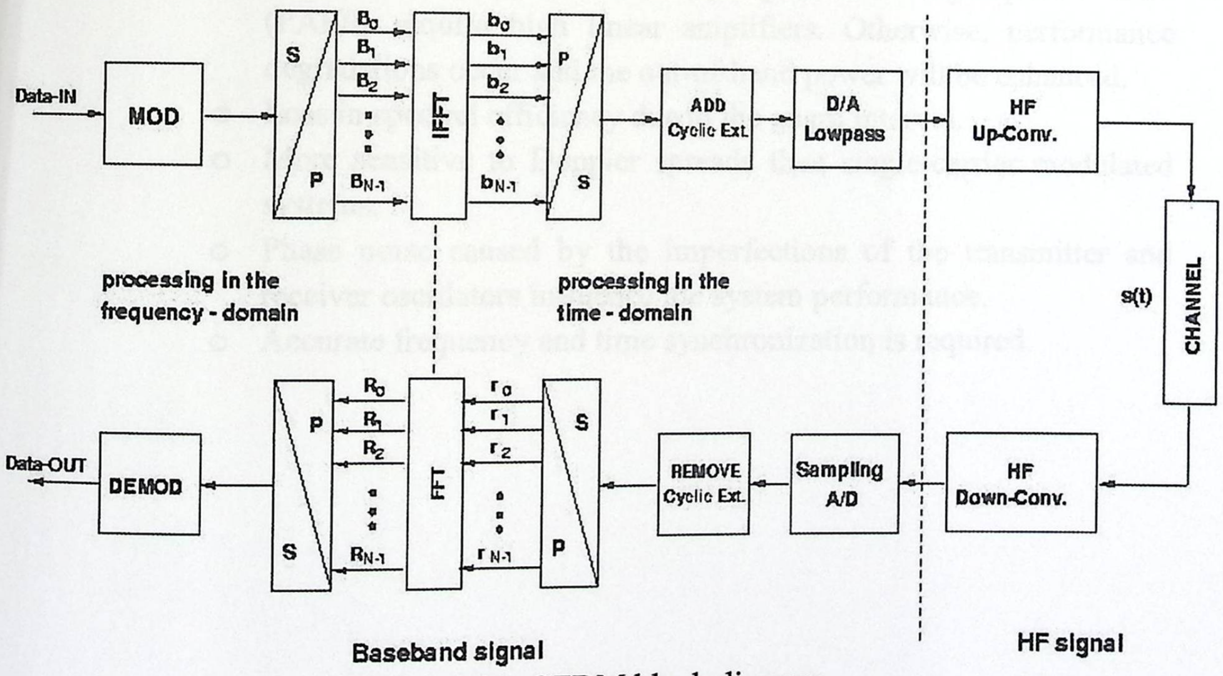


Figure 2.21: OFDM block diagram.

2.8.5. Advantages and disadvantages of OFDM.

This section summarizes the strengths and weaknesses of multi-carrier modulation based on OFDM.

Advantages:

- High spectral efficiency due to nearly rectangular frequency spectrum for high numbers of sub-carriers.
- Simple digital realization by using the FFT operation.
- Low complex receivers due to the avoidance of ISI and ICI with a sufficiently long guard interval.
- Flexible spectrum adaptation can be realized, e.g., notch filtering.
- Different modulation schemes can be used on individual sub-carriers which are adapted to the transmission conditions on each sub-carrier, e.g., water filling.

Disadvantages:

- Multi-carrier signals with high peak-to-average power ratio (PAPR) require high linear amplifiers. Otherwise, performance degradations occur and the out-of-band power will be enhanced.
- Loss in spectral efficiency due to the guard interval.
- More sensitive to Doppler spreads then single-carrier modulated systems.
- Phase noise caused by the imperfections of the transmitter and receiver oscillators influence the system performance.
- Accurate frequency and time synchronization is required.

Chapter 3

System Design and Implementation

3.1 Introduction.

3.2. Design of the wireless network.

3.2.1. Access Point.

3.2.2. Peripheral Component Interconnect (PCIs).

3.1 Introduction.

The aim of this project is to measure the throughput of Wi-Fi network that consists of different combination of Wi-Fi technologies (Wi-Fi 802.11b, 802.11g, and 802.11n) in 2.4GHz band.

This chapter contains real case scenarios; which will be measured with one AP and four clients in different AP scenarios.

In the next semester we will be able to measure the throughput in five scenarios when the AP operating in **bgn mix** mode, in **bg mix** mode, in **b only** mode, **g only** mode and **n only** mode with all clients cases, we want to clarify the difference between effects of wireless network with combination of clients that use different Wi-Fi technologies.

3.2. Design of the wireless network.

The principle is to design network that consists of different combination of different numbers of clients that use b\g\n technologies, by changing the mode of clients there are different cases, we want to measure the throughput of five AP scenarios.

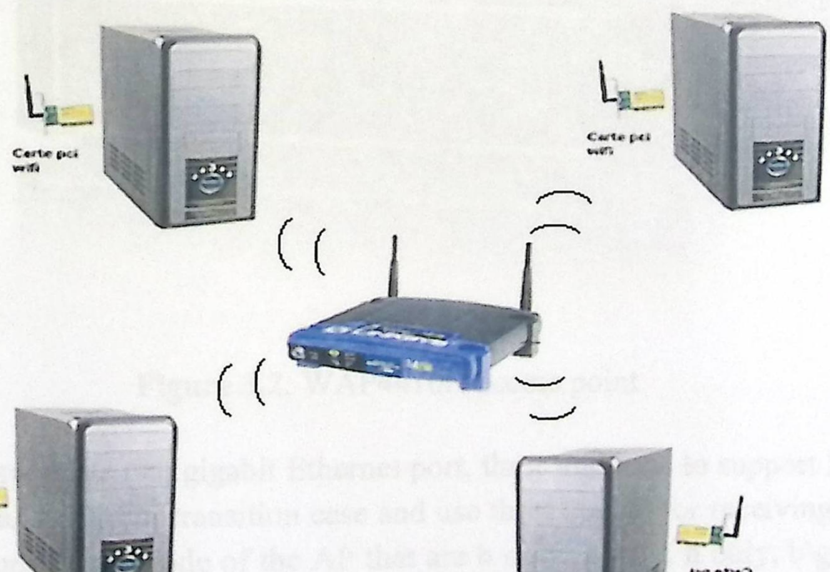


Figure 3.1: Wireless network with four clients.

The distance between AP and clients is the same for all cases. if the distance between AP and one client is higher than other clients in the same combination, throughput of this client is decreased and an incorrect measurement is obtained in this case.

3.2.1. Access Point.

One access point is required in this project, this AP must support n technology to operate it in **ngb** mode, **bg** mode, **b only** mode , **g only** mode and **n only** mode. This AP must support 802.11b\g\n clients.

Since n technology support data rate 300 Mbps, the AP must support gigabit Ethernet not fast Ethernet, since fast Ethernet provide data rate 100Mbps which is less than 300Mbps.

CISCO Company provides many types of AP that provide gigabit Ethernet port and required operating needed in this project, such as WAP4410N, as shown.

Figure 3.2: WAP4410N access point.

This AP supports one gigabit Ethernet port, three antennas to support 3T3R (can use three spatial stream in transition case and use three spatial for receiving case) and also different operating mode of the AP that are b only, g only, n only, b\g and b\g\n modes, as shown below.

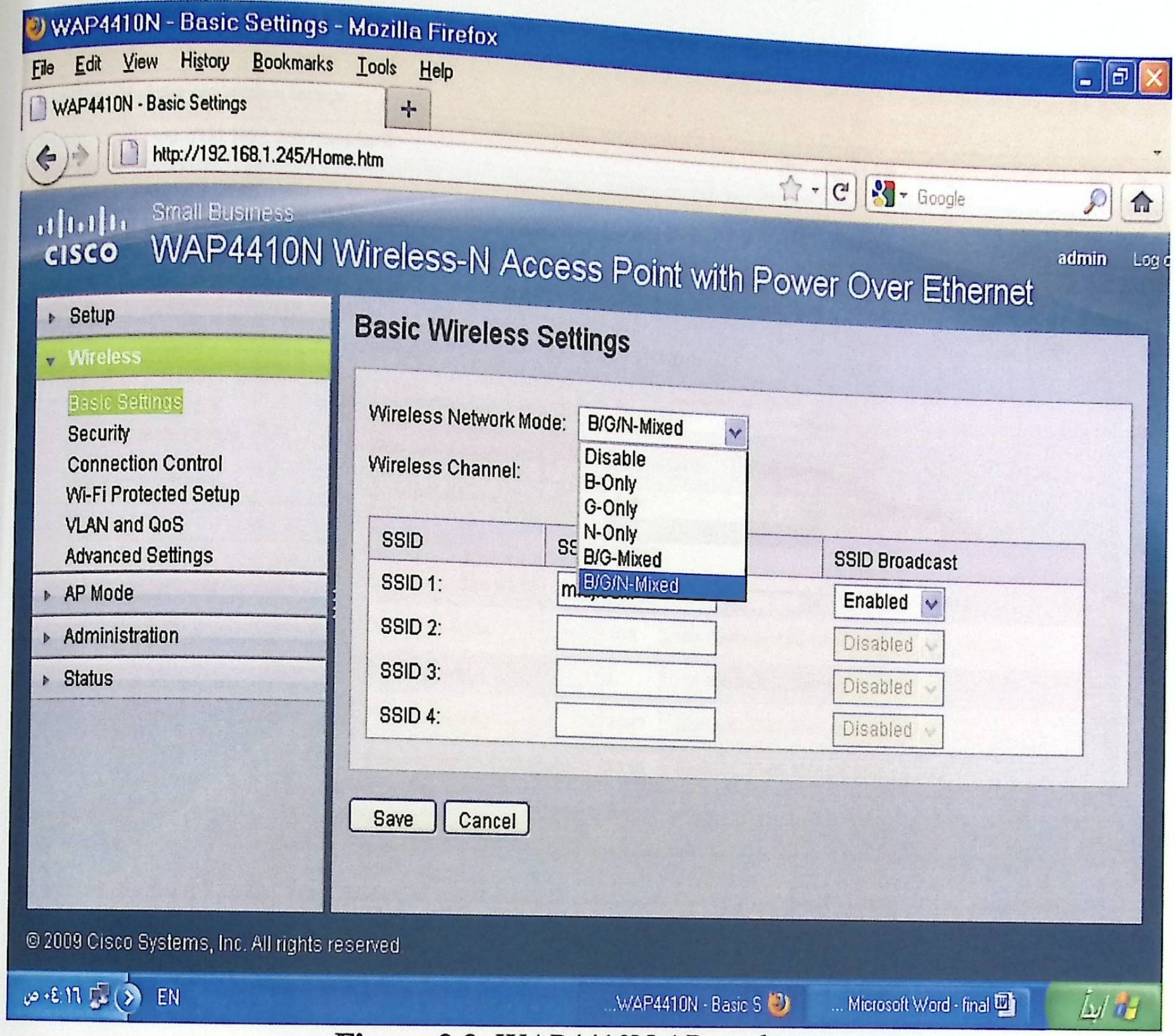


Figure 3.3: WAP4410N AP modes.

- **11b only** - Only 802.11b wireless clients can connect to the AP.
- **11g only** - Only 802.11g wireless clients can connect to the AP.
- **11n only** - Only 802.11n wireless clients can connect to the AP.
- **11bg mixed** - Both 802.11b and 802.11g wireless clients can connect to the AP.
- **11bgn mixed** - All 802.11b, 802.11g and 802.11n wireless clients can connect to the AP.

WAP4410N AP provides many features such as operating frequency with channel width 20MHz or 20/40MHz; the AP must operates in channel that is not used in the neighboring APs; to avoid interference from the others APs.

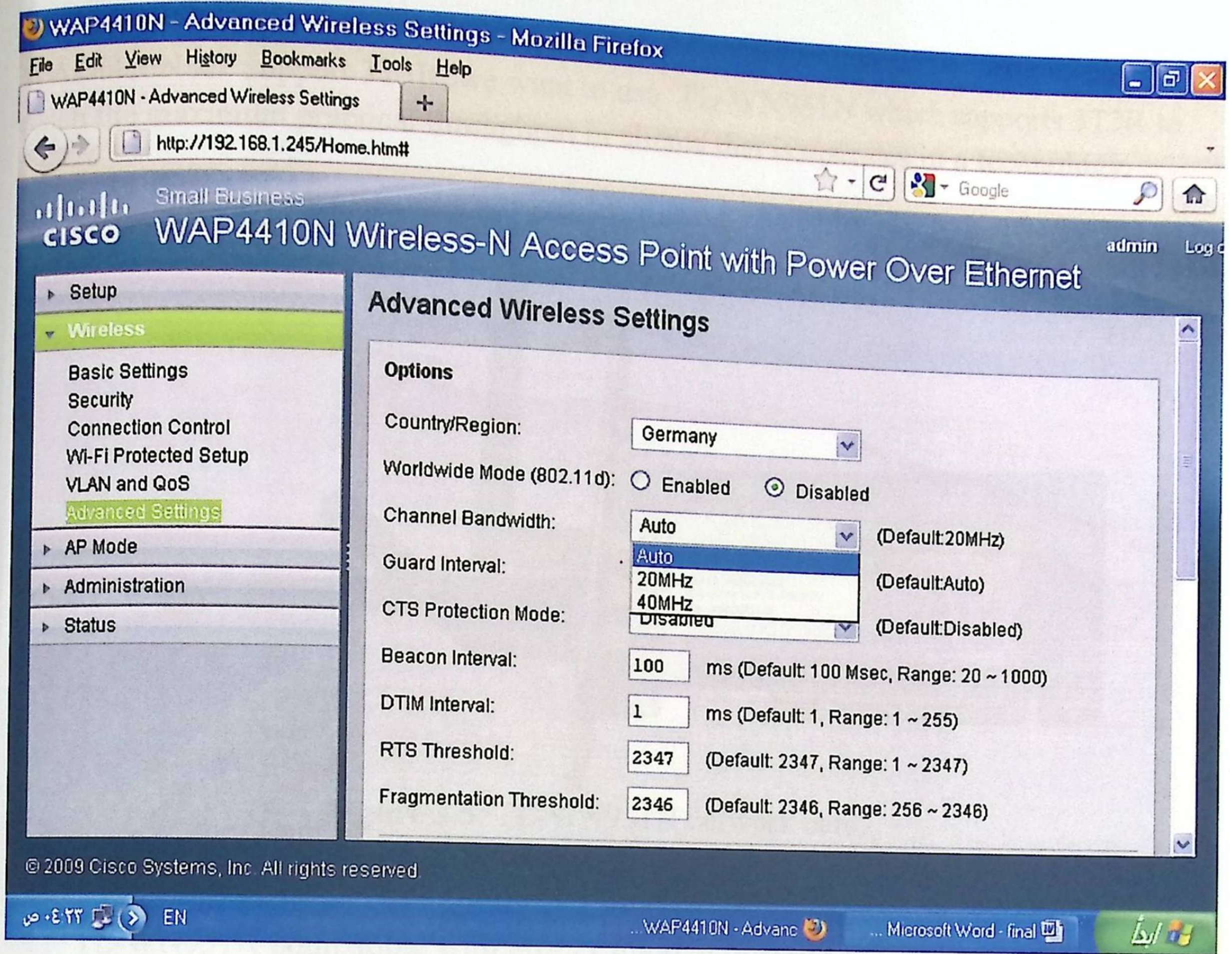


Figure 3.4: WAP4410N AP channel width.

3.2.2. Peripheral Component Interconnect (PCIs).

PCIs network cards allow users to change the operating mode that USB can't provide, in this project we want to design wireless network with combinations of PCIs that support 802.11b,802.11g and 802.11n.

Each PCI must support 802.11b/g/n technologies, and we want four PCIs to support all cases, the TP-LINK company provides many types of products of PCIs, such as TL-WN951N, TL-WN851N, and TL-WN751ND

TL-WN751ND and similar devices support b, g and also support n technology. but in these devices n technology use only 20Mhz channel with maximum data rate 150Mbps. In this project we want to use n clients that can support 300Mbps; so this kind of clients is not used in the project.

TL-WN951N and TL-WN851N both are classified as 802.11n network cards operated in 40MHz channel with the ability to transmit and receive two spatial streams to provide maximum data rate up to 300Mbps.

TL-WN851N uses two antennas to support 2T2R technology, but since the WAP4410N AP support 3T3R; we want to use TL-WN951N which supports 3T3R to reach the maximum practical throughput in clients that is operates in n technology.

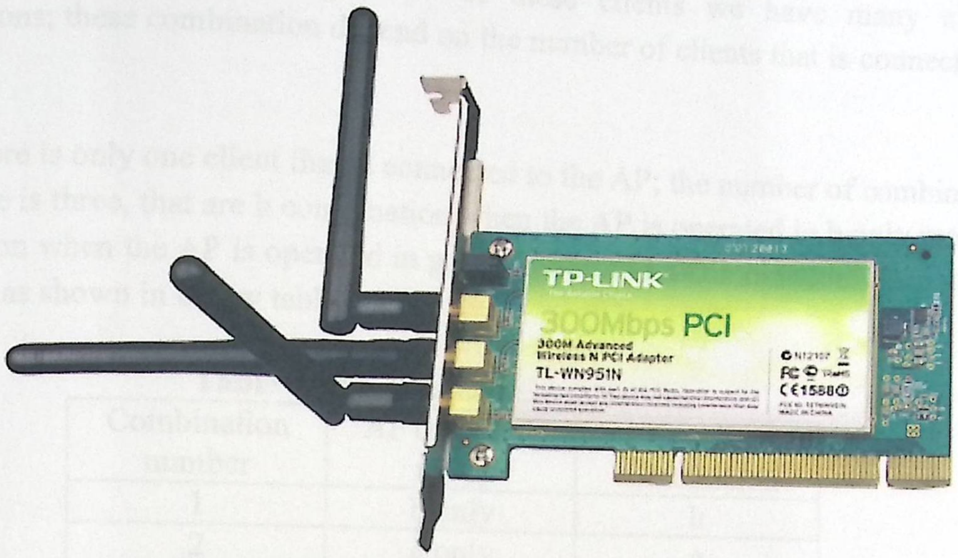


Figure 3.5: TL-WN951N network card.

TL-WN951N compatible with 802.11 n\g\b. it operates in n mode if the wireless mode is adjusted to 2.4 GHZ 300Mbps, in g mode if 2.4GHz 54Mbps is selected, and in b mode if 2.4GHz 11Mbps is selected, as shown below.

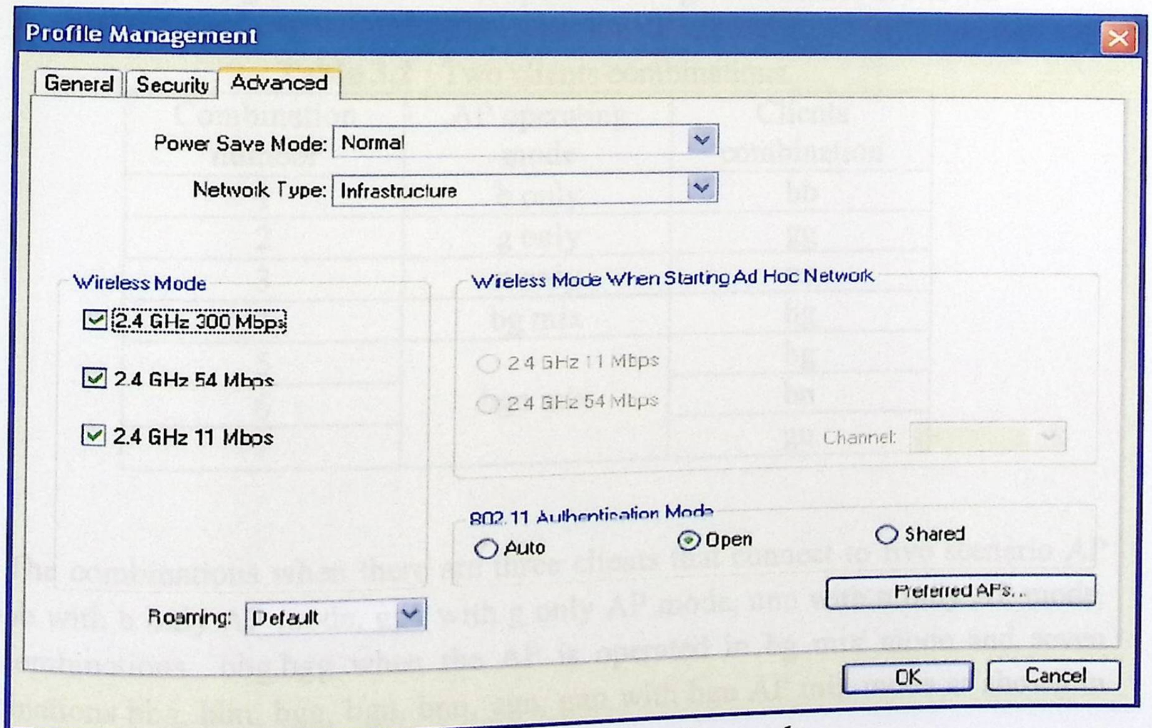


Figure 3.6: TL-WN951N operating mode.

The aim of this project is to build a wireless network that contains four clients ,each one has a ability to change the operating mode of it between b, g and n technology.

By changing the operating mode of these clients we have many clients combinations; these combination depend on the number of clients that is connected to the AP.

If there is only one client that is connected to the AP; the number of combination in this case is three, that are b combination when the AP is operated in b only mode, g combination when the AP is operated in g only mode and n combination when n only AP mode, as shown in below table.

Table 3.1 : One clients combinations.

Combination number	AP operating mode	Clients combination
1	b only	b
2	g only	g
3	n only	n

When there are two clients, the number of combination are seven, that are bb when the AP is operated in b only mode, gg combination when g only AP mode, nn with n only AP mode, bg when the AP is operated in bg mix mode and three combinations bg, bn, gn when the AP is operated in bgn mix mode, as shown.

Table 3.2 : Two clients combinations.

Combination number	AP operating mode	Clients combination
1	b only	bb
2	g only	gg
3	n only	nn
4	bg mix	bg
5	bgn mix	bg
6		bn
7		gn

The combinations when there are three clients that connect to five scenario AP are bbb with b only AP mode, ggg with g only AP mode, nnn with n only AP mode, two combinations bbg,bgg when the AP is operated in bg mix mode and seven combinations bbg, bbn, bgg, bgn, bnn, ggn, gnn with bgn AP mix mode as shown in the table below.

Table 3.3 : Three clients combinations.

Combination number	AP operating mode	Clients combination
1	b only	bbb
2	g only	ggg
3	n only	nnn
4	bg mix	bbg
5		bgg
6	Bgn mix	bbg
7		bbn
8		bgg
9		bgn
10		bnn
11		ggn
12		gnn

The combination with four clients is eighteen combination, and that are bbbb with b only AP mode, gggg with g only AP mode, nnnn with n only AP mode, three combinations bbbg, bbgg, bggg when the AP is operated in bg mix mode and twelve combinations bbbg, bbbn, bbgg, bbgn, bbnn, bggg, bggn, bgnn, bnnn, gggn, ggnn, gnnn with bgn mix mode, as shown below.

Table 3.4 : Four clients combinations.

Combination number	AP operating mode	Clients combination
1	b only	bbbb
2	g only	gggg
3	n only	nnnn
4	bg mix	bbbg
5		bbgg
6		bggg
7	bgn mix	bbbg
8		bbbg
9		bbgg
10		bbgn
11		bbnn
12		bggg
13		bggn
14		bgnn
15		bnnn
16		gggn
17		ggnn
18		gnnn

So for five AP operating mode scenarios and with different number of clients that are connect to the AP; there are forty clients combination in this project.

For example, if the combination of three clients that is connectd to bgn AP mix mode is nnn, in this case since the AP supports two spatial streams with 40 MHz channel, theoretical throughput of it is 300Mbps, each client can use two spatial streams and 40MHz channel for transmit and receive data between it and the AP; so each one can achieve 300Mbps, as shown below.

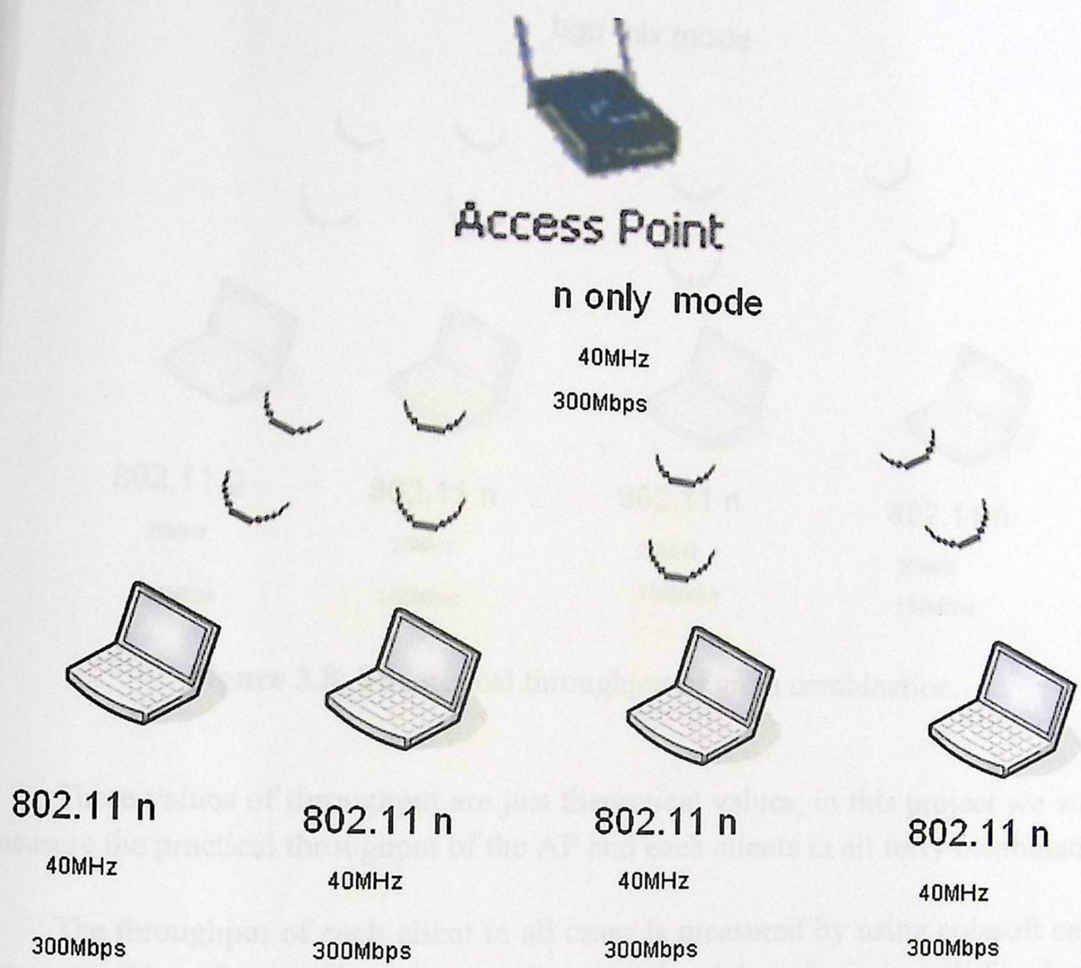


Figure 3.7: Theoretical throughput of nnn combination.

With the same AP operating mode, if one g client adds to nnn combination, the new combination is gnnn as shown below, since g clients operates with only 20 MHz channel the AP is forced to operate in 20MHz channel to support g client; throughput of the AP is reduced to 150Mbps in this case, because AP uses 20MHz the n clients use also 20MHz channel with two spatial streams, each n client has 150Mbps throughput ,and g client with 20MHz channel and one spatial stream has 54Mbps theoretical throughput.

If a user configures AP to operate in 40 MHz channel, a protocol that is called coexistence protocols checks the medium if there is only n type of clients and there is no g or b clients, and so the AP will use 40MHz channel, in the opposite, if there is a b or g clients this protocol forces the AP to use only 20 MHz.

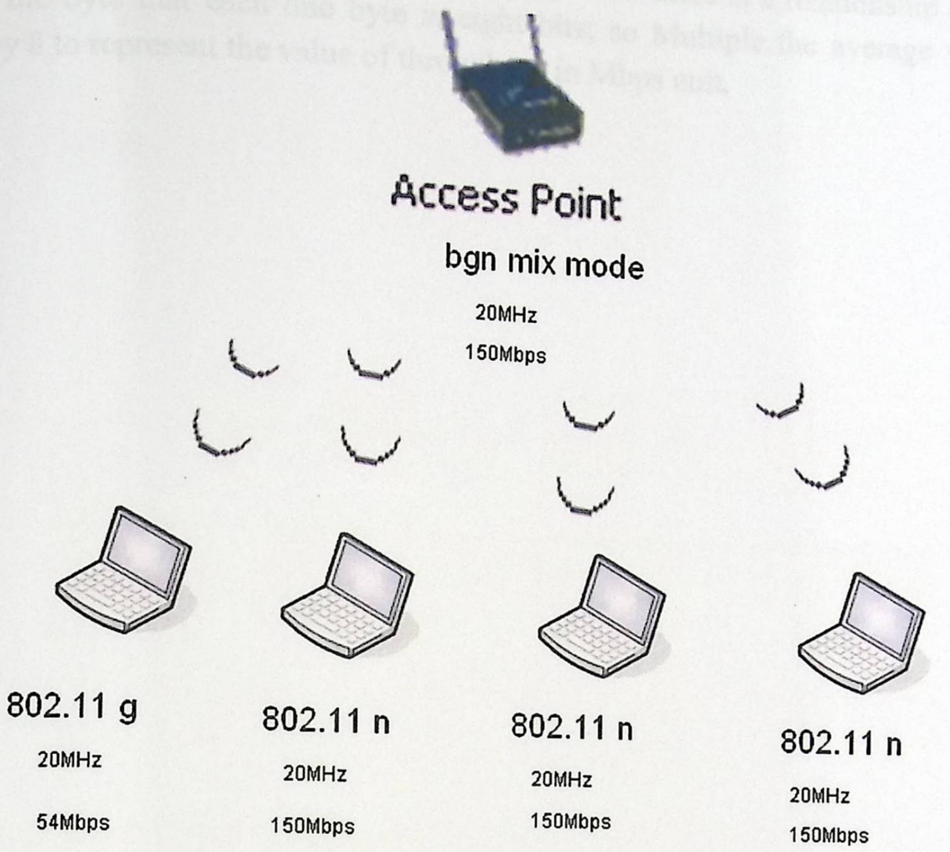


Figure 3.8: Theoretical throughput of gnnn combination.

These values of throughput are just theoretical values, in this project we want to measure the practical throughput of the AP and each clients in all forty combinations.

The throughput of each client in all cases is measured by using colasoft capsa 7 program; this software allows users to monitor the status of wireless WiFi adapter(s) and gathers information about nearby wireless access points and also provids comprehensive graphing of throughput value. All IEEE 802.11 standards are supported by this program including 802.11a, 802.11b and 802.11g and 802.11n.

We will use colasoft capsa 7 program to measure the throughput of each client in all client's combinations, to compare and analysis these values.

Each data throughput that is measured by colasoft capsa 7 show the throughput variation of the devices (client or AP) in a two minuets time. The colasoft capsa 7 takes a sample every one second; so there are 120 samples in each data throughput figure, so this program can provide a good measurement for data variation in wireless environment, for simplification and approximately we can take a bout 23 samples in each figure with 5 seconds separation between two successive samples.

After taking 23 samples, we want to take the average of them that will be done by Microsoft Office Excel program. Colasoft capsa 7 measures the value of throughput in MBps unit, to translate it to Mbps unit there is a relationship between bit and the byte that each one byte is eight bits; so Multiple the average value of MBps by 8 to represent the value of throughput in Mbps unit.

Chapter 4

Design details

4.1. Access Point Configuration.

4.2. Wireless Adapters Configuration.

4.3. How to Connect Clients with the Access Point.

4.4. Design Details.

This chapter contains the design details and steps of configuration the CISCO 4410N access point and also configuration steps of TP-LINK 951N Wireless Adapter that are used in this project.

4.1. Access Point Configuration.

The CISCO 4410N AP is the access point we used, to begin in the configuration login must be occur to enter the configuration of this device by entering the static IP address 192.168.1.200 with subnet mask 255.255.255.0

To login to the configuration page; open your browser such as Mozilla firefox for example and then enter this IP address192.168.1.245 when enter this address a login page that requires you to enter the username and password, the default username and password are admin, after that you are now in configuration page of this AP, as shown below.

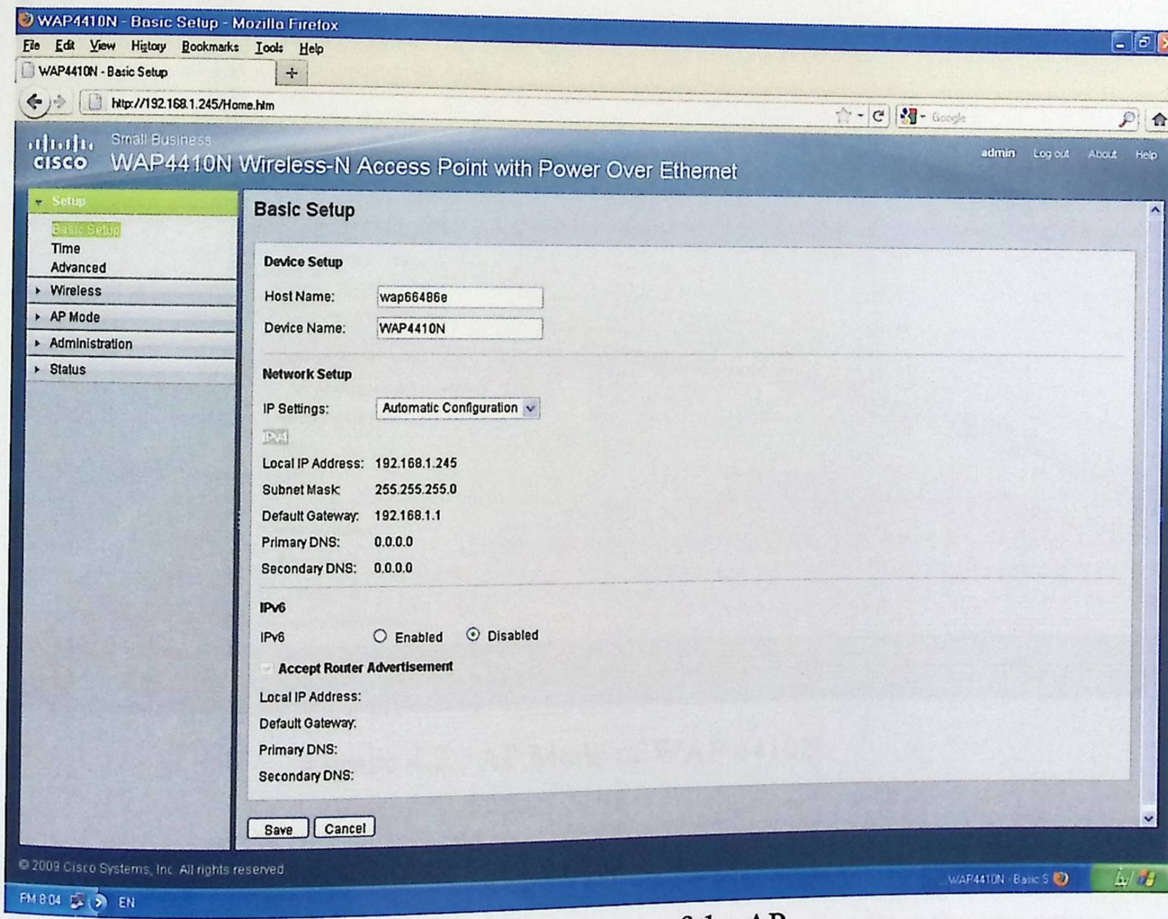


Figure 4.1 : Basic setup of the AP.

The AP provides many utility such as VLAN , adjacent of CTS\RTS and fragmentation threshold, in this project we're not interested about this utility. We're interested in changing the operating mode of the access point and some utility that is related to our project.

To configure this device to operate in AP mode go to the AP mode in the left of the previous figure and choose Access Point, This device provides many operating mode that are:

Access Point (default): To adjust this device to operate in AP mode
Wireless WDS Repeater: To adjust this device to operate in repeater mode
Wireless WDS Bridge: To adjust this device to operate in bridge mode
Wireless Client: To adjust this device to operate in client mode
Wireless Monitor: To adjust this device to monitor the traffics

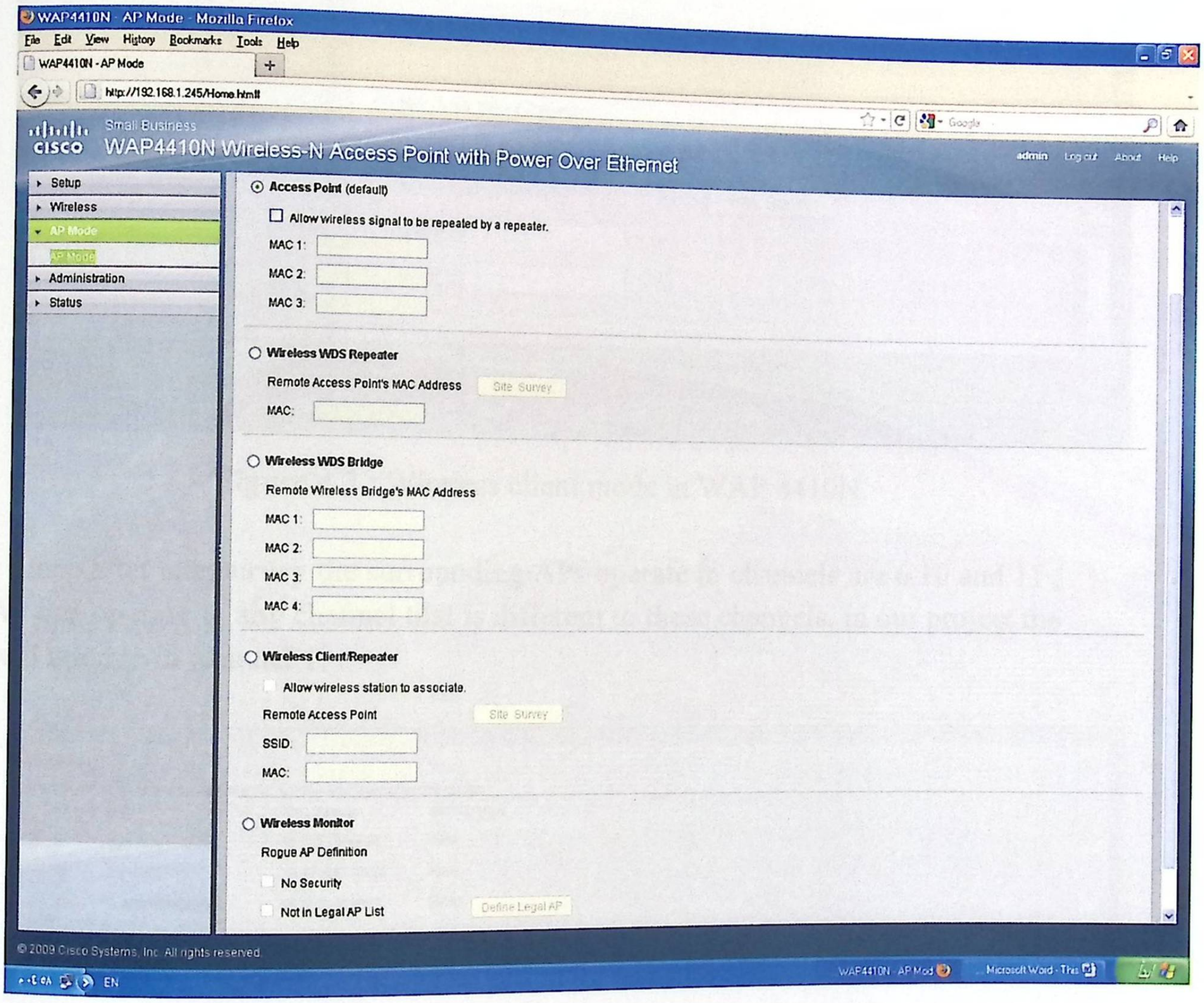


Figure 4.2 : AP Mode of WAP 4410N.

Now to make the ability to change the operating mode of this access point, go to the Wireless in the left screen; you have many choices. The Basic Settings allow you to change the wireless mode of this access point and also you can adjust the operating channel, it is important of this project to operate the AP with channel that is not used in the neighbor APs to avoid the interference from the other APs.

To ensure that there is no any one AP uses the same operating channel; change the operating mode of the AP to client\repeater in the AP mode in the left side of screen and scan the site by site survey as shown below.

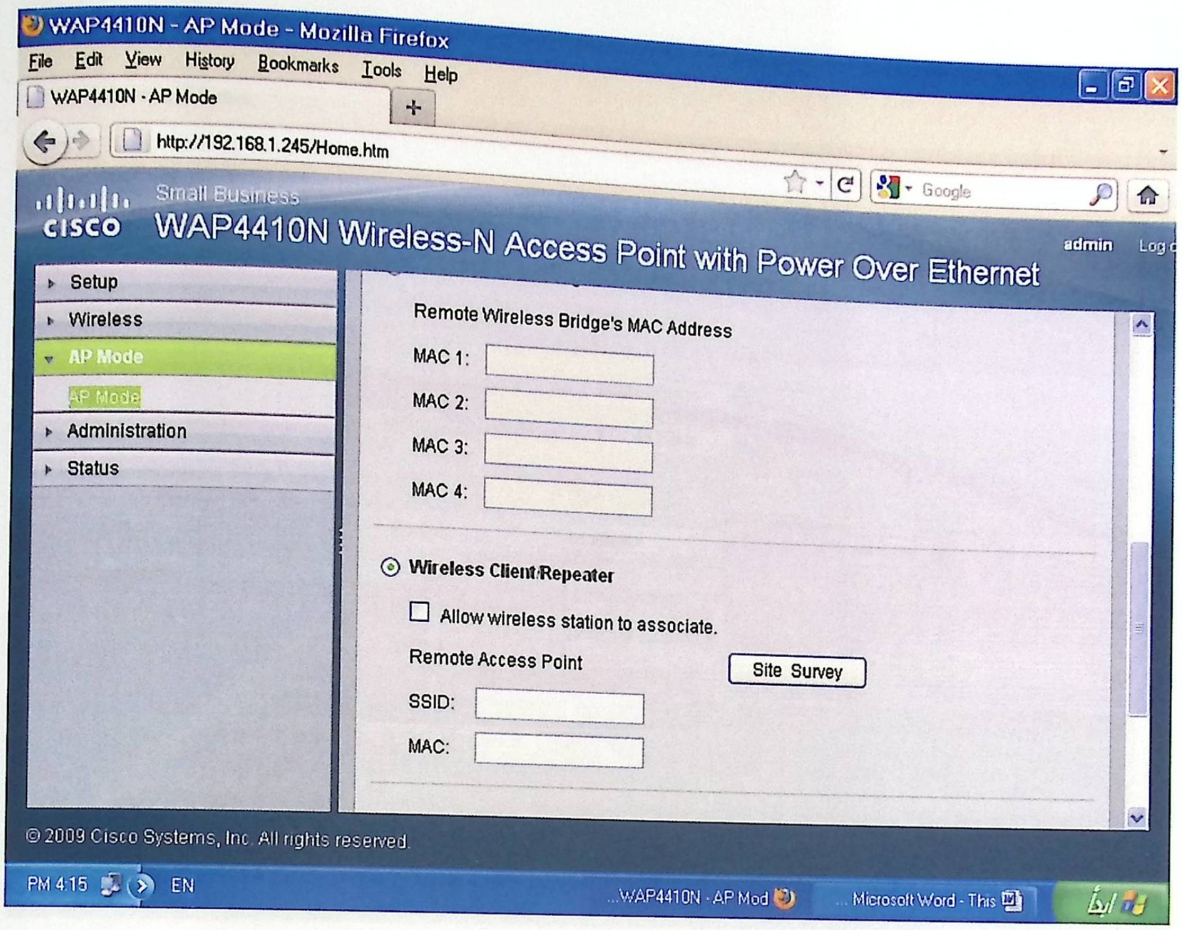


Figure 4.3 : Wireless client mode in WAP 4410N.

Since after site survey the surrounding APs operate in channels are 6,10 and 11 , the AP can operate in any channel that is different to these channels, in our project the AP will operate in channel 1.

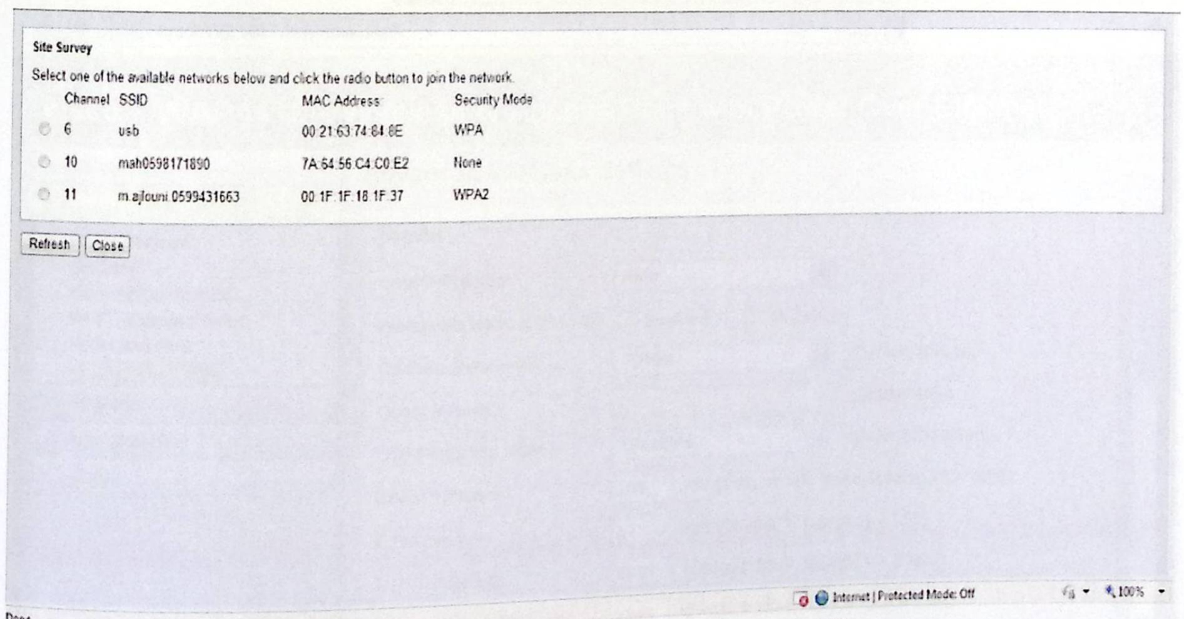


Figure 4.4 : Site survey result by using AP.

You can also change the host name (SSID), this device can support four SSID, in this project the SSID of the AP is 'm.ajlouni' as shown

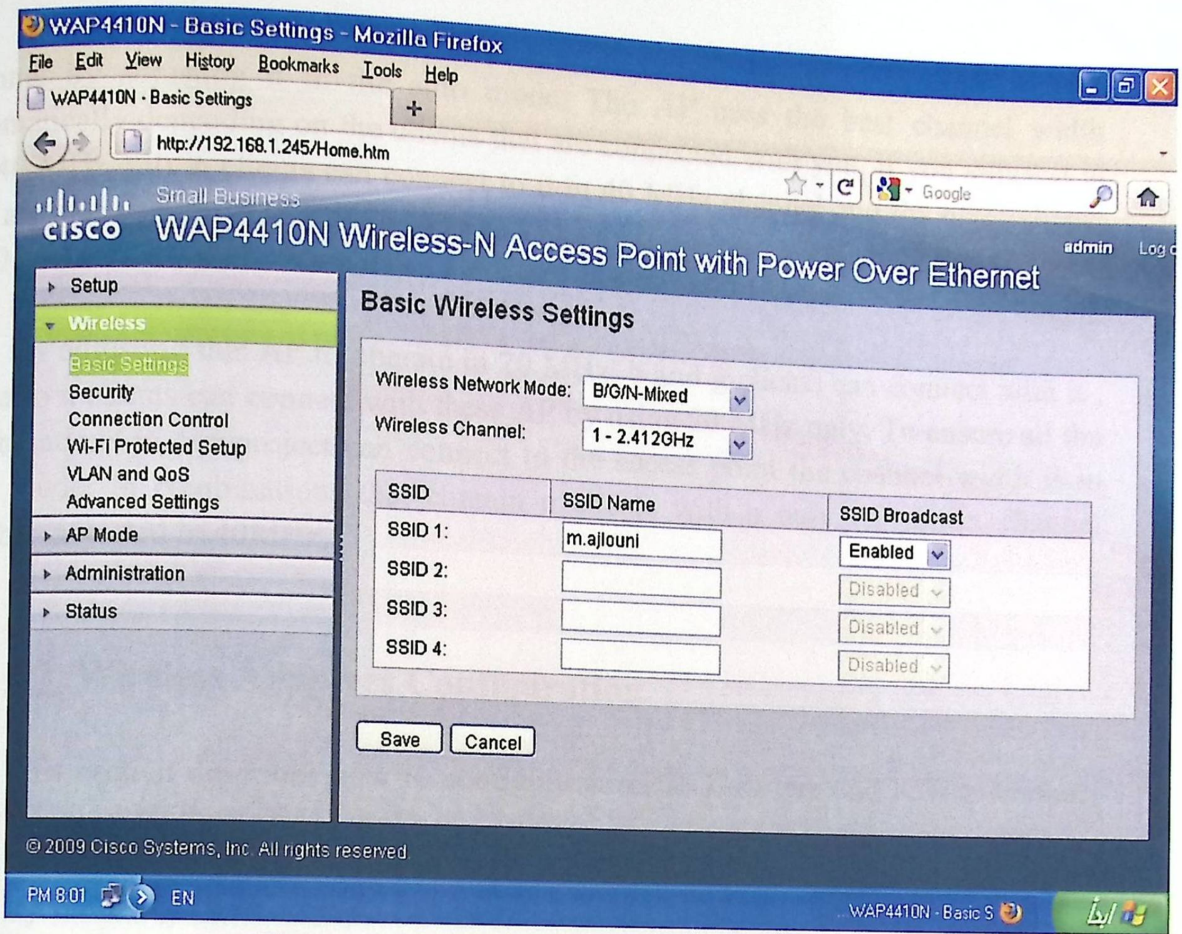


Figure 4.5 : AP's basic wireless setting.

The Advance setting provides some options such as Country/Region , Fragmentation Threshold . RTS\CTS and channel width.

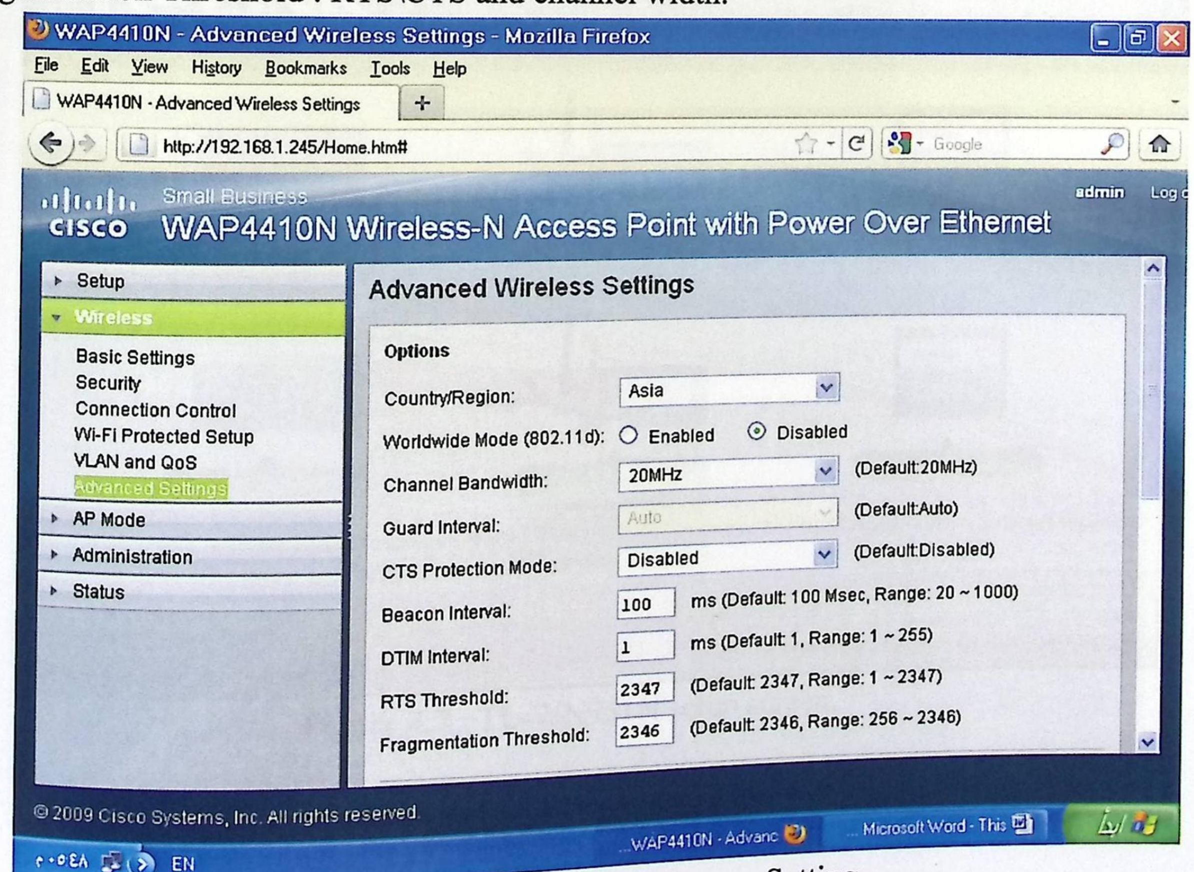


Figure 4.6 : WAP 4410N Advance Setting

Channel width provides you the option to adjust the width of the operating channel by adjusting it in the auto mode. The AP uses the best channel width automatically depending on the clients that are connected with you, if you adjust it in the 40 MHz only n clients can connect to it in 40 MHz channel and the other clients that are operating in b or g mode cant connect to this access point since that operated in 20 MHz only.

By adjusting this AP to operate in 20 MHz, b and g clients can connect with it , and also n clients can connect with these AP by using 20 MHz only. To ensure all the combinations in our project can connect to the access point the channel width is in auto mode. In combinations that contain n clients with n only AP mode, channel width is adjusted in 40MHz.

4.2. Wireless Adapters Configuration.

This section describes how to configure wireless Adapters and how to connect these clients with the access point.

By inserting the Resource CD into CD-ROM drive, figure below will appear. choose install Driver & Utility of TL-WN951N.

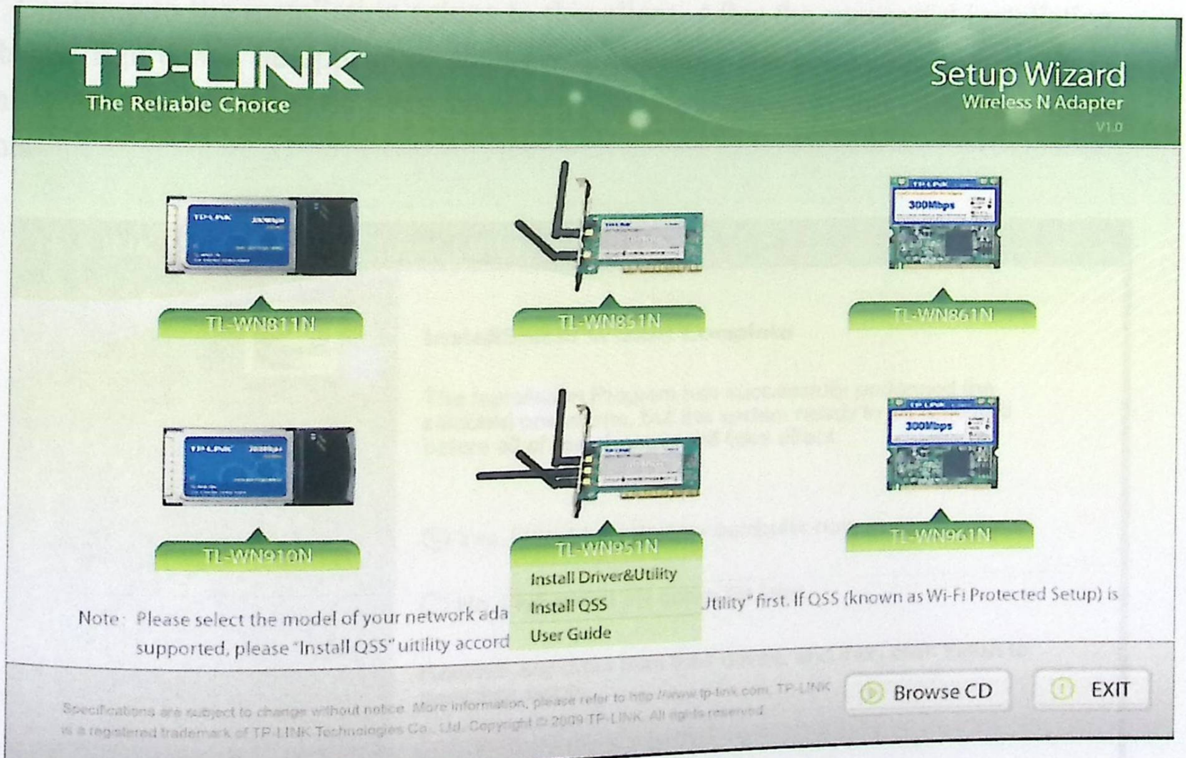


Figure 4.7 : TL-WN951N setup screen.

After that the below figure will be appeared soon, Next to continue.

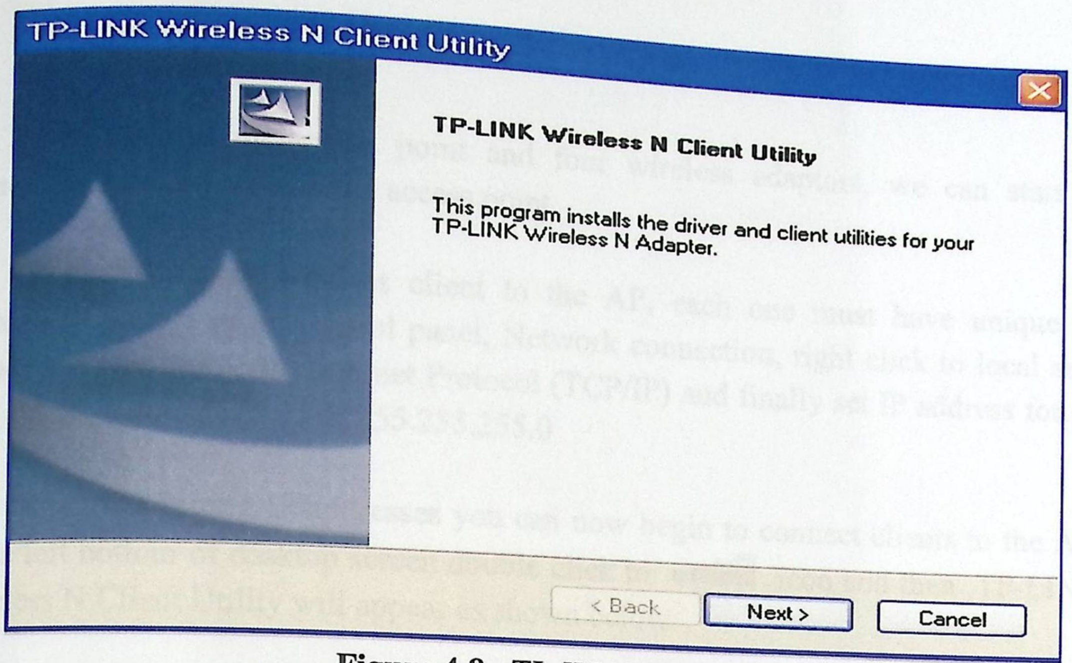


Figure 4.8 : TL-WN951N utility.

Choose a Setup type. It is recommended that you select Install Client Utilities and Driver as shown below. If you select Install Driver the driver is instilled without utility , the utility allows to change the operating mode of this adaptor and that is important in this project, because we want to change the operating mode of each client.

Continue to the installation setups to this client. After the successful installation the below figure will be appeared, click finish to restart the computer, after that this client is already installed on your computer, do these steps to the remaining three clients.

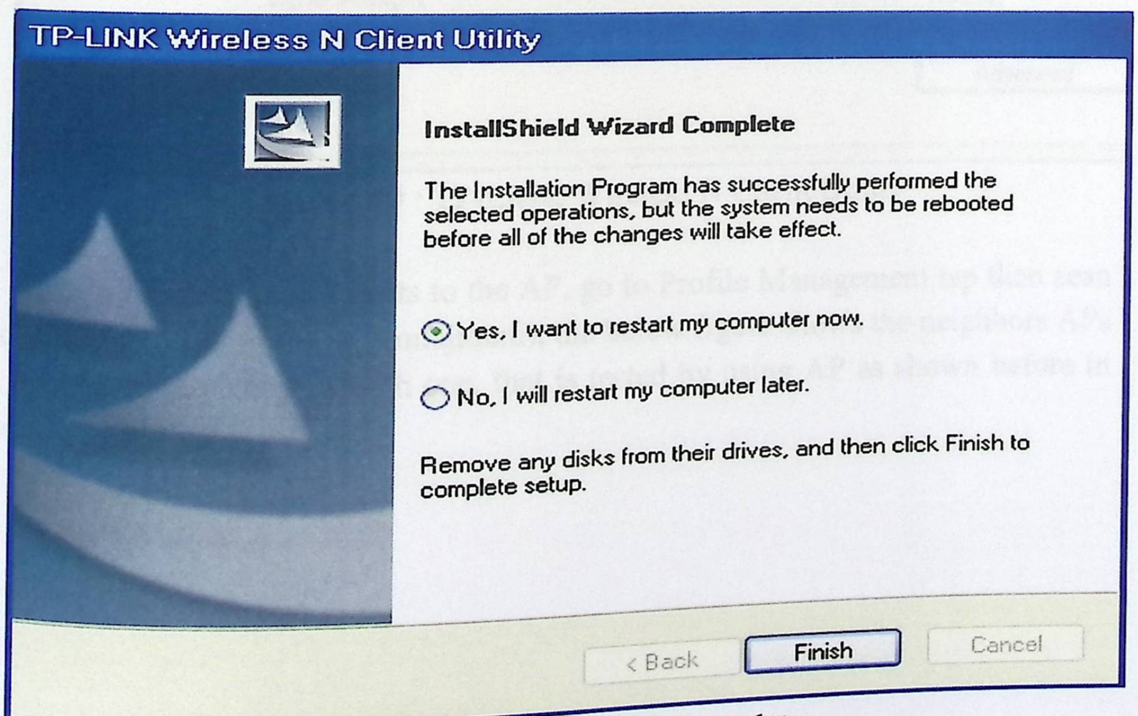


Figure 4.9 : Client instills complete.

4.3. How to connect clients with the access point.

After configuring access point and four wireless adaptors, we can start to connect these adaptors with the access point.

To connect each wireless client to the AP, each one must have unique IP address, to do that go to control panel, Network connection, right click to local area connection then property, Internet Protocol (TCP/IP) and finally set IP address for all four clients with subnet mask 255.255.255.0

Now after setting IP addresses you can now begin to connect clients to the AP, in the left bottom of desktop screen double click to icon and then TP-LINK Wireless N Client Utility will appear as shown below

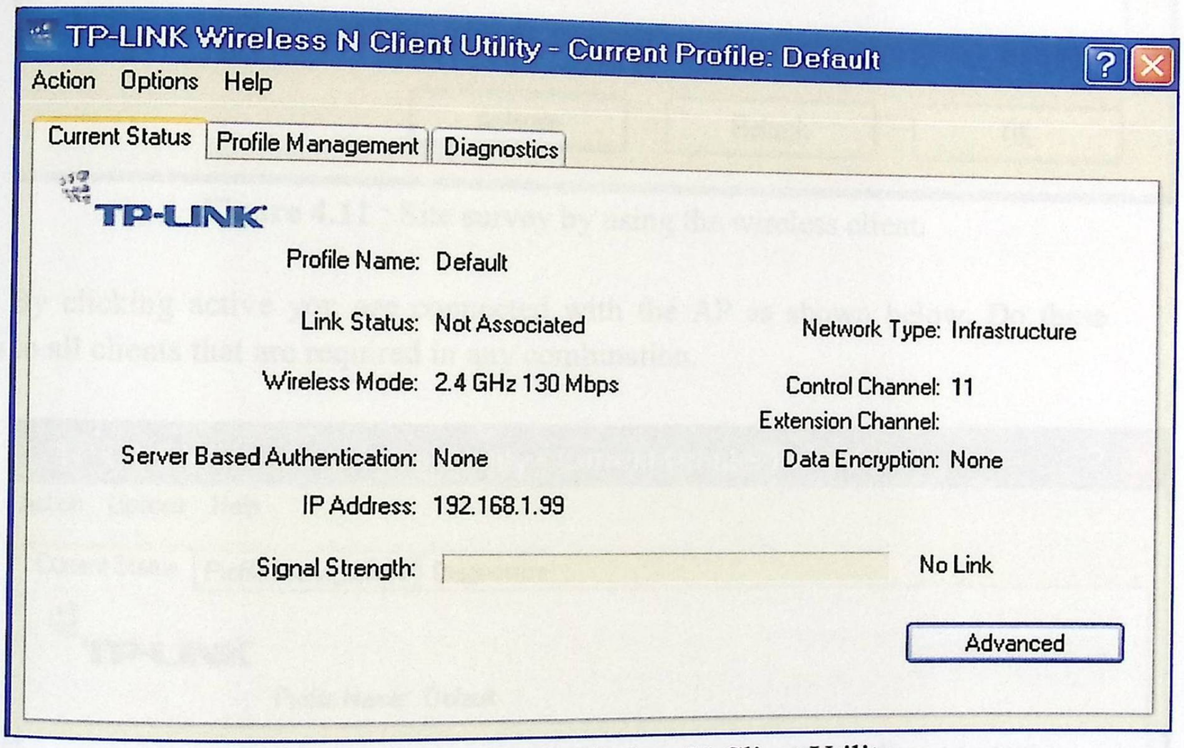


Figure 4.10 : TP-LINK Wireless N Client Utility

Now to connect these clients to the AP, go to Profile Management tap then scan and choose the SSID of the AP (m.ajlouni), the below figure shows the neighbors APs with operating frequency of each one, that is tested by using AP as shown before in section 4.2

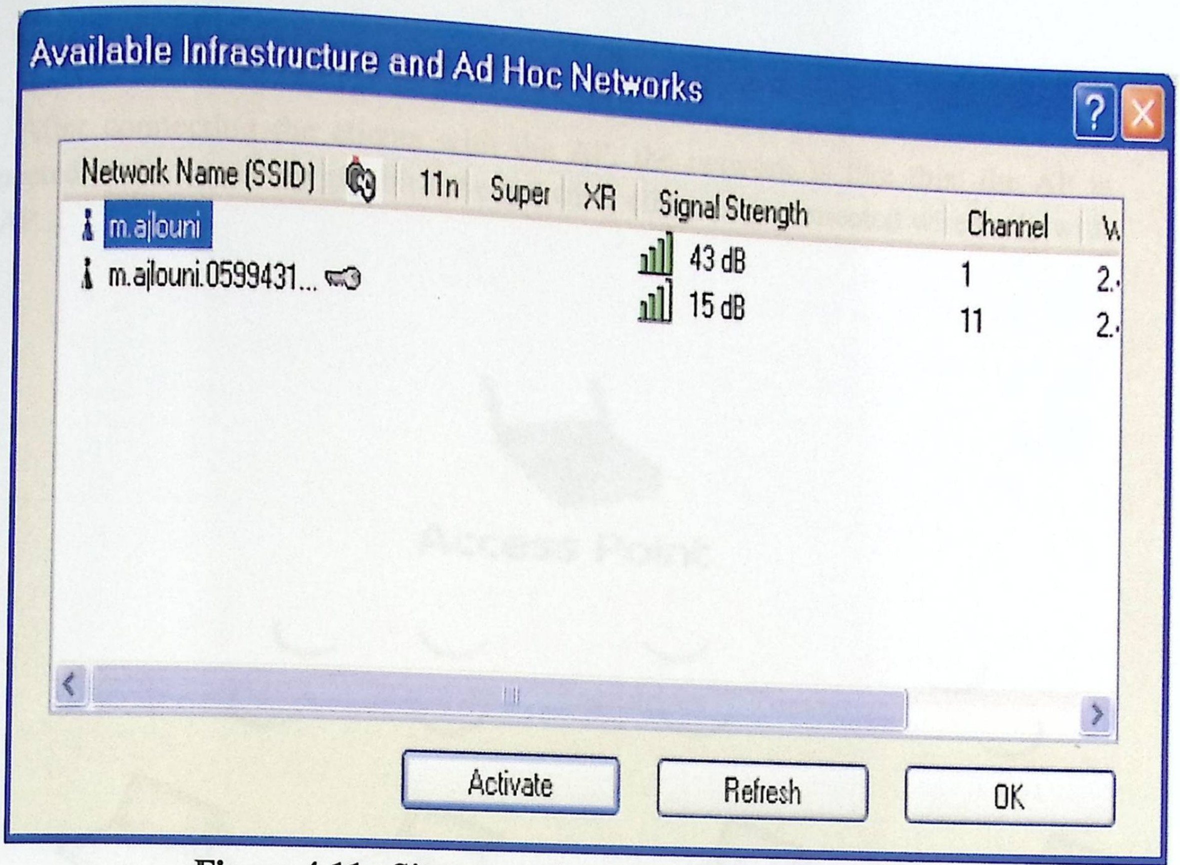


Figure 4.11 : Site survey by using the wireless client.

By clicking active you are connected with the AP as shown below. Do these steps to all clients that are required in any combination.

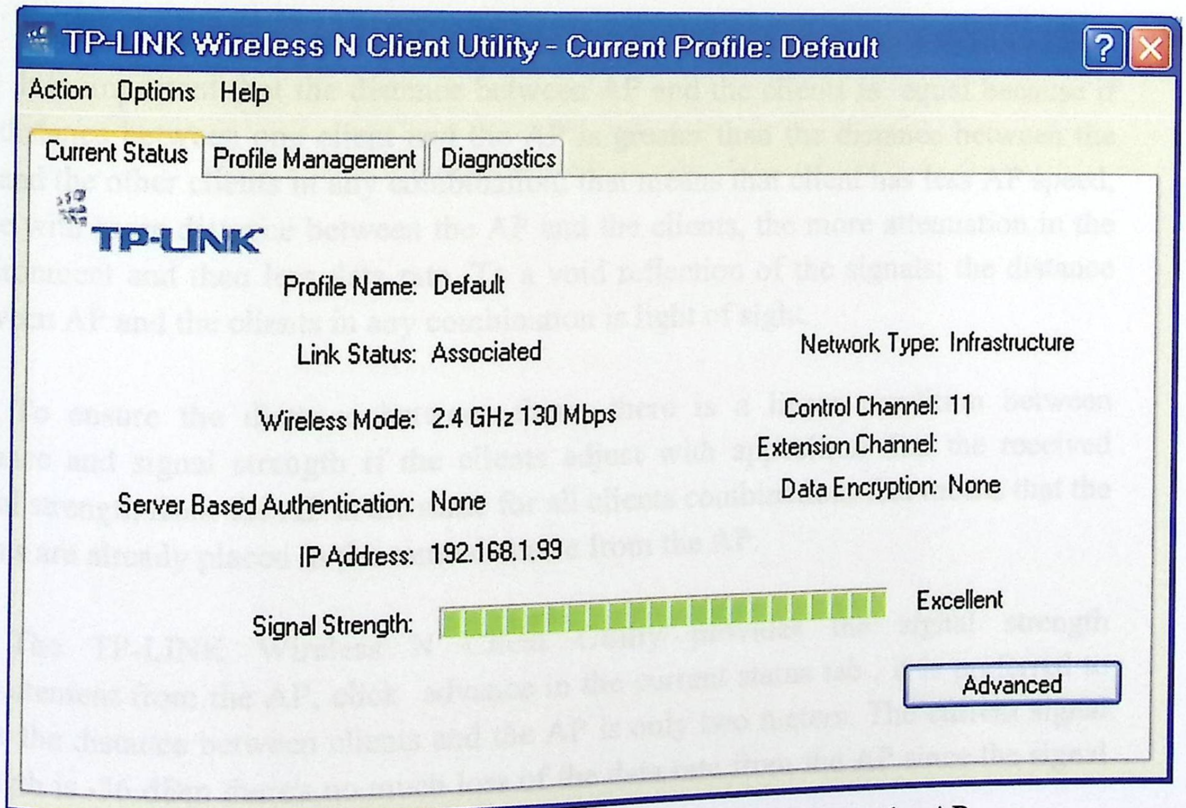


Figure 4.12 : Clients that is connected successfully to the AP.

4.4. Design details.

After connecting the clients with the AP, the network is like this: the AP is connected to the server by gigabit Ethernet wire, clients are connected wirelessly with the AP.

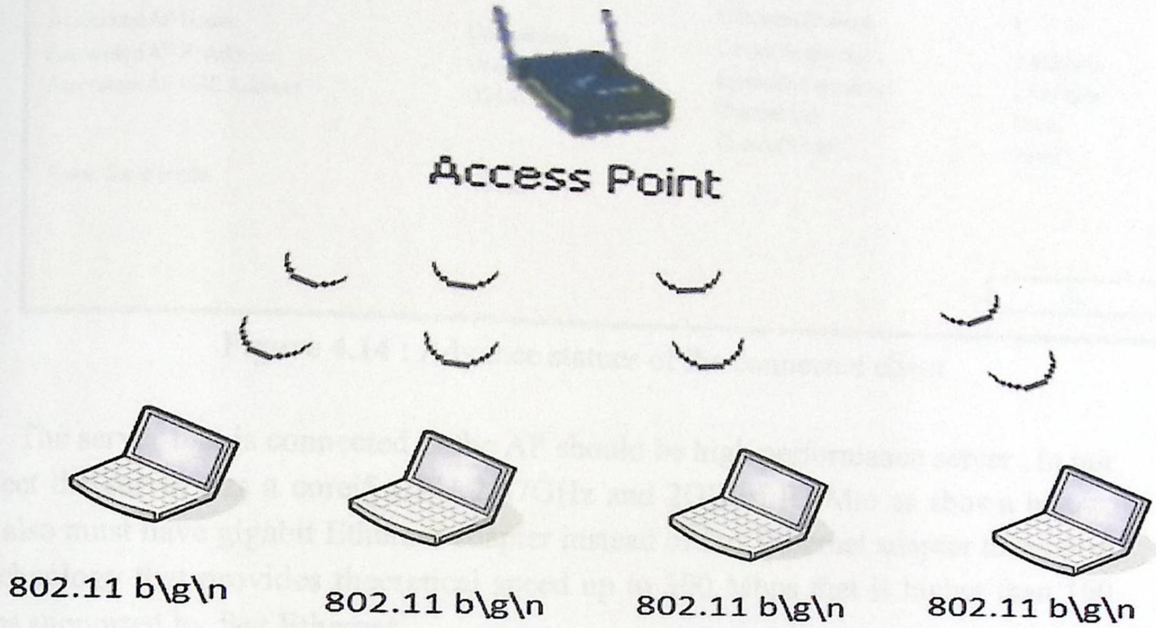


Figure 4.13 : Specification of project network.

It is important that the distance between AP and the clients is equal because if the distance between one client and the AP is greater than the distance between the AP and the other clients in any combination; that means that client has less AP speed, since with more distance between the AP and the clients, the more attenuation in the environment and then less data rate. To a void reflection of the signals; the distance between AP and the clients in any combination is light of sight.

To ensure the distance between them, there is a linear condition between distance and signal strength if the clients adjust with apposition that the received signal strength from the AP is the same for all clients combination; that means that the clients are already placed in the same distance from the AP.

The TP-LINK Wireless N Client Utility provides the signal strength measurement from the AP, click advance in the current status tab , it is preferred to make the distance between clients and the AP is only two meters. The current signal strength is -36 dBm there's no much loss of the data rate from the AP since the signal strength is not low, as shown below.

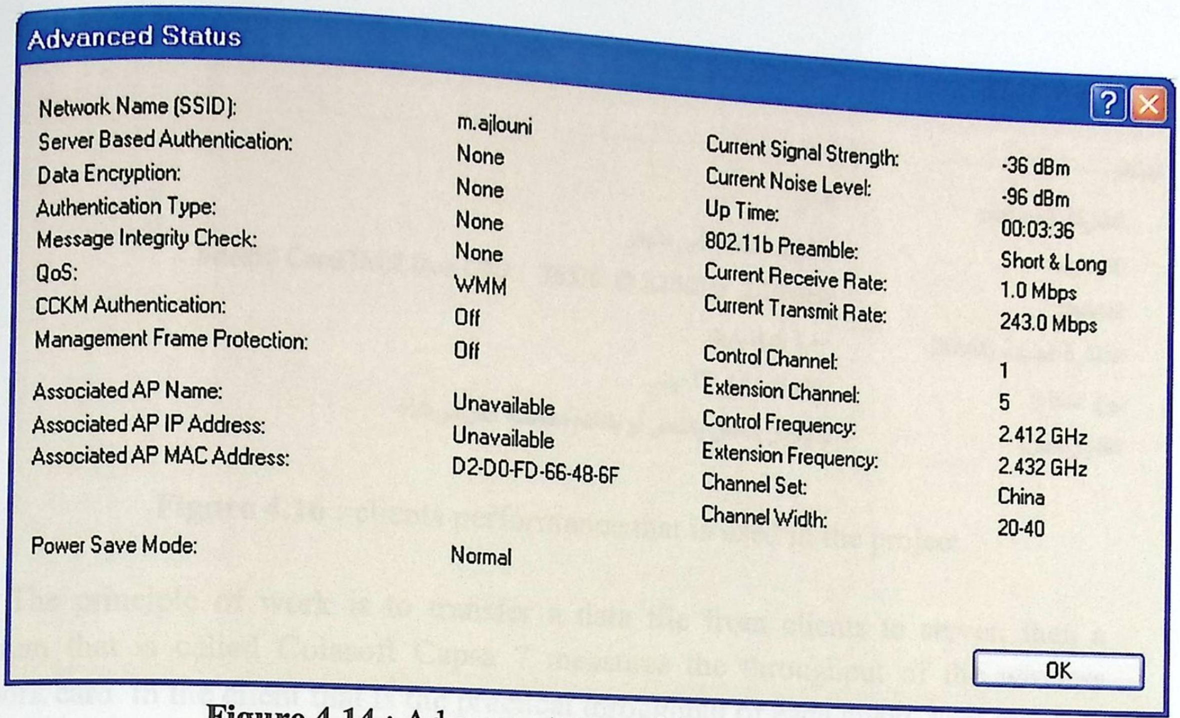


Figure 4.14 : Advance statues of the connected client.

The server that is connected to the AP should be high performance server , in our project the server has a corei5 CPU 2.67GHz and 2GB of RAMm as shown below, and also must have gigabit Ethernet adapter instead of fast Ethernet adaptor to support n technology that provides theoretical speed up to 300 Mbps that is higher than 100 Mbps supported by fast Ethernet.

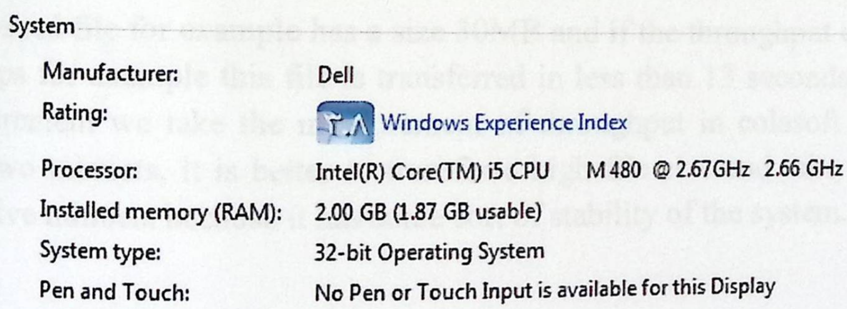


Figure 4.15 : Server performance that is used in the project.

Gigabit Ethernet network card support rates 10,100,1000Mbps and since the AP support also is one gigabit Ethernet port 1000,100,10Mbps after auto-negotiation between them both are operate in gigabit speed, as shown below.

Also the clients that are used in this project have a good performance devices, each one has Core 2 Duo 2.1GHz CPU and 2 GB of RAM, to support the high speed n technology, as shown below.

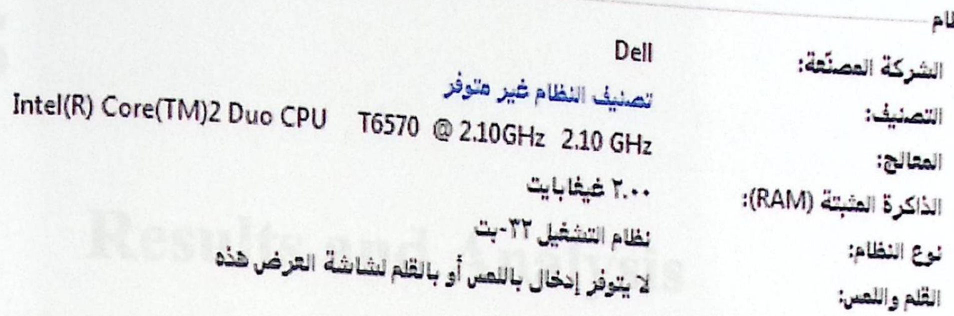


Figure 4.16 : clients performance that is used in the project.

The principle of work is to transfer a data file from clients to server, then a program that is called Colasoft Capsa 7 measures the throughput of the wireless network card in the client that is the practical throughput of each client, then this data file propagates wirelessly to the AP, Colasoft Capsa 7 measures the throughput of the gigabit network card of the server that is the practical throughput of the AP.

Throughput of the AP is measured approximately by ignoring the data losses in Ethernet wire between server and AP, in order to reduce the losses of the wire we use a Category 6 twisted pair cable with only one meters distance.

The size of file that transferred from clients to the server is 600 MB, since if the transferred file for example has a size 30MB and if the throughput of the AP is about 18Mbps for example this file is transferred in less than 13 seconds. To make a good measurement we take the measurement of throughput in colasoft capsa 7 for more than two minuets, it is better to transfer a high file size and take the average value after five minuets because it has some sort of stability of the system.

Chapter 5

Results and Analysis

Chapter five
Results and Analysis

This chapter contains the results of all our network combinations that are measured in Colasoft Capsa 7 program, and also contains the analysis and compare between the results.

5.1. Introduction.

In our project we want to measure the value of throughput in all combination of clients, these combinations are when the number of clients in the network are one, two, three and four With all access point operating modes in all of them, there are forty cases of clients combinations.

When the access point operates in b only mode we want to measure the practical throughput value of b client, when there are one, two, three and four b client.
The same case for g only AP, and when the AP is operates in n only mode the practical throughput is measured when it is operates in 40 MHz channel width.

In b\g mix mode of the AP, throughput is measured when there are two, three and four clients that are operates in b and g mode, that are connecting to it with all combination of operating mode of them.

Since b\g mix mode only operates with one spatial stream and n client uses two spatial streams when it connect to this AP it works as g client, so if we have a combination for example of two b and n clients, the n client is work as g client so this combination is become bg combination, so all clients combination in this AP mode is becomes between b and g clients only.

b\g\n mix AP mode operates with two spatial streams, so n clients can connect to it in addition of b and g clients. In this AP mode we want to measure throughput of two, three and four clients combinations.

All combinations with different AP mode and different number of clients that are connected to the AP are shown in table 5.1

Table 3.1 : All clients combinations.

AP mode	Number of clients	Client one mode	Client two mode	Client three mode	Client four mode
b only	1	b	-	-	-
	2	b	b	-	-
	3	b	b	b	-
	4	b	b	b	b
g only	1	g	-	-	-
	2	g	g	-	-
	3	g	g	g	-
	4	g	g	g	g
n only	1	n	-	-	-
	2	n	n	-	-
	3	n	n	n	-
	4	n	n	n	n
b\g mix	2	b	g	-	-
	3	b	b	g	-
		b	g	g	-
	4	b	b	B	g
		b	b	g	g
		b	g	g	g
b\g\n mix	2	b	g	-	-
		b	n	-	-
		g	n	-	-
	3	b	b	g	-
		b	b	n	-
		b	g	g	-
		b	g	n	-
		b	n	n	-
		g	g	n	-
		g	n	n	-
	4	b	b	b	g
		b	b	b	n
		b	b	g	g
		b	b	g	n
		b	b	n	n
		b	g	g	g
		b	g	g	n
		b	g	n	n
		b	n	n	n
		g	g	g	n
		g	g	n	n
		g	n	n	n

5.2. b only AP mode.

In this section the AP operates in b only mode, in this mode the AP uses 20 MHz channel and one spatial stream to transmit and receive data from clients, there are many of clients that are connecting to it.

Since this AP is operating in b only mode that means only b clients can connect to it, for example if there are two b clients and one g client. The AP allows two b clients to connect to it and refuse the connection from g client; so in this case the combination becomes bb not bbg.

5.2.1. Combination with one b client.

In this section there is only one b client that connects to AP that is operating in b only mode, as shown below.

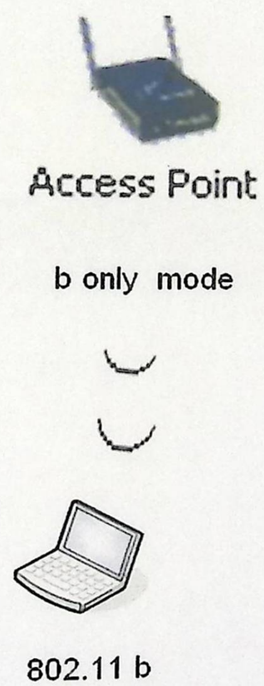


Figure 5.1: One b client combination.

The theoretical throughput of b technology is 11 Mbps, but in practical based in our measurements the throughput of the AP is just 6.880Mbps and the throughput of the client is 6.863 Mbps, this value is the maximum throughput of the client that operates in b technology.

Throughput value of the AP and b client is closed to each other not equal. Since there is a losses in wireless for only two meters link between AP and the client. Throughput of the b client and the AP are shown in figure 5.2

.

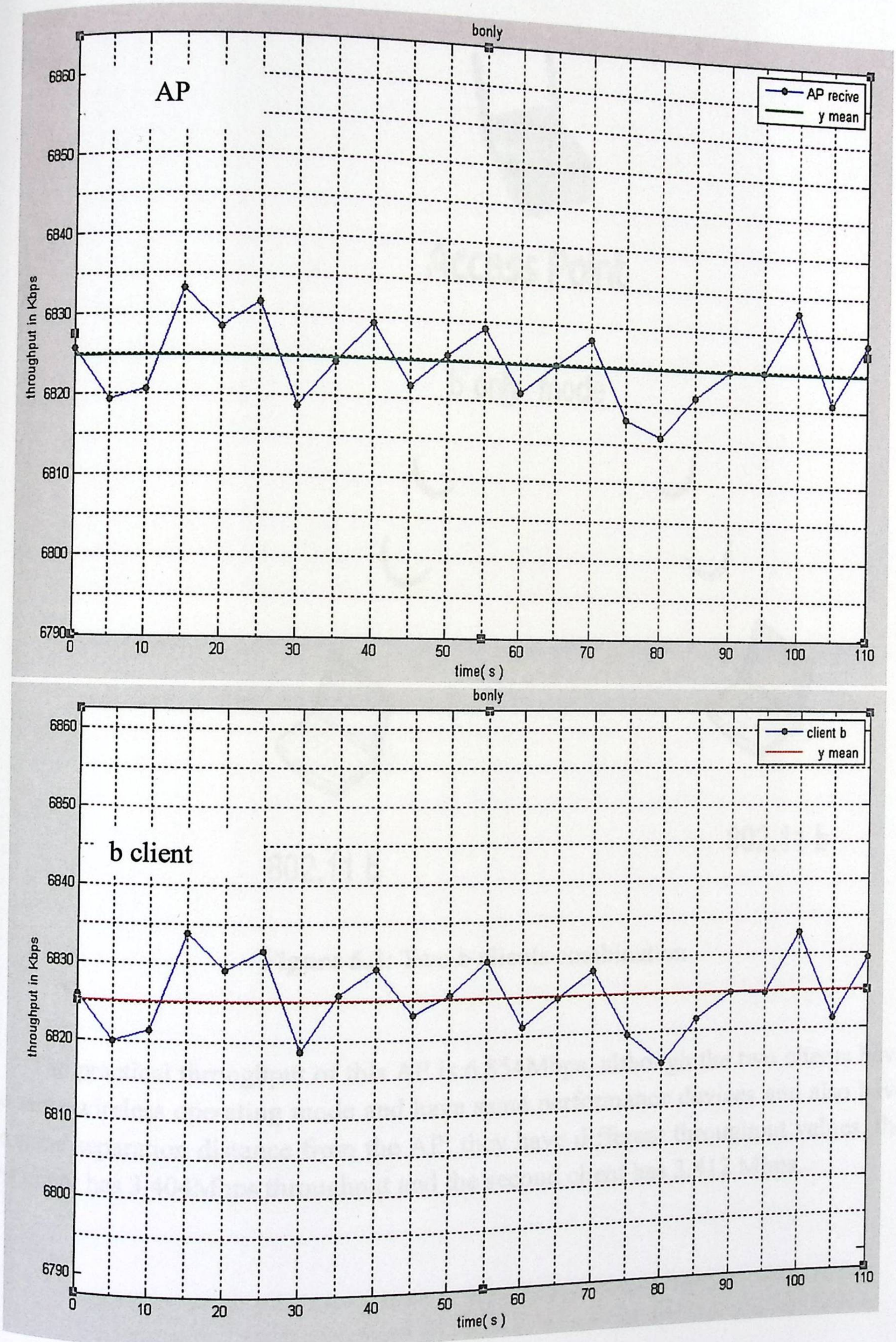


Figure 5.2 : Throughput of one b combination.

5.2.2 Combination with two b clients.

There are two clients that are operating in b mode connected to b only AP mode as shown in figure 5.3 below.

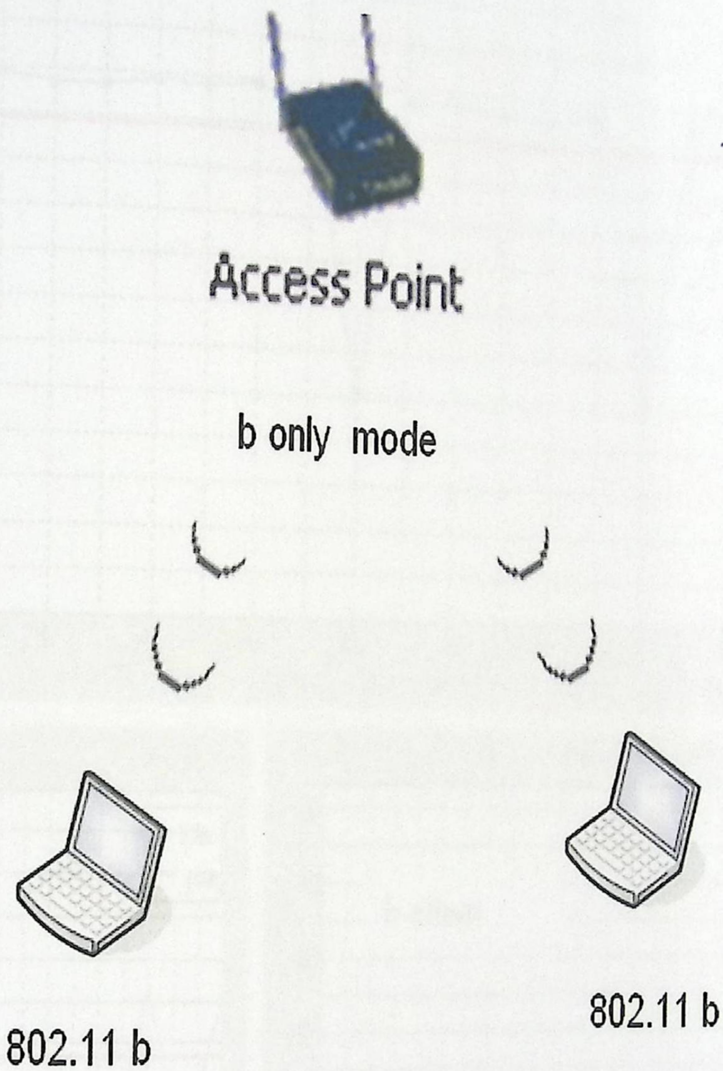


Figure 5.3: Two b clients combination.

The practical throughput of this AP is 6.854Mbps, although the two clients have the same wireless operating mode and have same performance devices and also have the same separation distance from the AP; they have different throughput values, the first client has 3.404Mbps throughput and the second client has 3.412 Mbps.

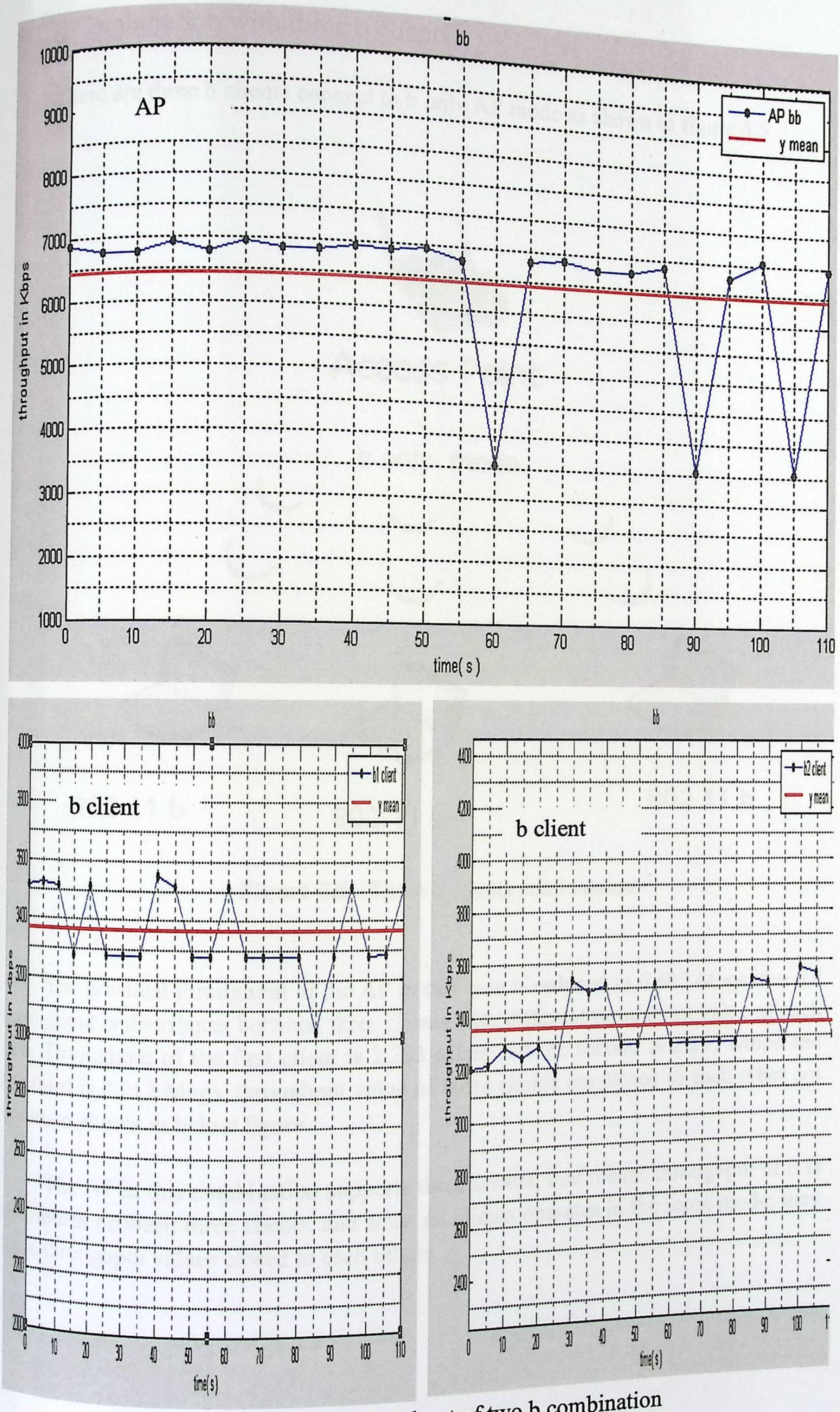


Figure 5.4 : Throughput of two b combination

5.2.3. Combination with three b clients.

There are three b clients connect to b only AP mode as shown in figure 5.5

.

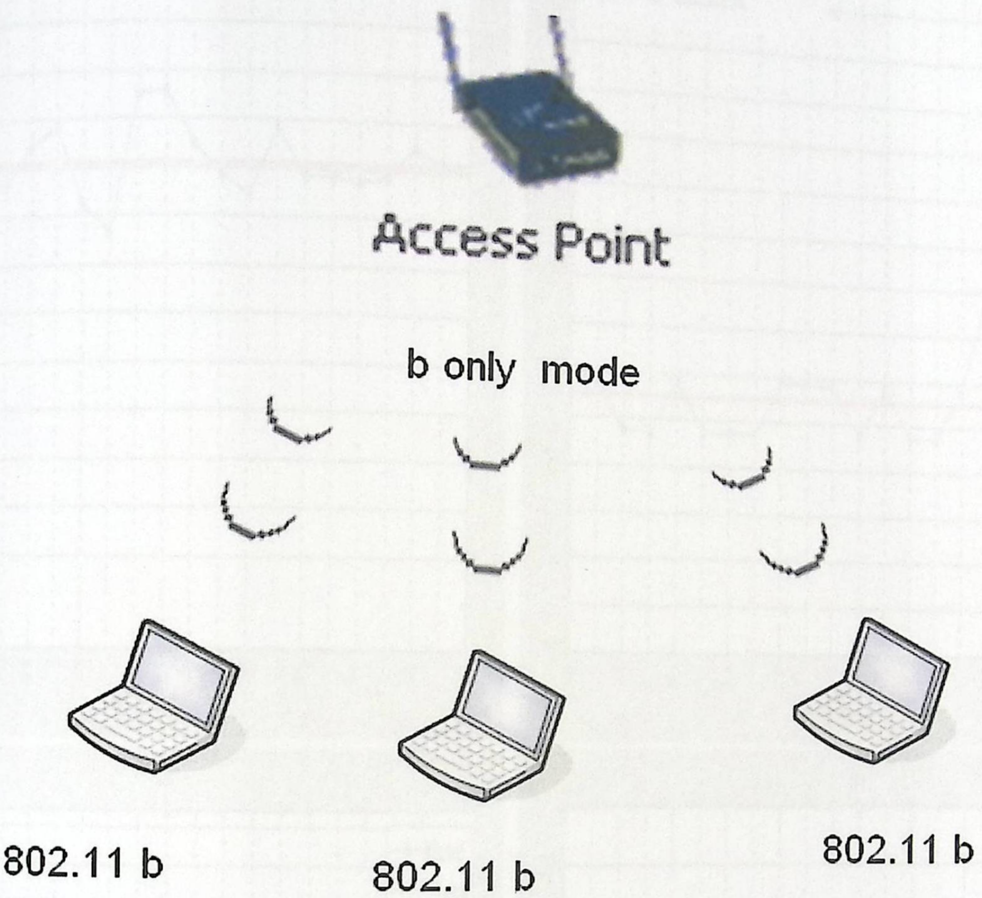


Figure 5.5 : Three b clients combination.

The practical throughput of the AP in this case is reduced to 6.695 Mbps, the AP throughput is distributes between three clients with different throughput value of each one. Throughput of the first client is 2.233 Mbps and the second is 2.247 Mbps and the third is 2.212 Mbps, throughput value of these clients are closed to each other not equal, as shown in below figure.

The AP in this combination supports three clients, that means throughput of it is distributes between three clients, and since all clients operates in the same mode; they have throughput values closed to each others.

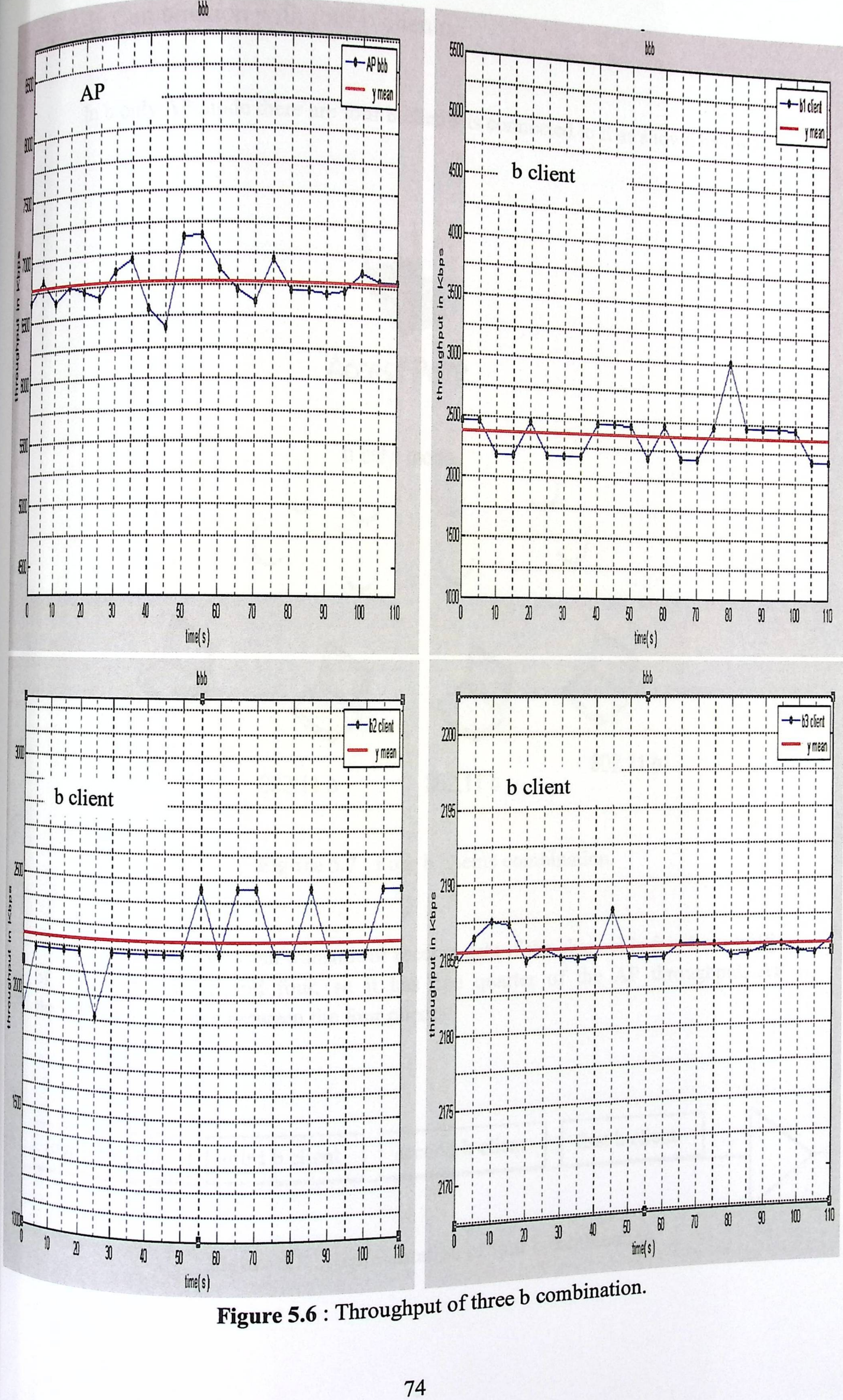


Figure 5.6 : Throughput of three b combination.

5.2.4. Combination with four b clients.

In b only AP mode there are four b clients is connected to it as shown below.

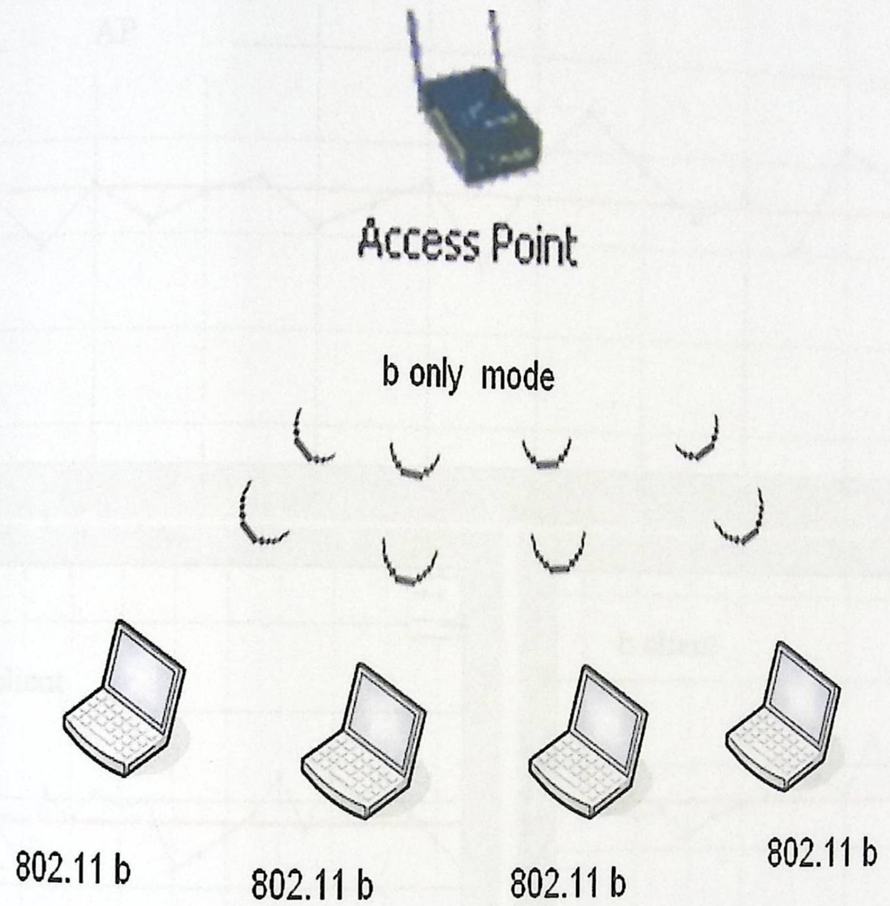


Figure 5.7 : Four b clients combination.

Client number two can transmit or receive data if the channel is free from traffic of clients one ,three and four, so it has one quarter of the AP throughput, AP throughput distributes between the four clients.

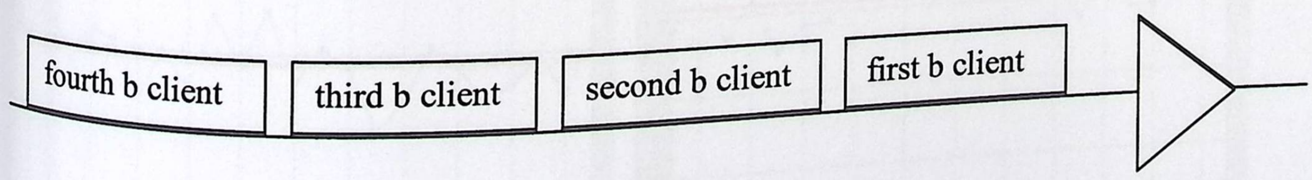


Figure 5.8 : Representation of four b combination

As mentioned before in section 5.2.3 the throughput of the AP is distributes between connected clients; so the AP throughput which is 6.337Mbps distributes between four b client, throughput of the four clients are 1.390Mbps, 1.480Mbps, 1.492Mbps and 1.606Mbps, as shown in figure 5.9.

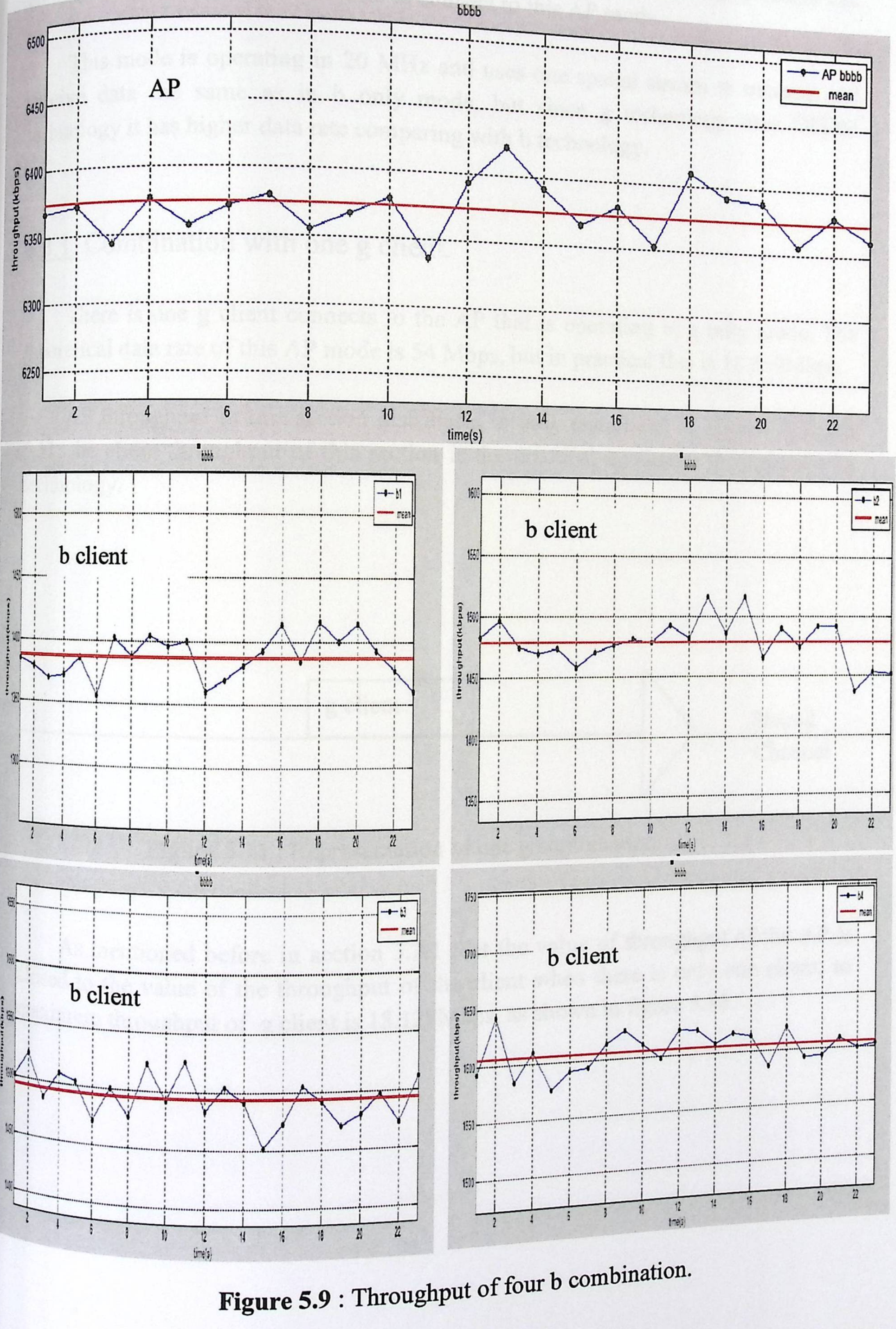


Figure 5.9 : Throughput of four b combination.

5.3. g only AP mode.

The AP in this section operates in g only mode; that means only g clients can connect to it, b and n clients not able to connect to this AP mode.

This mode is operating in 20 MHz and uses one spatial stream to transmit and receive data the same as in b only mode, but since g technology uses OFDM technology it has higher data rate comparing with b technology.

5.3.1. Combination with one g client.

There is one g client connects to the AP that is operating in g only mode. The theoretical data rate of this AP mode is 54 Mbps, but in practical this is 18.360Mbps.

AP throughput in this section distributes to only one client, as shown in figure 5.11, the client throughput of this section is the practical maximum throughput of g technology.

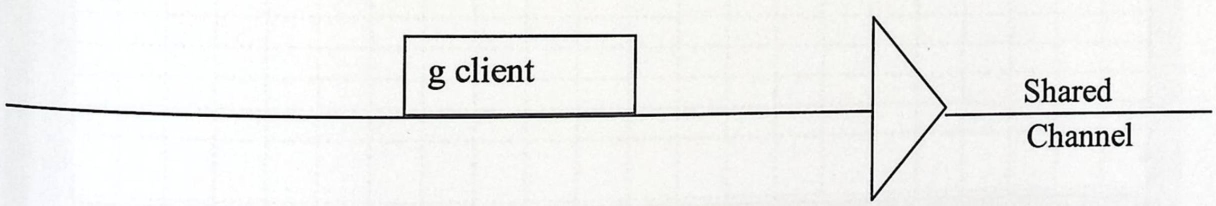


Figure 5.11 : Representation of one g combination.

As mentioned before in section 5.2.1 that the value of throughput of the AP is closed to the value of the throughput of the client when there is only one client; so maximum throughput of g client is 18.128Mbps, as shown in figure 5.10.

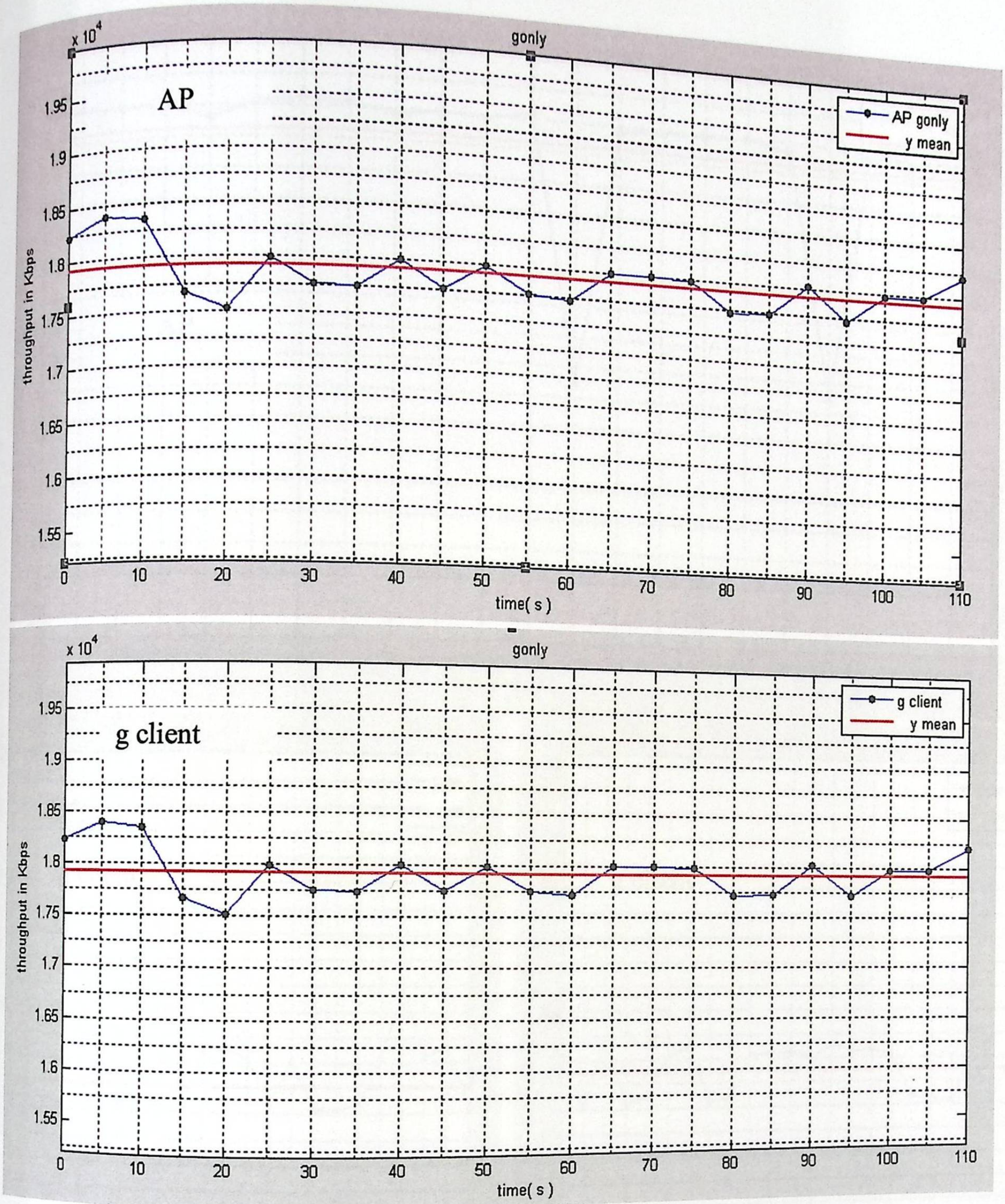


Figure 5.10 : Throughput of one g combination.

5.3.2. Combination with two g clients.

There are two clients that are operating in g mode connected to g only AP mode as shown below in figure 5.12. Throughput of this AP is 18.128Mbps which is less than throughput in the case of using one client, throughput of the first client is 9.184Mbps and in the second client 9.152Mbps.

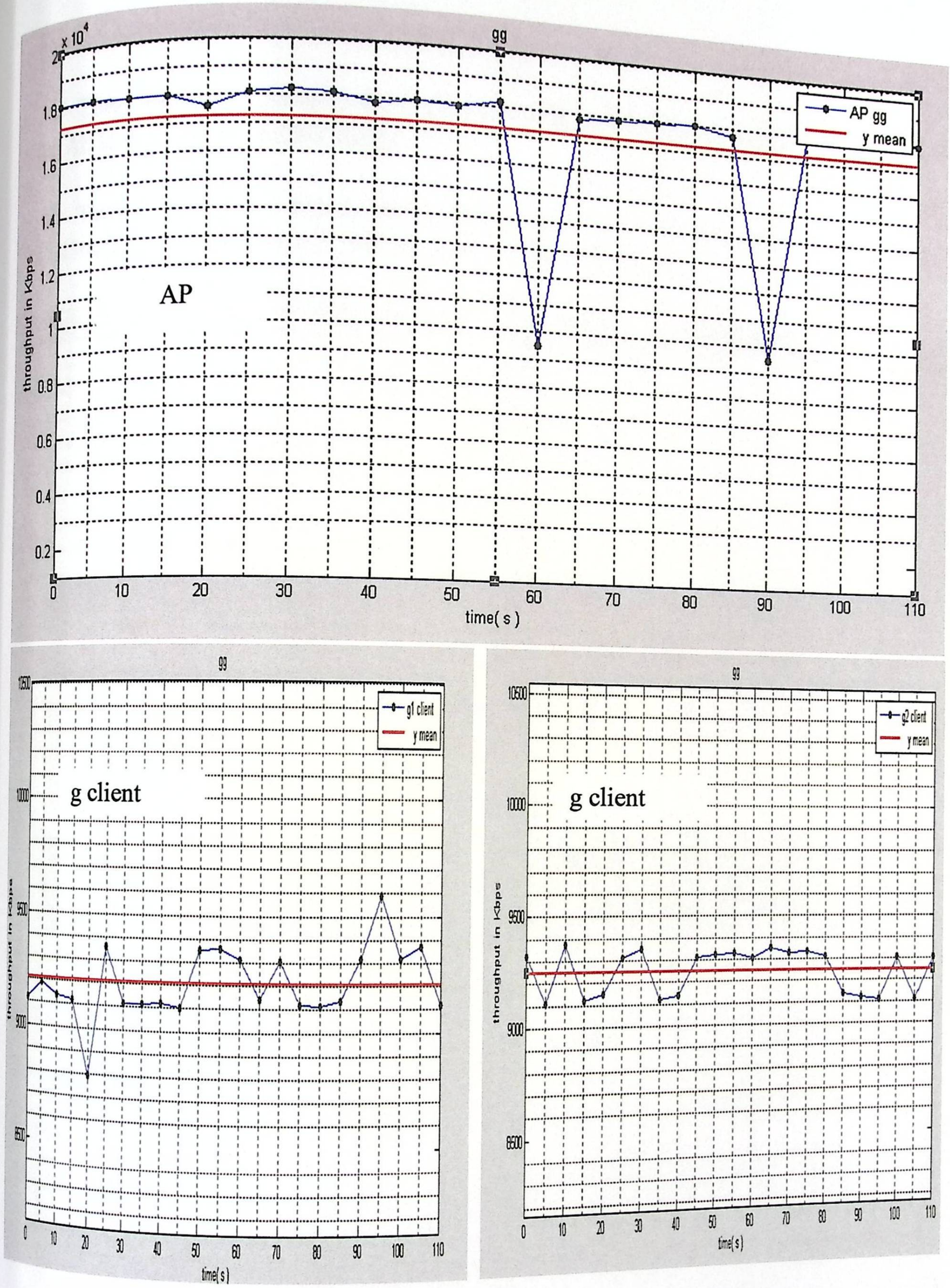


Figure 5.12 : Throughput of two g combination.

Since this AP in this combination support two clients, it has more time to switching between clients; so less throughput value to it, and since with more device the property of collegian is increased the AP reduced its own speed.

5.3.3. Combinations with three g clients.

There are three g clients connect to g only AP mode. The practical throughput of the AP in this case is 18.080 Mbps.

The AP throughput distributes between three clients with throughput of them are 4.443Mbps,4.667Mbps and 8.968Mbps, as shown in figure 5.13.

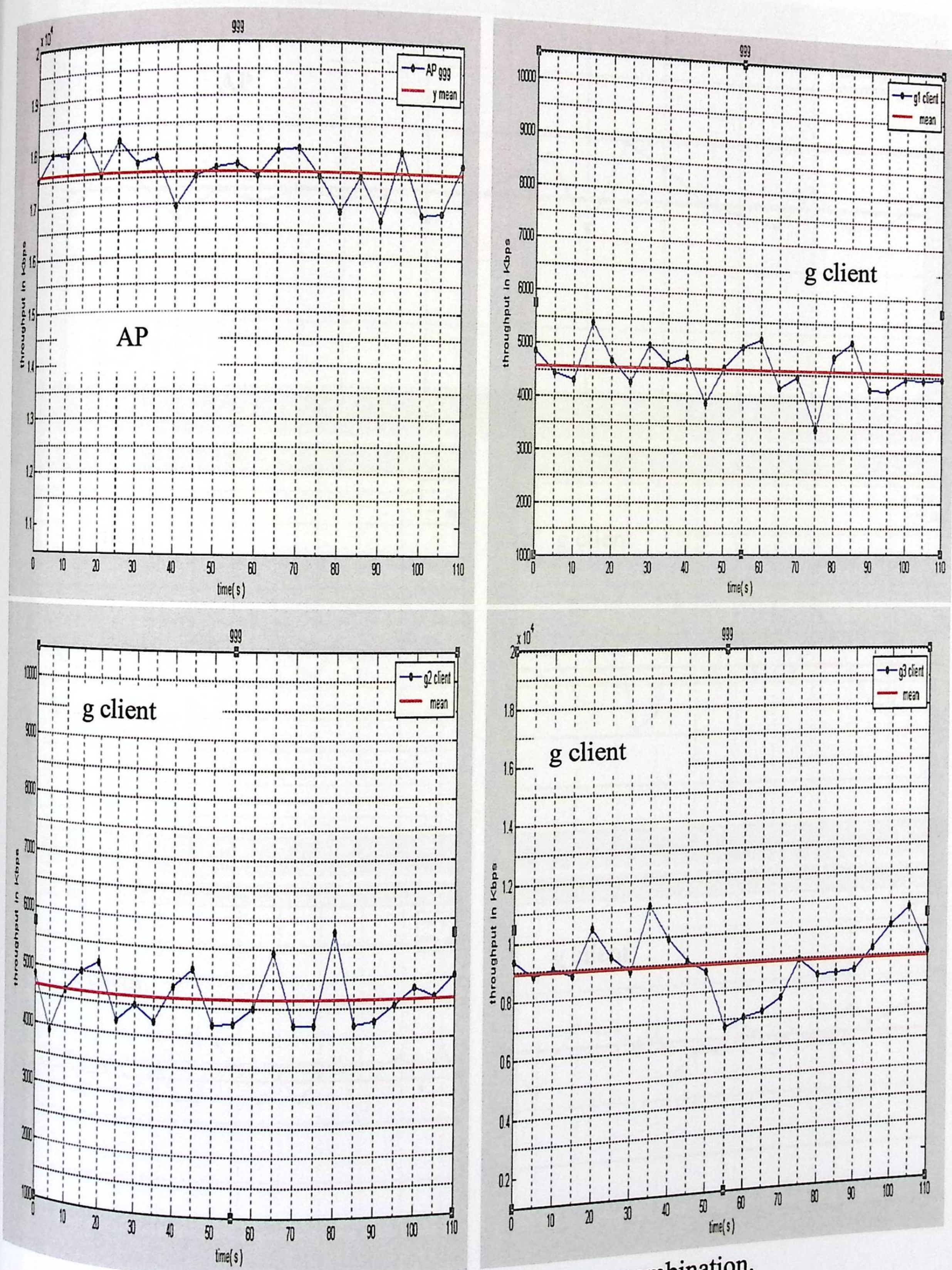


Figure 5.13 : Throughput of three g combination.

5.3.4. Combinations with four g clients.

In g only AP mode there are four g clients are connected to it. The AP throughput is 17.200Mbps that distributes between four g clients as shown below in figure 5.14, throughput of these clients are 4.455Mbps, 3.526Mbps, 4.089Mbps and 2.808Mbps.

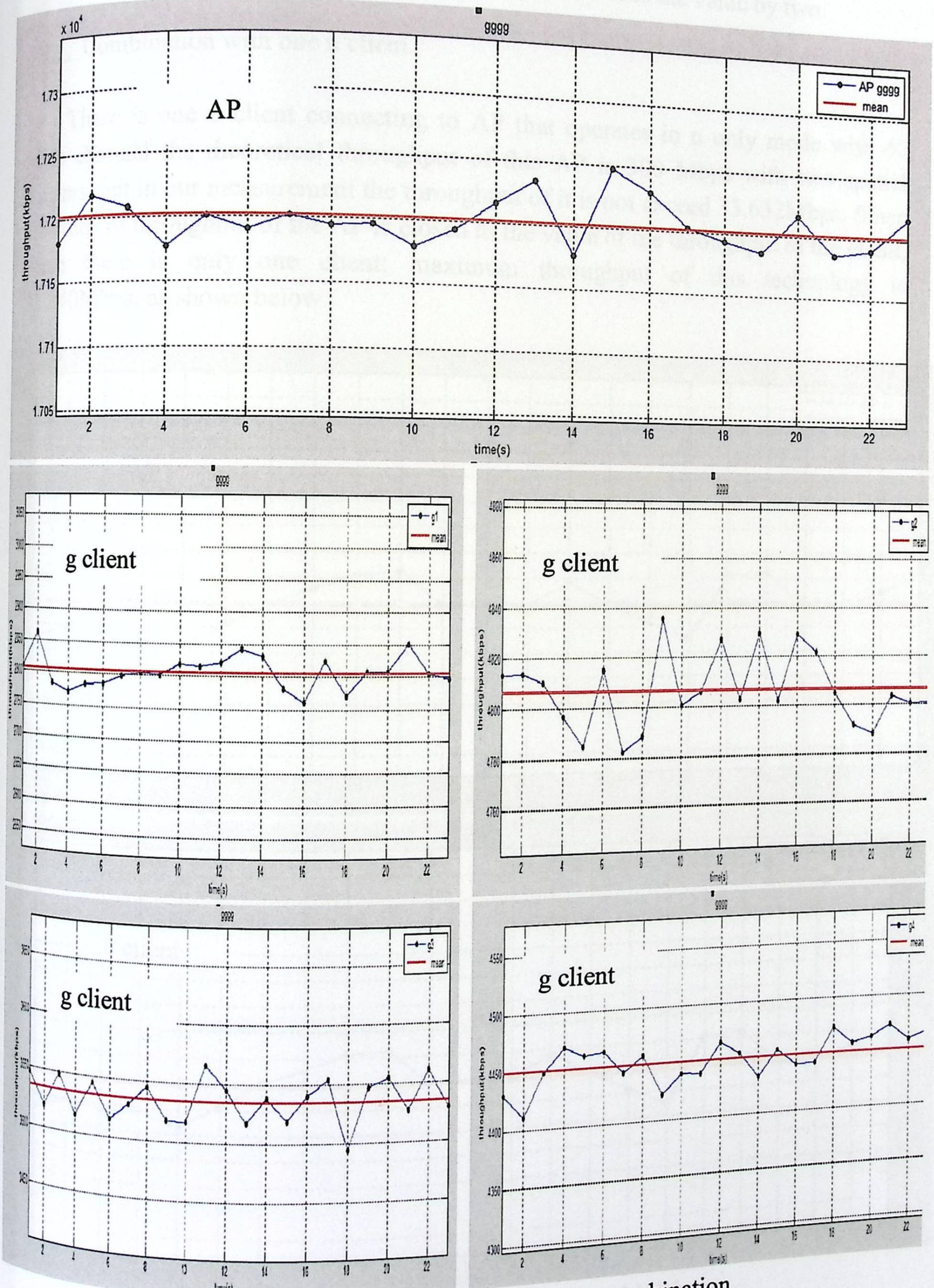


Figure 5.14 : Throughput of four g combination.

5.4. n only AP mode.

In n client there are two cases when it is operating in 20 MHz and when it in 40MHz, since the value of throughput when the AP is operates in 40MHz is double the value of throughput in 20MHz channel, we want to operate n only AP mode in 40MHz channel. To find throughput of n in 20 MHz divides the value by two.

5.4.1. Combination with one n client.

There is one n client connecting to AP that operates in n only mode with 40 MHz channel the theoretical throughput of this AP is 300 Mbps with two spatial streams, but in our measurement the throughput of it is not exceed 33.632Mbps. Since the value of throughput of the AP is closed to the value of the throughput of the client, when there is only one client; maximum throughput of this technology is 33.240Mbps, as shown below.

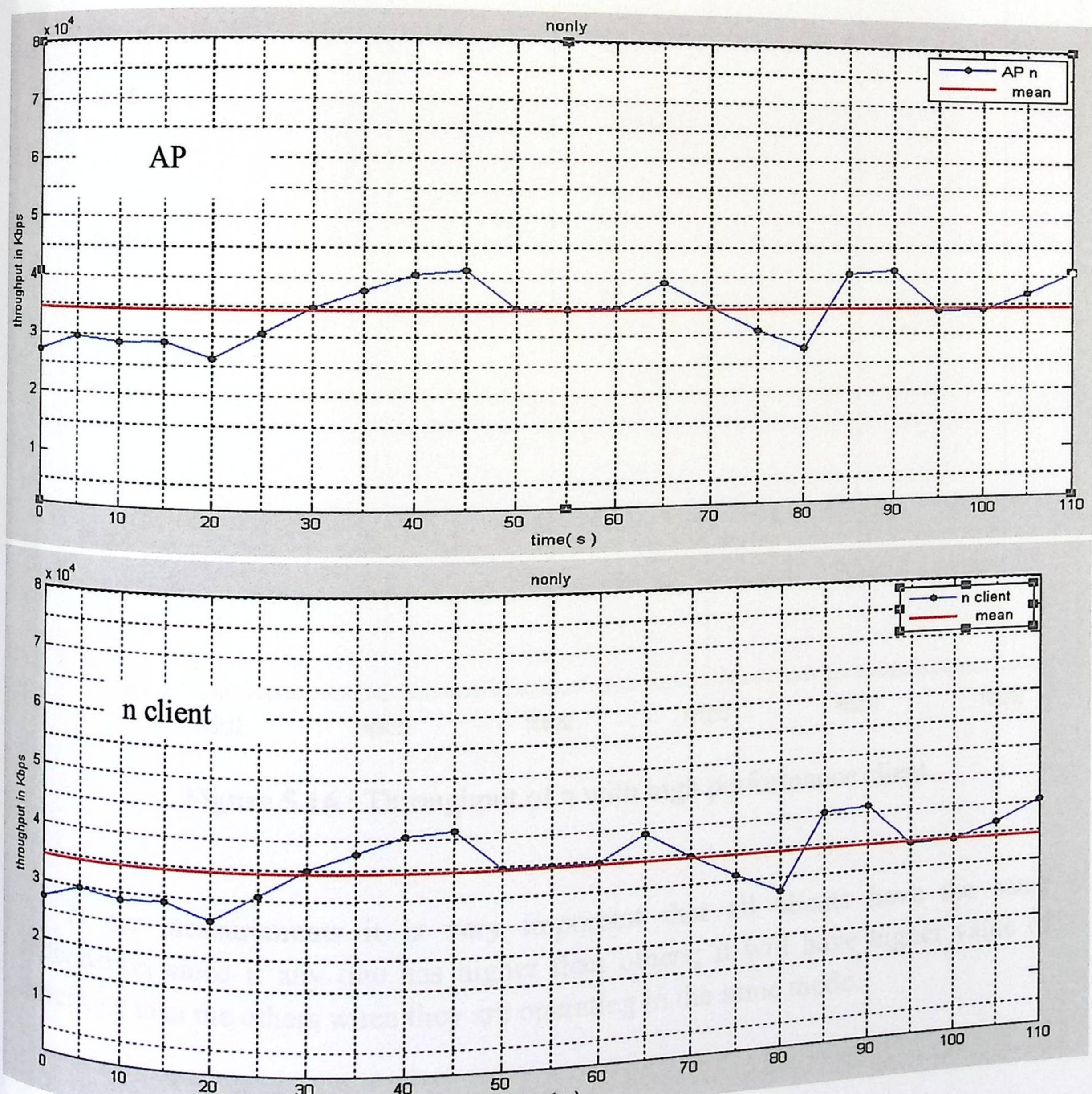


Figure 5.15 : Throughput of one n combination.

As mentioned before in chapter four this value is depending to the performance of the client, if there is a client with core i5 CPU and 2 GB RAM the theoretical throughput in this case is about 45Mbps. This proves that the client can have higher throughput if it has higher performance, as shown in figure 5.16

This result is higher than the same combination when we use less device performance of this client.

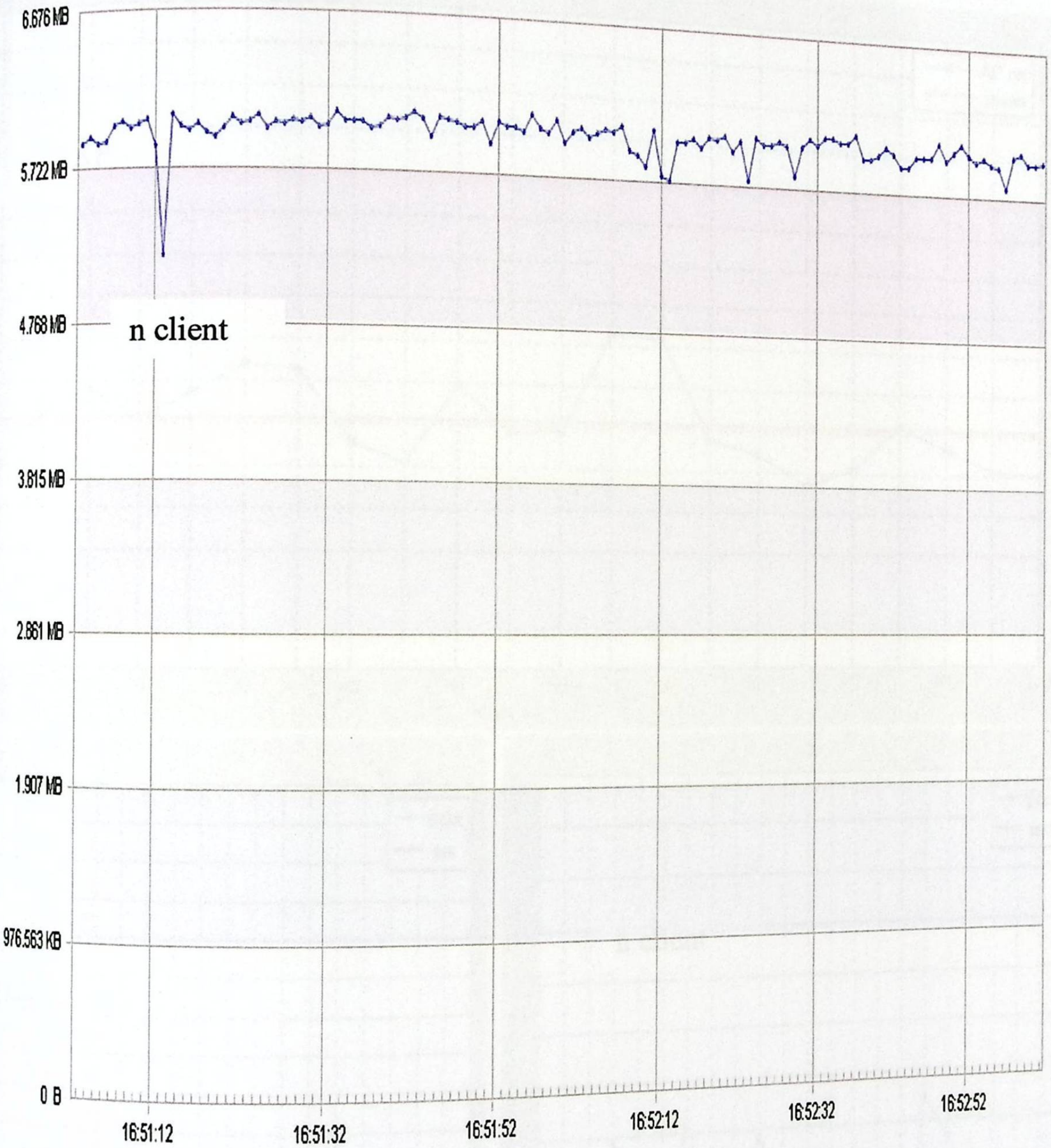


Figure 5.16 : Throughput of n with high performance client.

In our measurements it is very important that all clients have the same performance, since if any one has higher than others; it will have higher value of throughput than the others when they are operating in the same mode.

5.4.2. Combination with two n clients.

There are two clients that operate in n mode connected to n only AP mode, the practical throughput of this AP is 32.040Mbps which is less than of AP that is connected to only one client, throughput of the first client is 10.010Mbps and in the second client is 19.840Mbps.

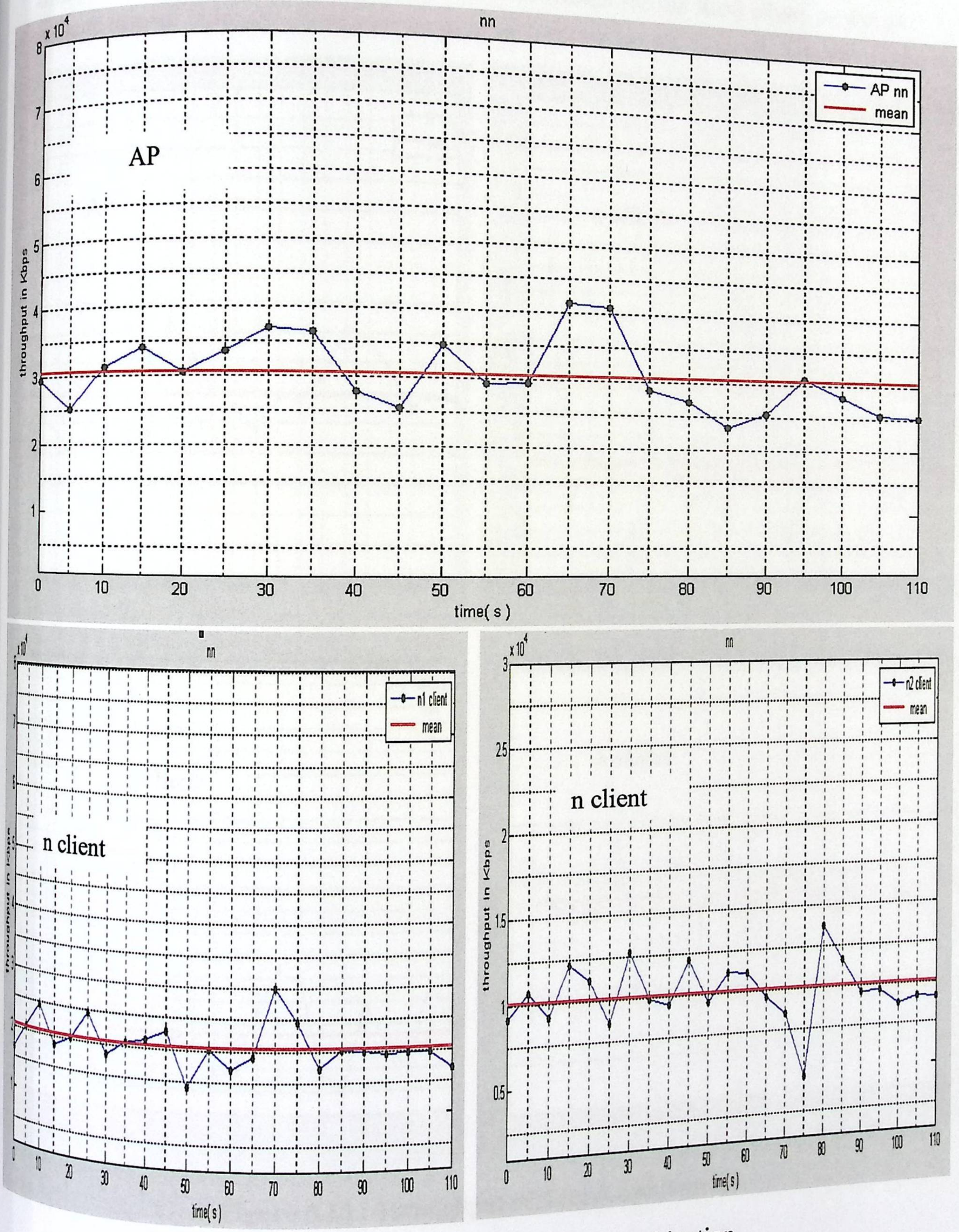


Figure 5.17 : Throughput of two n combination.

5.4.3. Combination with three n clients.

There are three n clients connect to n only AP mode, the practical throughput of the AP in this case is 29.752Mbps.

The AP throughput distributes between three clients, 9.800Mbps for the first client, 9.835Mbps for the second client and 9.875Mbps for the third client, as shown in figure below.

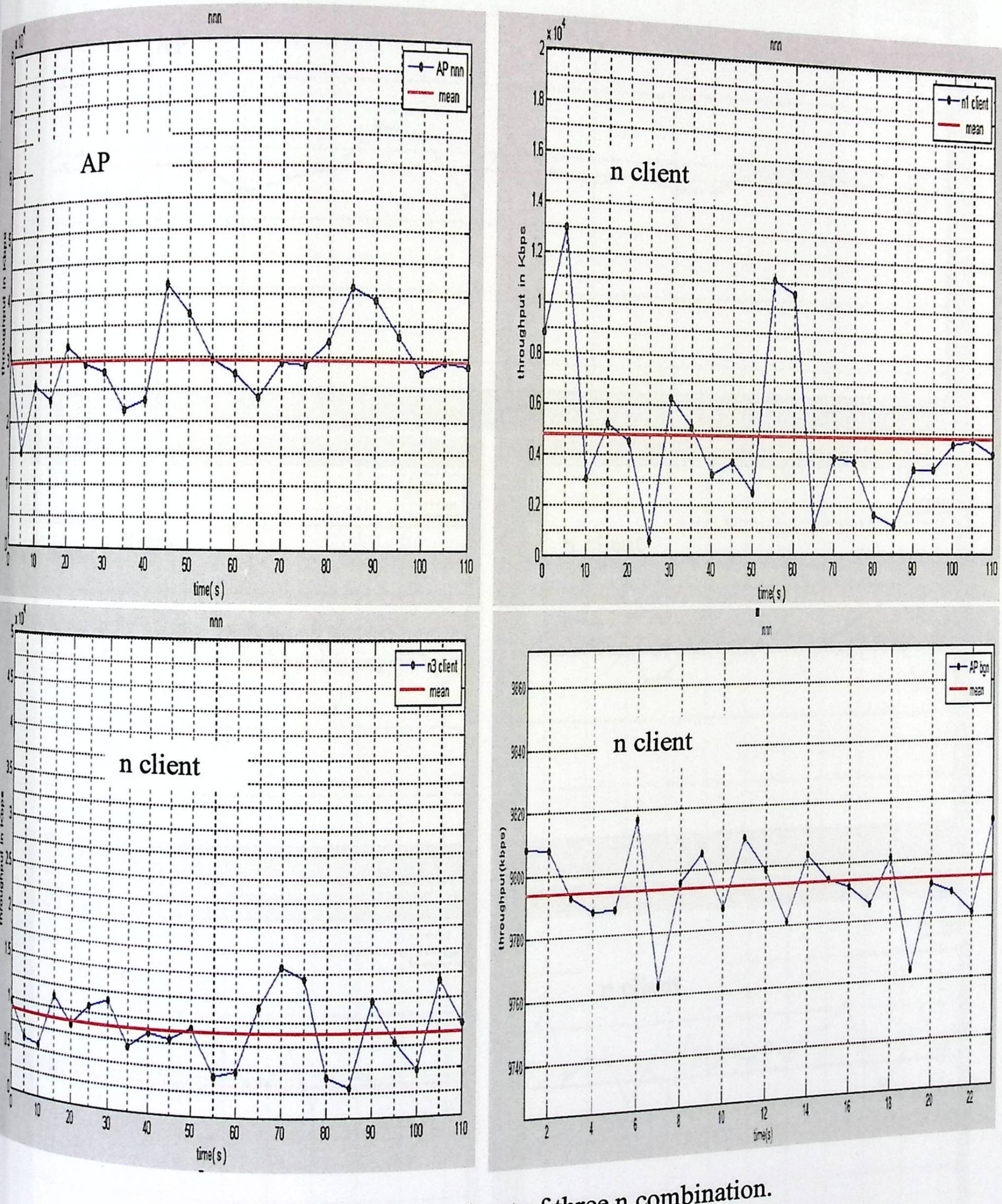


Figure 5.18 : Throughput of three n combination.

5.4.4. Combination with four n clients.

In n only AP mode there are four n clients are connecting to it, the throughput of the AP which is 27.200Mbps in this combination distributes as shown below in figure 5.19 between the four n clients, throughput of these clients are 10.420Mbps, 8.292Mbps, 3.704 Mbps and 4.584Mbps.

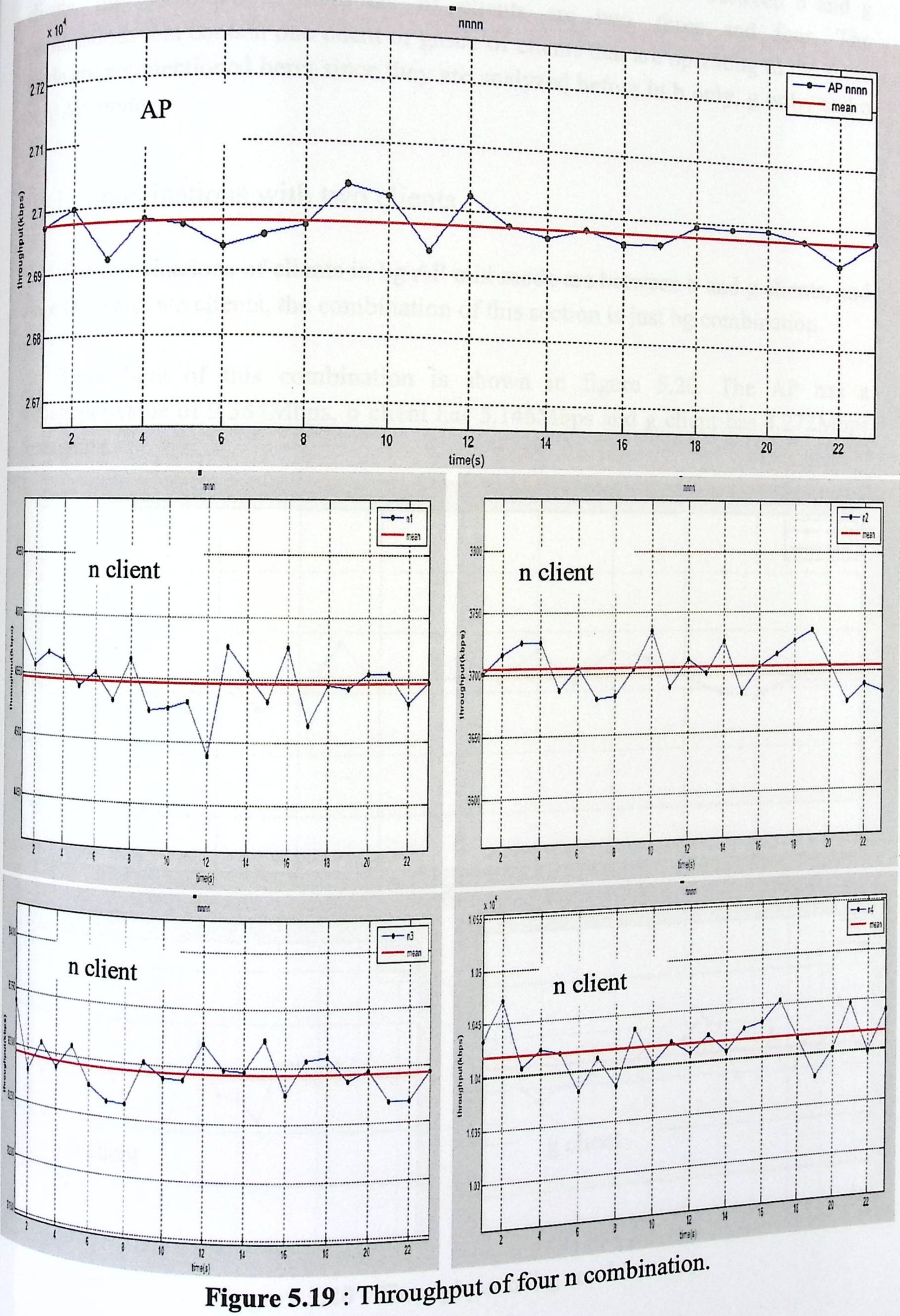


Figure 5.19 : Throughput of four n combination.

5.5. b\g AP mix mode.

In this section the AP is configuring to operate in bg mode, In this mode the AP operates at 20MHz channel with only one spatial stream.

With this operation mode of the AP, the combinations are between b and g clients, the combinations numbers of clients are two, three and four. The combinations that contain one client or group of clients that are operating in the same mode are not mentioned here; since they are analyzed before in b only, g only, and n only AP mode.

5.5.1. Combinations with two clients.

The combinations of clients in bg AP mix mode are between b and g clients, and since there are two clients, the combination of this section is just bg combination.

Throughput of this combination is shown in figure 5.20. The AP has a throughput value of 9.384Mbps, b client has 5.146Mbps and g client has 4.272Mbps throughput.

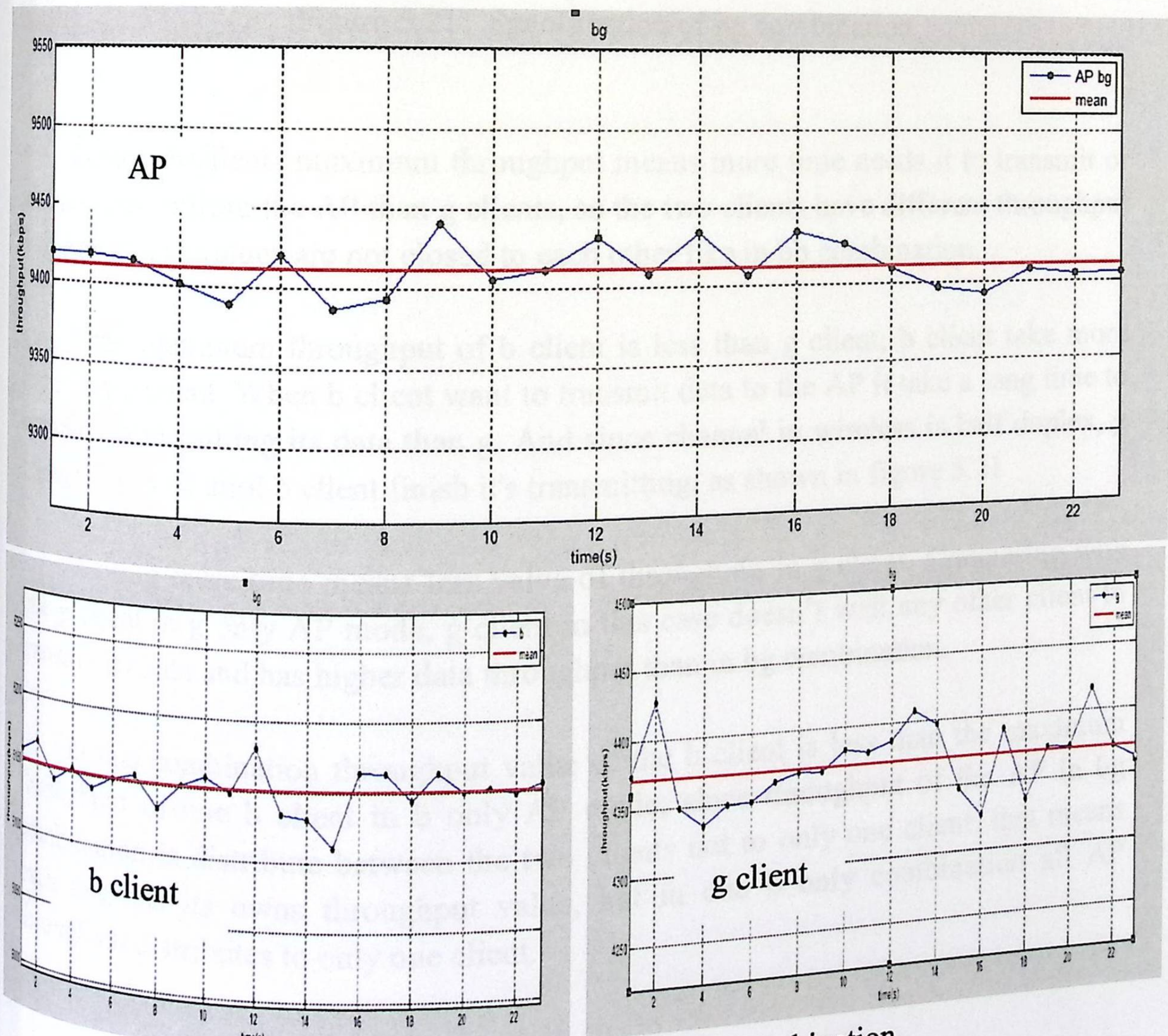


Figure 5.20 : Throughput of bg combination.

Because the two clients are operating with different operating mode, each one has different AP throughput, although b client is operates in lower throughput than g client, b client operates at higher throughput value than g.

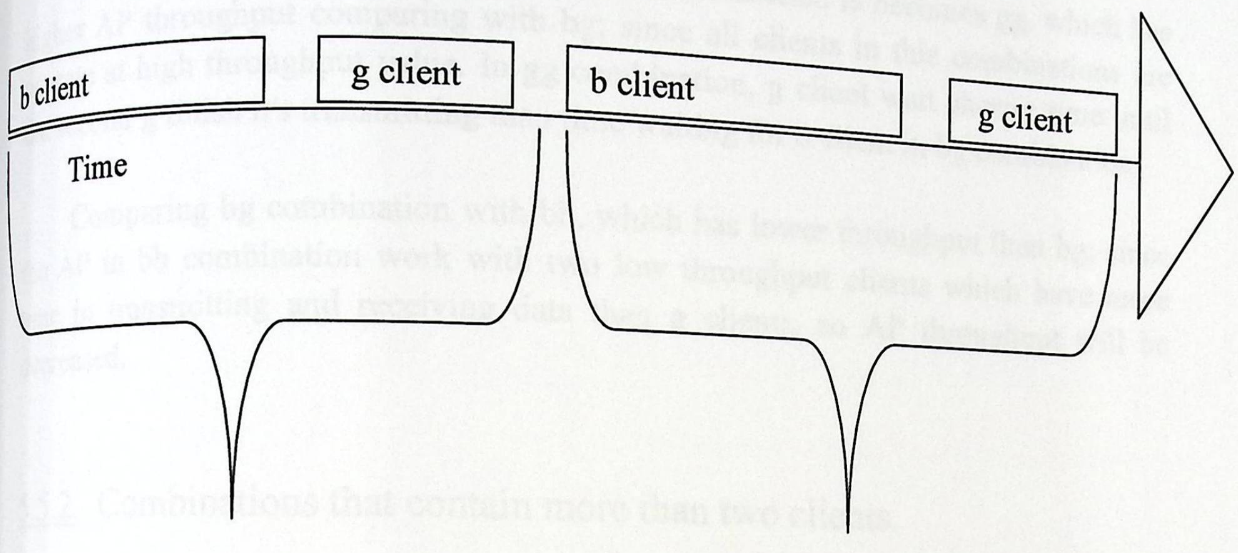


Figure 5.21: Specification of bg combination

Lessees b clients maximum throughput means more time needs it to transmit or receive data to\from the AP than g clients, so the two clients have different throughput value and these values are not closed to each other like in bb combination.

Since maximum throughput of b client is less than g client; b client take more time than g client. When b client want to transmit data to the AP it take a long time to complete transmitting its data than g. And since channel in wireless is half duplex, g client must wait until b client finish it's transmitting, as shown in figure 5.21

Waiting more time means less value of throughput in g client. Comparing with one g client in g only AP mode, g client in this case doesn't wait any other client to transmit its data and has higher data throughput than in bg combination.

In this combination throughput value of the b client is less than the maximum throughput of one b client in b only AP mode; since throughput of the AP in bg combination is distribute between the two clients not to only one client, that means each one has its owns throughput value, but in one b only combination all AP throughput distributes to only one client.

In combination that contains one b client with b only AP mode throughput of this AP is 6.880Mbps which is less than throughput in bg combination, adding high throughput g client increase AP throughput, so g client increases AP throughput than in one b combination, and has less throughput than b client in bg combination.

If the b client is replaced by g client, the combination is becomes gg, which has higher AP throughput comparing with bg; since all clients in this combinations are operate at high throughput value. In gg combination, g client wait shorter time until the second g finish it's transmitting than time waiting for b client in bg combination.

Comparing bg combination with bb, which has lower throughput than bg; since the AP in bb combination work with two low throughput clients which have more time in transmitting and receiving data than g clients, so AP throughput will be decreased.

5.5.2. Combinations that contain more than two clients.

This section contains the combinations between b and g technologies when there are three and four clients in all combinations.

The AP in bbg combination in bgn AP mix mode has 6.240Mbps throughput which is higher than the same combination in bg AP mix mode, first b client has 3.108Mbps, and the second has 3.140Mbps and g client has 1.538Mbps throughput, as shown in figure 5.23.

Comparing the throughput of bbg to bbb combination that is operates under b only AP mode; replacing one b client in bbb with g client increases throughput of the AP in bbg than in bbb combination.

Client that operates in g mode in bbg combination has lower throughput value than any b clients, g client can transmit or receive data after waiting the two low data rate b clients, as shown in figure 5.22. Since g client wait longer time that is waiting in bg combination; throughput of the g client is lower than in bg combination.

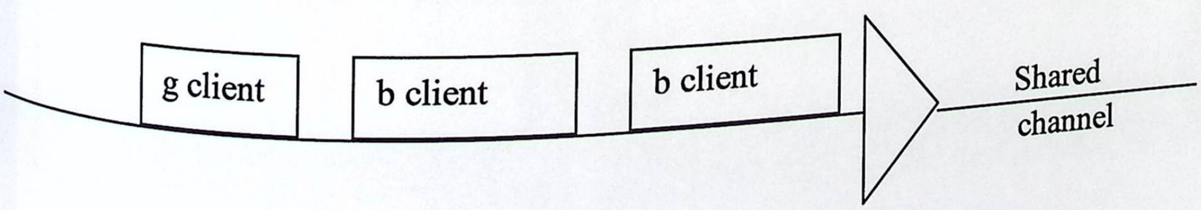


Figure 5.22: bbg combination

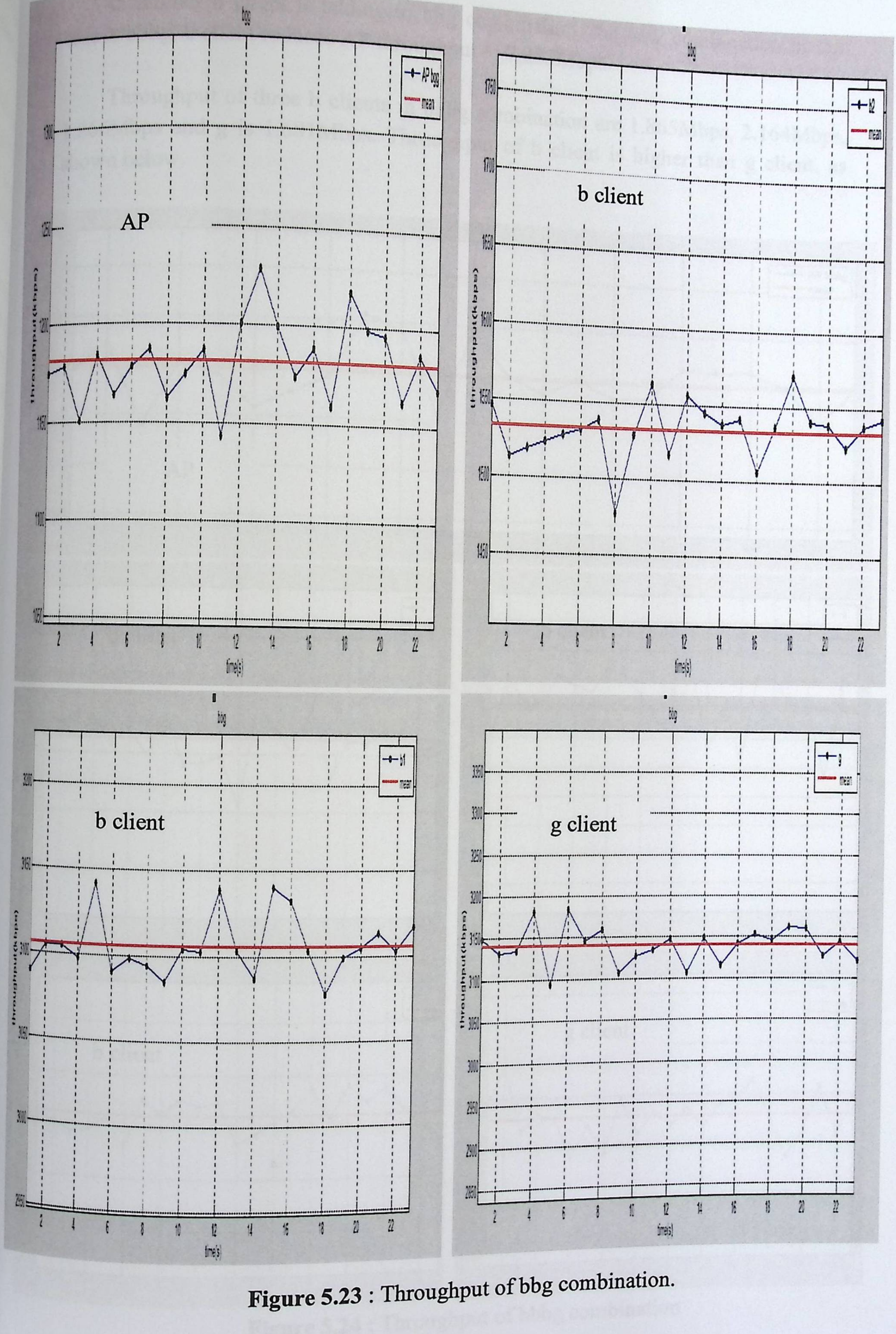


Figure 5.23 : Throughput of bbg combination.

If another b client is adding to bbg combination, the new combination in this case is bbbg, b client reduces AP throughput to 7,285Mbps.

Throughput of three b clients in bbbg combination are 1.865Mbps, 2.164Mbps, 1.866Mbps and g is 1.681Mbps. Throughput of b client is higher than g client, as shown below.

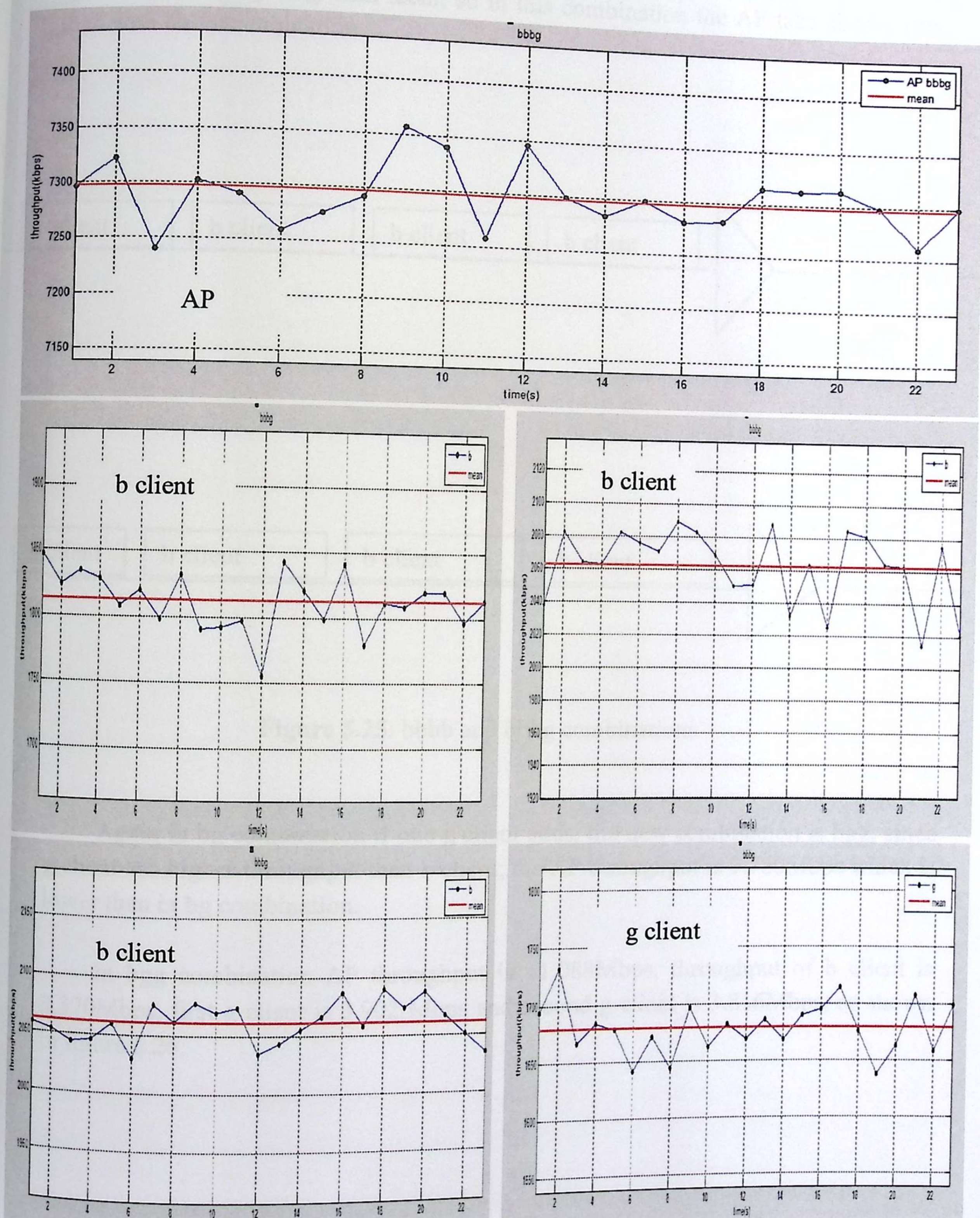


Figure 5.24 : Throughput of bbbg combination

Comparing with bbbb combination throughput to bbbg, by replacing one b client in bbbb with one g client the AP throughput increases, since in bbbb combination the AP support four low data throughput which takes longer time than in bbbg as shown below.

In bbbg there are three clients that take long time and one g client that takes shortest time comparing with them, so in this combination the AP take shorter time than with bbbb combination.

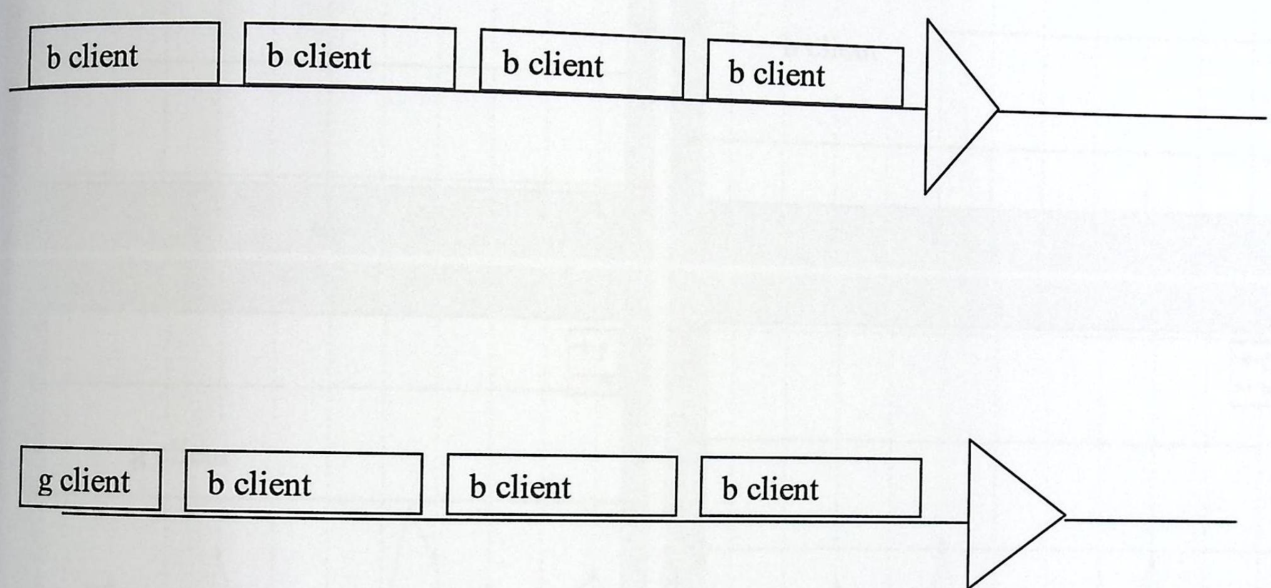


Figure 5.25: bbbb and bbbg combinations

Again in bg combination if one g client adds, the new combination is bgg, since g client has higher throughput than b client; the AP throughput is 9.780Mbps which is lower than in bg combination.

In bgg combination AP throughput is 11.088Mbps, throughput of b client is 3.370Mbps, first g client is 3.902 Mbps and second g client is 3.816Mbps, as shown in figure 5.26.

Comparing with bbbb combination throughput to bbbg, by replacing one b client in bbbb with one g client the AP throughput increases, since in bbbb combination the AP support four low data throughput which takes longer time than in bbbg as shown below.

In bbbg there are three clients that take long time and one g client that takes shortest time comparing with them, so in this combination the AP take shorter time than with bbbb combination.

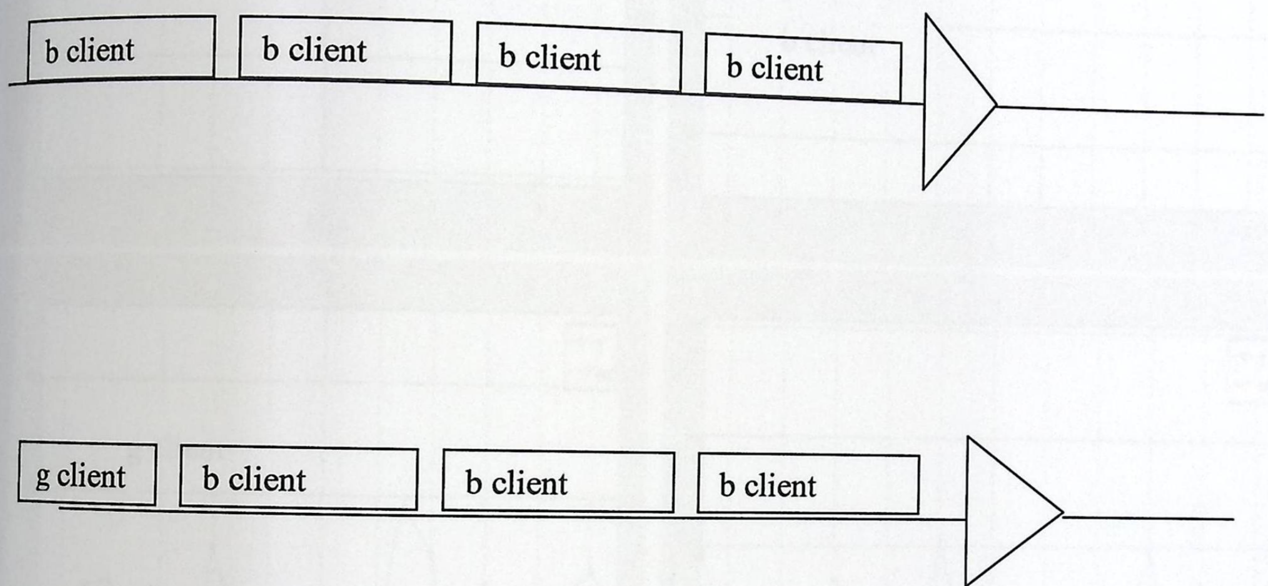


Figure 5.25: bbbb and bbbg combinations

Again in bg combination if one g client adds, the new combination is bgg, since g client has higher throughput than b client; the AP throughput is 9.780Mbps which is lower than in bg combination.

In bgg combination AP throughput is 11.088Mbps, throughput of b client is 3.370Mbps, first g client is 3.902 Mbps and second g client is 3.816Mbps, as shown in figure 5.26.

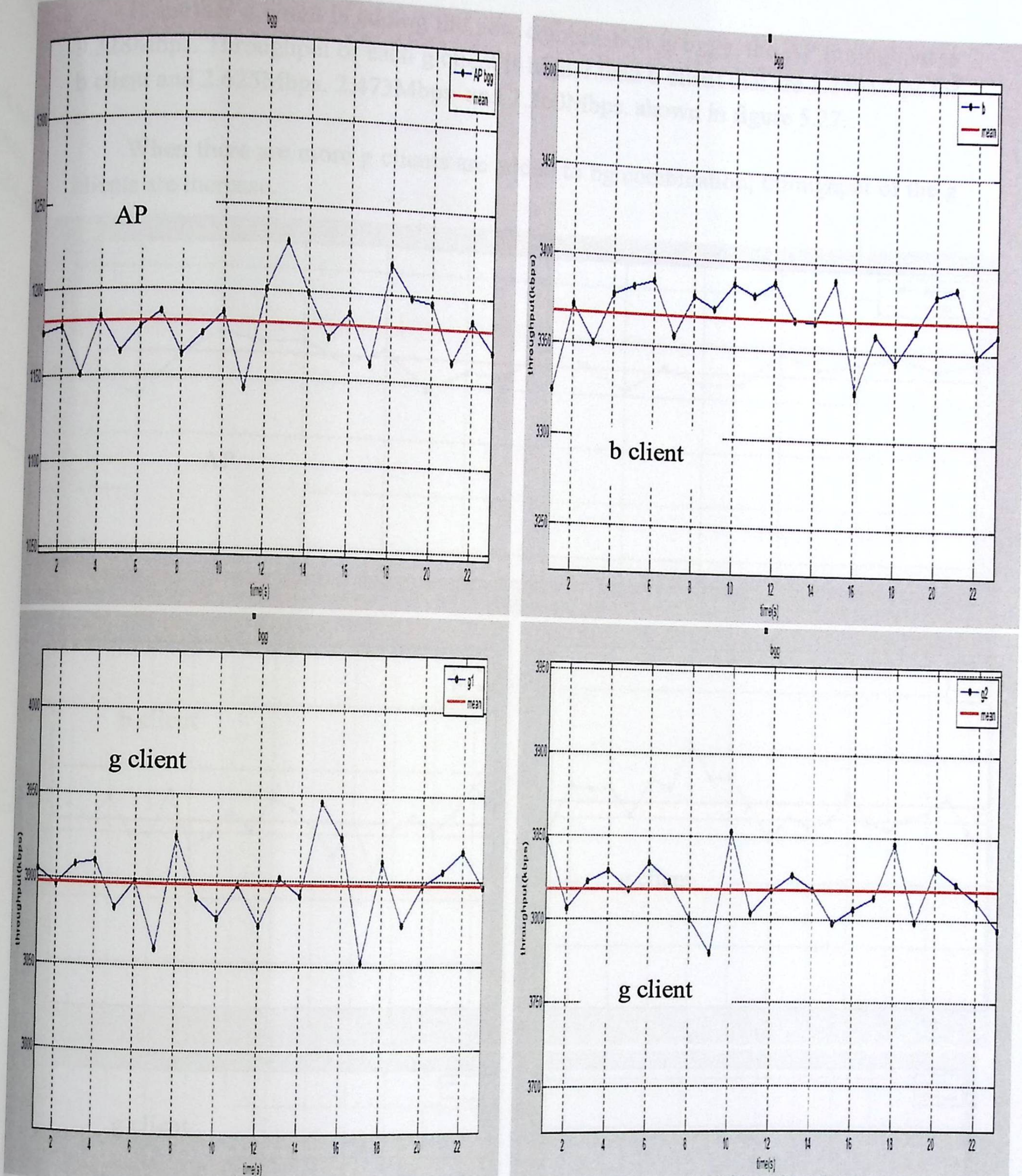


Figure 5.26 : Throughput of bgg combination

Client that operates in g mode not wait long time until the other clients finish there transmitting, since there is only one long time b client in this combination like in bg combination, but since there are more g client in bgg than in bg combination, throughput of the AP in bgg combination is lower than in bg combination.

If another g client is adding the new combination is bggg, the AP throughput is 9.328Mbps. Throughput of each g client is higher than b client that are 1.849Mbps for b client and 2.625Mbps, 2.473Mbps and 2.360Mbps. shown in figure 5.27.

When there are more g clients are added to bg combination; throughput of the g clients are increase.

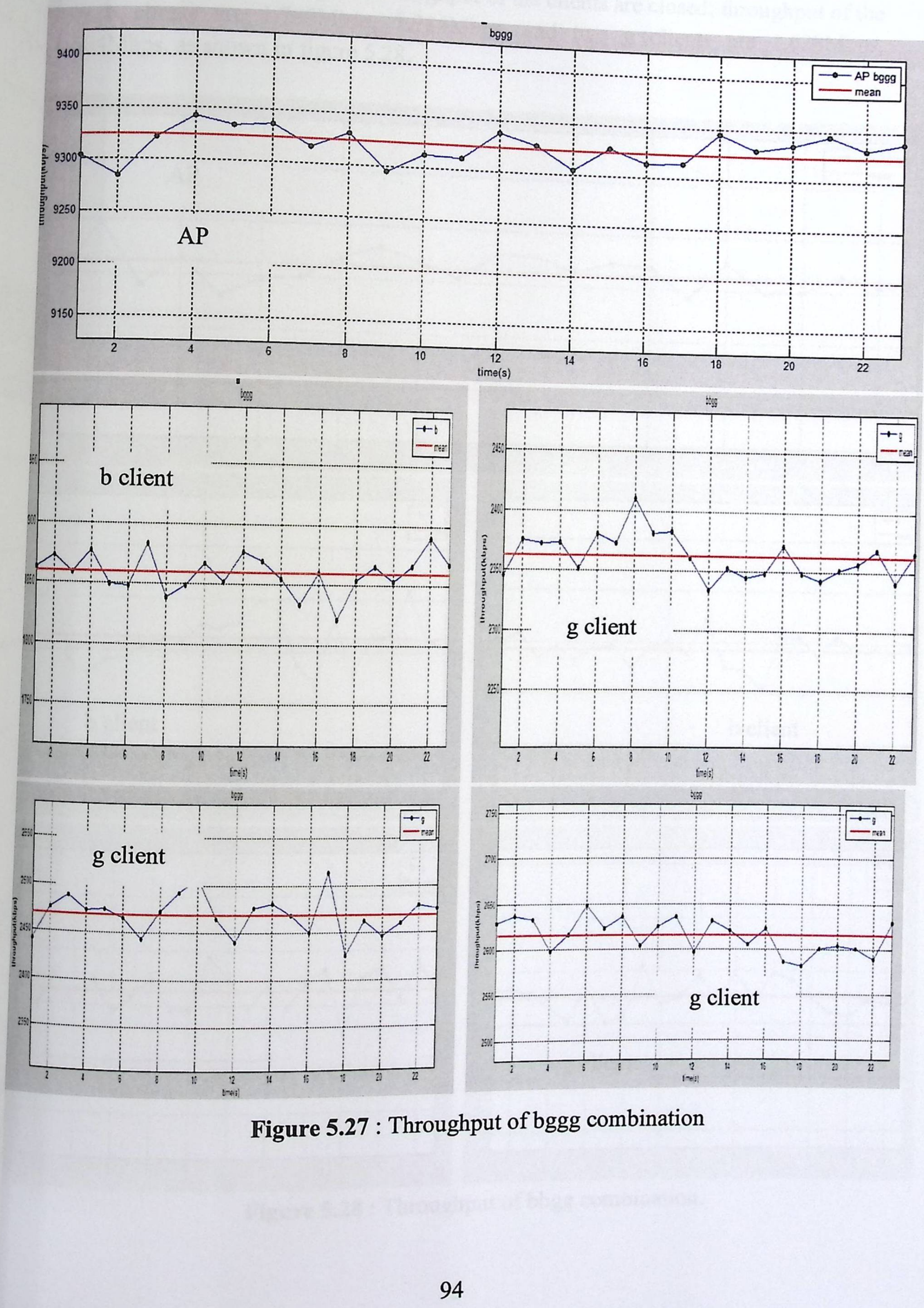


Figure 5.27 : Throughput of bggg combination

Comparing with gggg combination in g only AP mode, since there is one b client places one g client in gggg that reduce AP throughput from 17.200Mbps in gggg to 328Mbps in bggg.

In bbgg the number of b clients and g clients are equal, AP throughput is .812Mbps. In this combination throughput of the clients are closed; throughput of the vo b clients are 1.788Mbps, 1.734Mbps, and two g clients are 1.628Mbps, .504Mbps, as shown in figure 5.28.

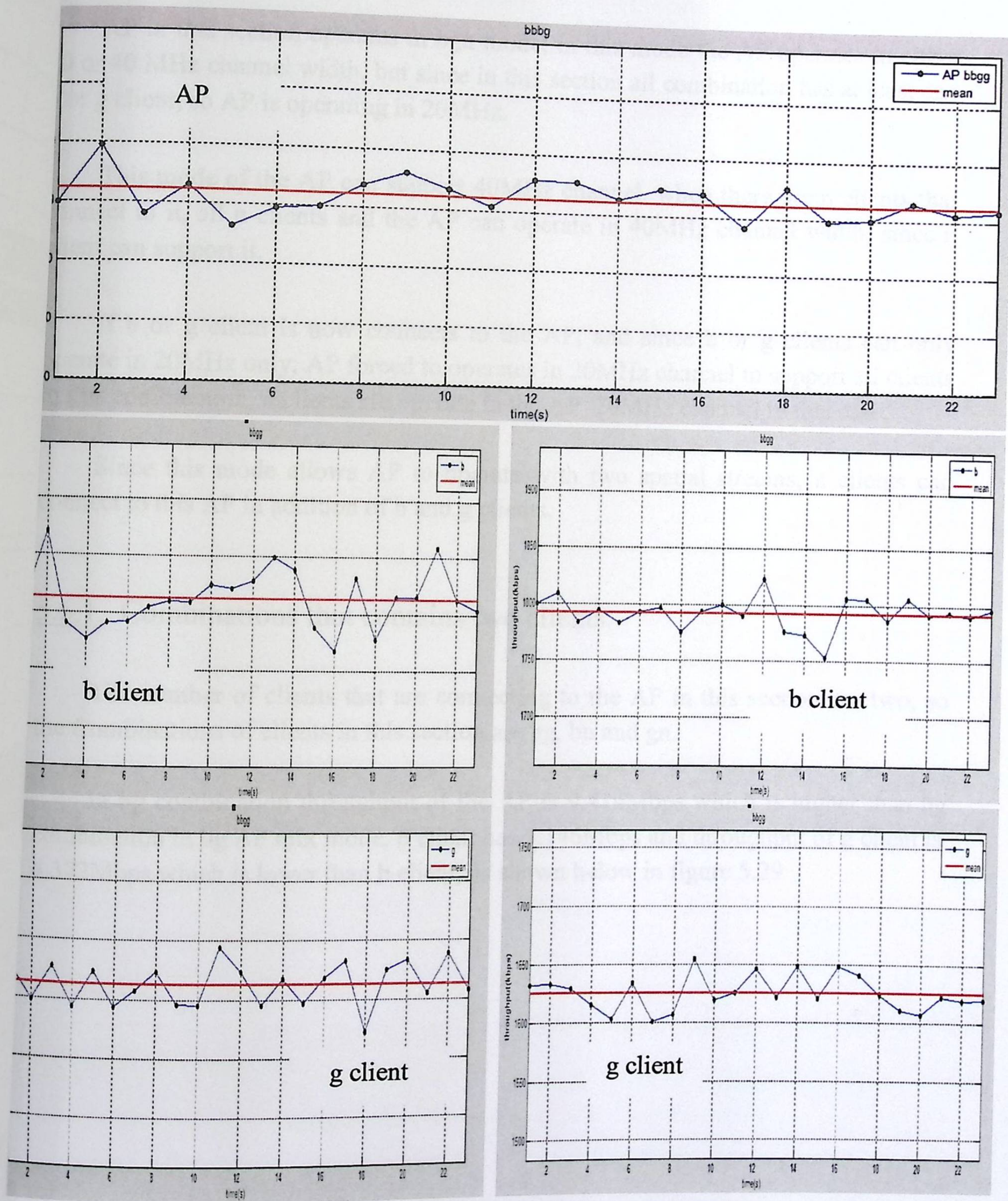


Figure 5.28 : Throughput of bbgg combination.

Comparing with gggg combination in g only AP mode, since there is one b client replaces one g client in gggg that reduce AP throughput from 17.200Mbps in gggg to 9.328Mbps in bggg.

In bbgg the number of b clients and g clients are equal, AP throughput is 7.812Mbps. In this combination throughput of the clients are closed; throughput of the two b clients are 1.788Mbps, 1.734Mbps, and two g clients are 1.628Mbps, 1.504Mbps, as shown in figure 5.28.

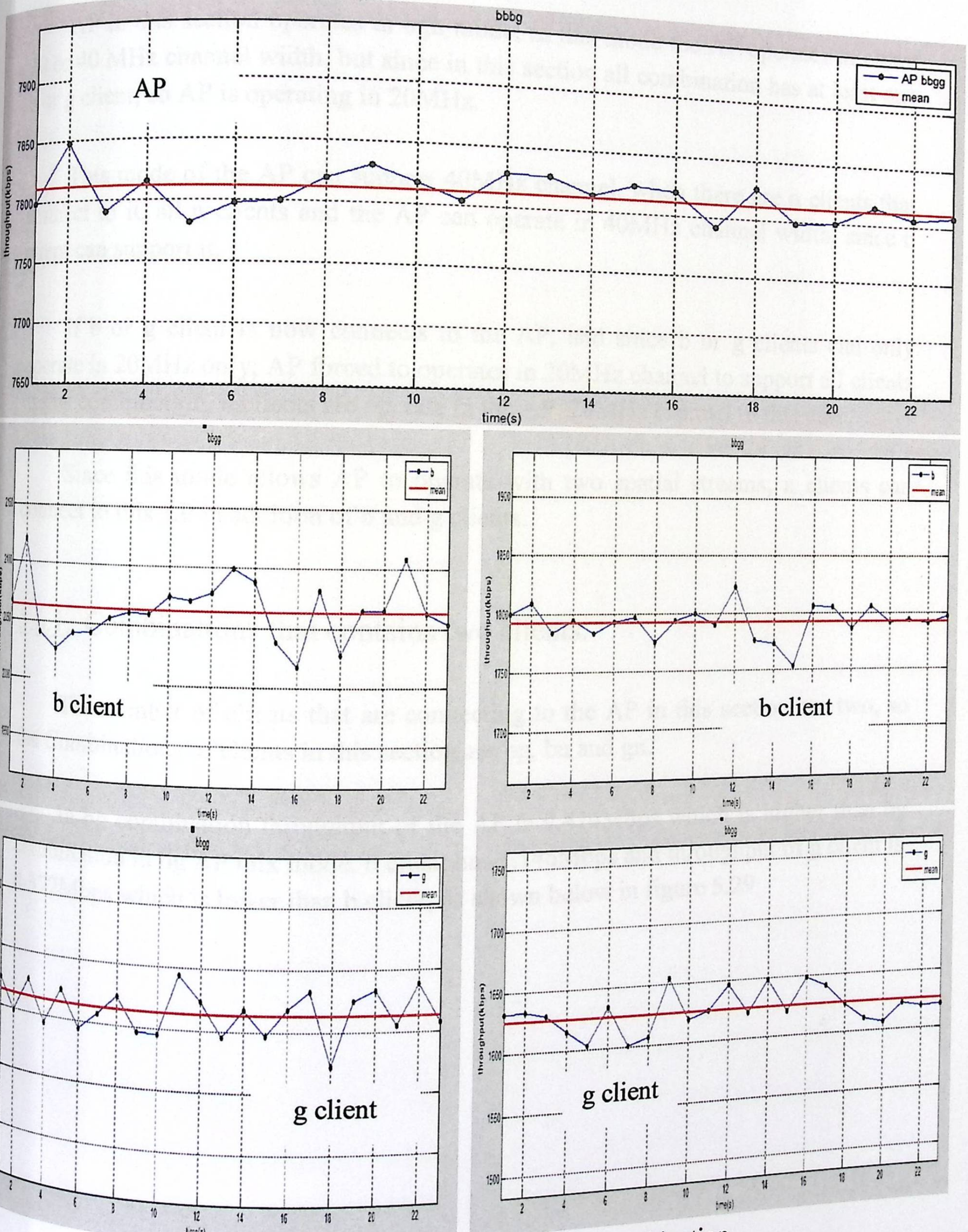


Figure 5.28 : Throughput of bbgg combination.

Comparing with bggg, throughput in this combination is higher than in bbgg; since there are more high throughput g clients. And also Comparing with bbbg, throughput in this combination is lower than in bbgg; since there are lower throughput b clients.

5.6. bgn AP mix mode.

AP in this section operates in bgn mode; in this mode the AP operates in either 20 or 40 MHz channel width, but since in this section all combination has at least one b or g client; so AP is operating in 20MHz.

This mode of the AP can support 40MHz channel, when there are n clients that connect to it, all n clients and the AP can operate in 40MHz channel width, since n client can support it.

If b or g client is now connects to the AP, and since b or g clients can only operate in 20MHz only; AP forced to operates in 20MHz channel to support all clients in this combination, n clients are operate in the AP 20MHz channel in this case.

Since this mode allows AP to operate with two spatial streams; n clients can connect to this AP in addition of b and g clients.

5.6.1. Combinations that contains two clients.

The number of clients that are connecting to the AP in this section are two, so the Combinations of clients in this section are bg, bn and gn.

In bg combination throughput of the AP is 9.414Mbps which is higher than bg combination in bg AP mix mode. b client has 5.146Mbps and throughput of g client is 4.372Mbps which is lower than b client, as shown below in figure 5.29

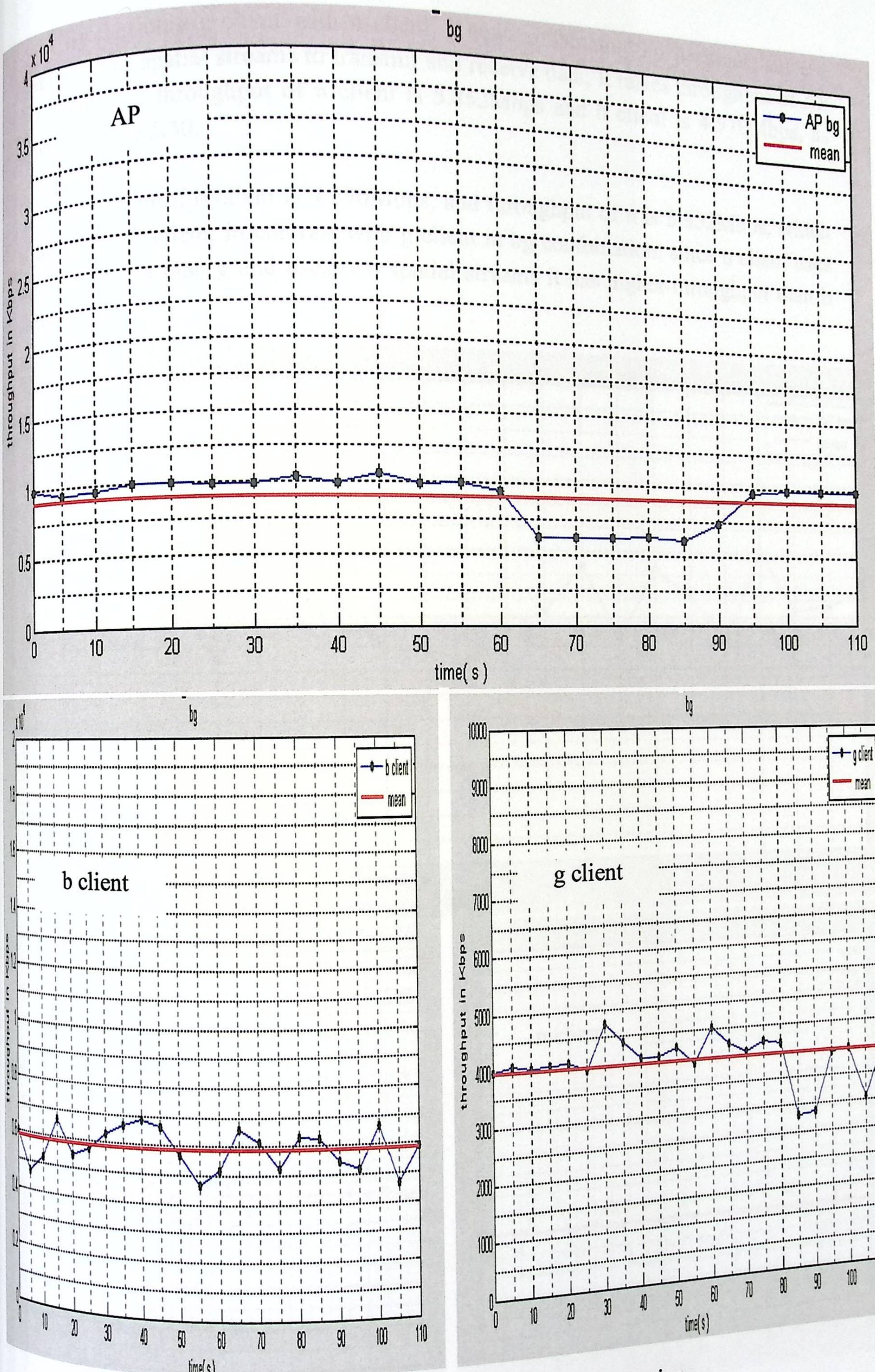


Figure 5.29 : Throughput of bg combination

By replacing g client with n client, a new combination bn becomes, since n client uses two spatial streams to transmit and receive data; It raises throughput of AP to 10.422Mbps. throughput of n client is 5.852Mbps and b client is 4.570Mbps, as shown in figure 5.30.

Throughput of b client is 4.570Mbps, and throughput of n is 5.852Mbps, which is higher than b client; in contrast with g client in bg combination; since n client uses high coding rate than g and uses two spatial streams it has higher throughput than b client.

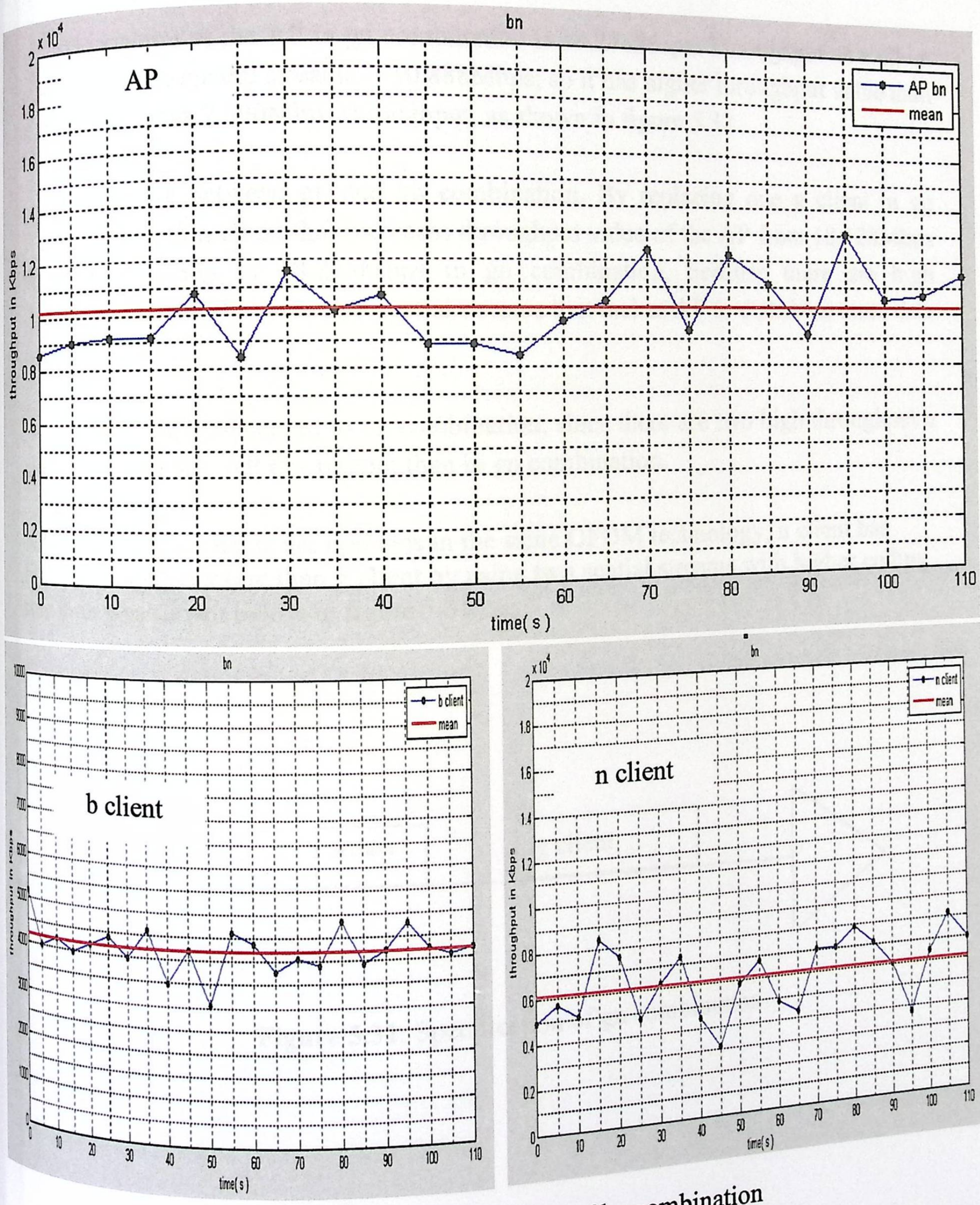


Figure 5.30 : Throughput of bn combination

Client that operates in n mode in bn combination increases throughput of the AP than in bb combination, b client in bn combination reduced throughput of n client and that reduced throughput of the AP than in nn combination.

In gn combination throughput of AP is higher than in bn combination; since the b client in bn combination is replaced by g client that has higher throughput than b client. In this combination all two clients are using the same modulation technique which is OFDM.

Throughput of the AP in gn combination is 18.278Mbps. Throughput of n client since it uses two spatial streams is 10.888Mbps; so it has higher throughput value than g client which has 7.390Mbps throughput, as shown in figure 5.32

Comparing between gg and gn combination. By replacing one g client in gg combination with n client that increases throughput value of the AP from 18.128Mbps in gg combination to 18.278Mbps in gn combination, because there are high throughput n client that uses two spatial streams that makes AP to distribute more data to this client.

Comparing between gn to nn combination, since there are two high throughput n clients that increase AP throughput than in gn combination.

Although g and n clients are operates in the same OFDM technology; n client has higher throughput value than g client by using two spatial streams with higher coding rate than g as shown below in figure 5.31.

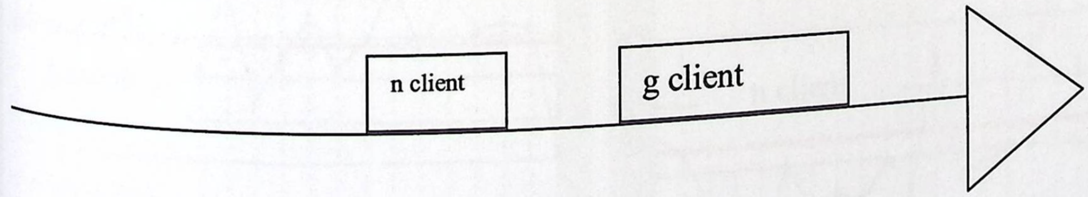


Figure 5.31: Specification of gn combination

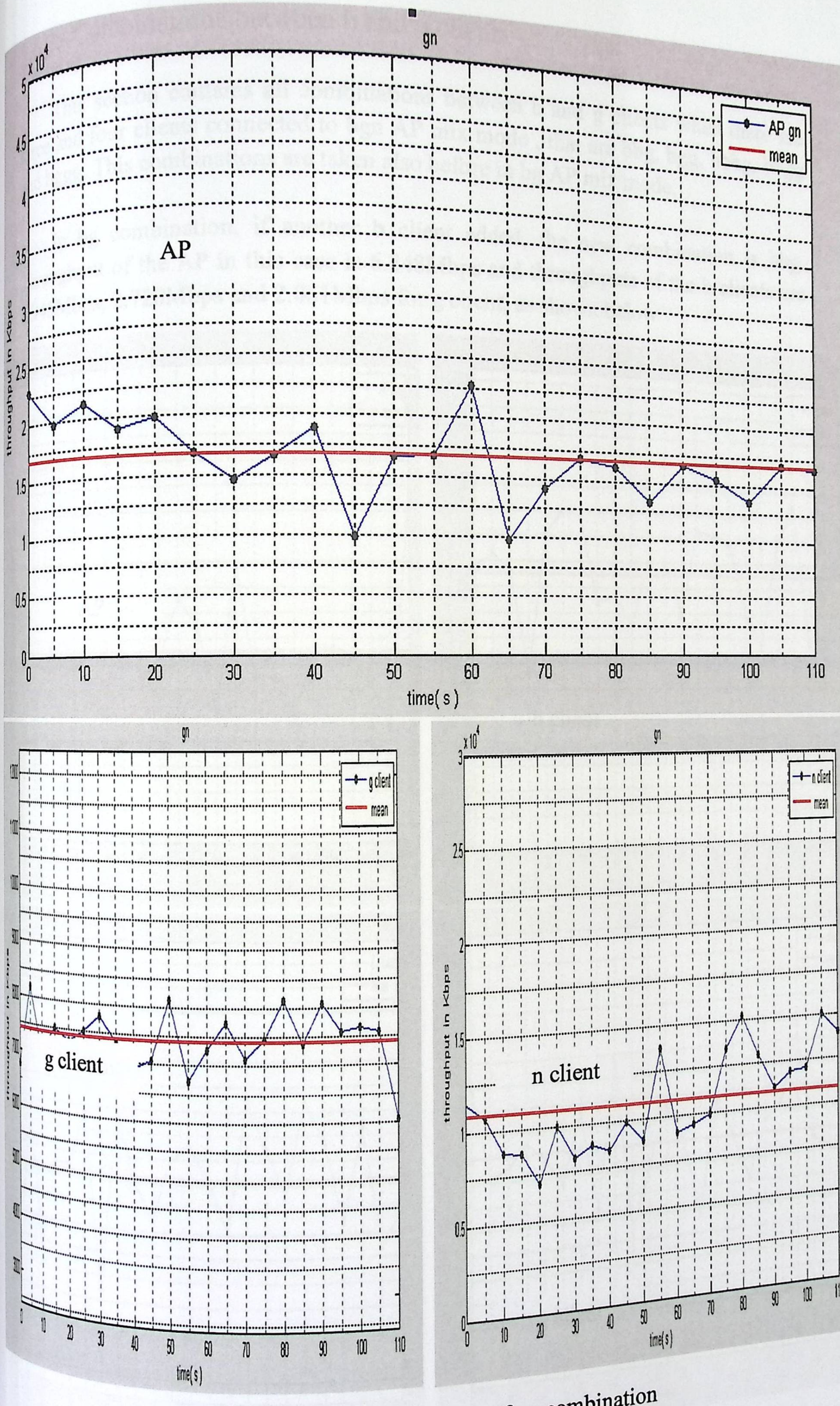


Figure 5.32 : Throughput of gn combination

5.6.2. Combinations between b and g clients

This section contains all combinations between b and g clients when there are three and four clients connected to bgn AP mix mode , that are bbg, bgg, bbbg, bbgg and bggg. This combinations are taken also before in bg AP mix mode.

In bg combination, if another b client added, the new combination is bbg. Throughput of the AP in this case is 6.248Mbps and throughputs of the b clients are 2.945Mbps, 2.720Mbps and 2.061Mbps for g client, as shown below

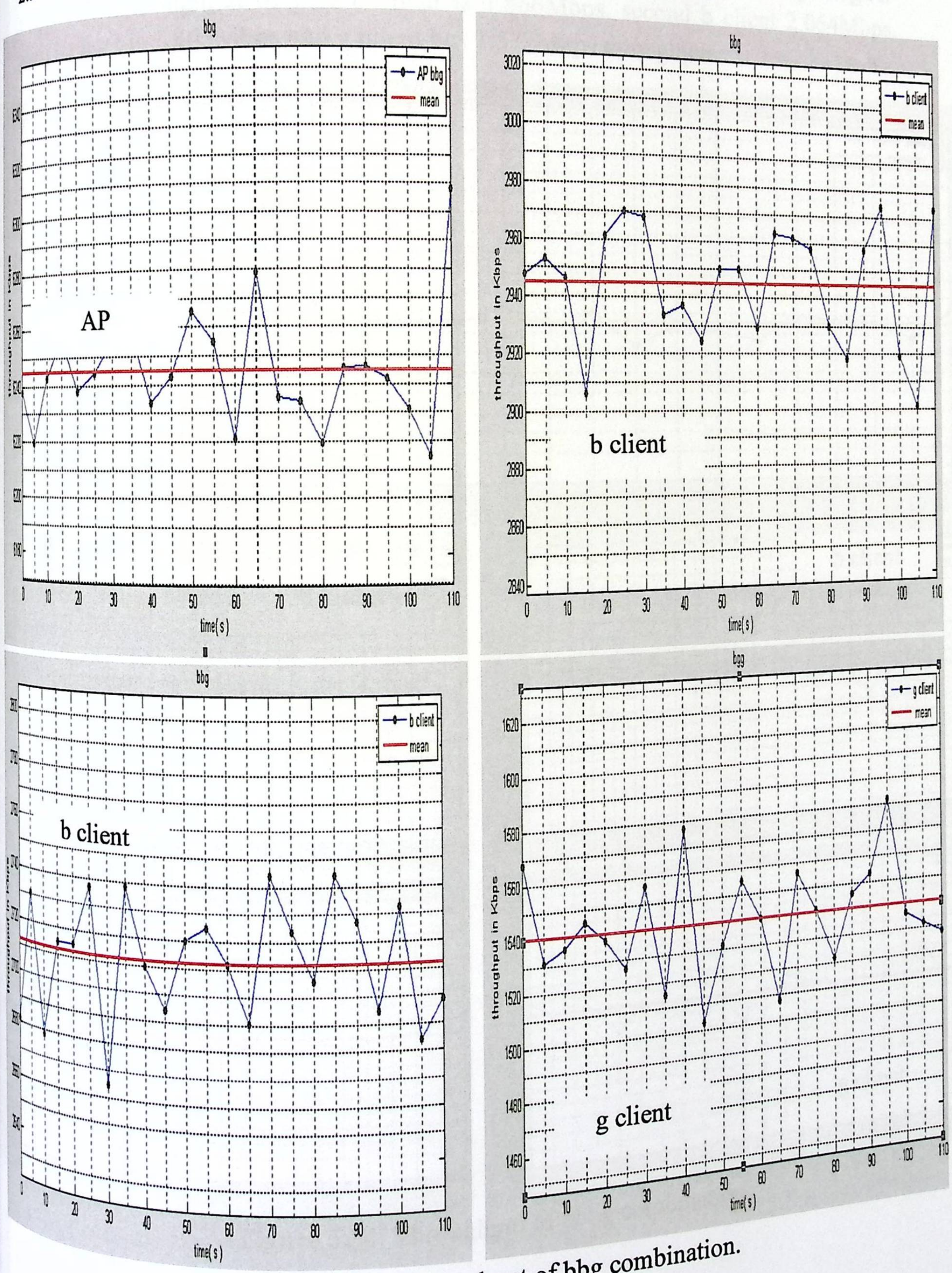


Figure 5.33: Throughput of bbg combination.

In bgn mix mode the AP transmits data by using two spatial streams, but since there are only b and g client in all combinations in this section; the AP transmits and receives data by only one spatial stream by using all three antennas.

The AP in bgn mix mode can use diversity technique, which is increased received power in each clients by increasing S/N ratio; and since by increasing S/N ratio throughput will be increased in AP and in all clients.

Throughput of the AP in bbbg is 7.657Mbps which is higher than bbbg in bg AP mix mode. Throughput of first b client is 1.866Mbps, second b client 2.064Mbps, third b client is 1.865Mbps and g client has 1.582Mbps throughput.

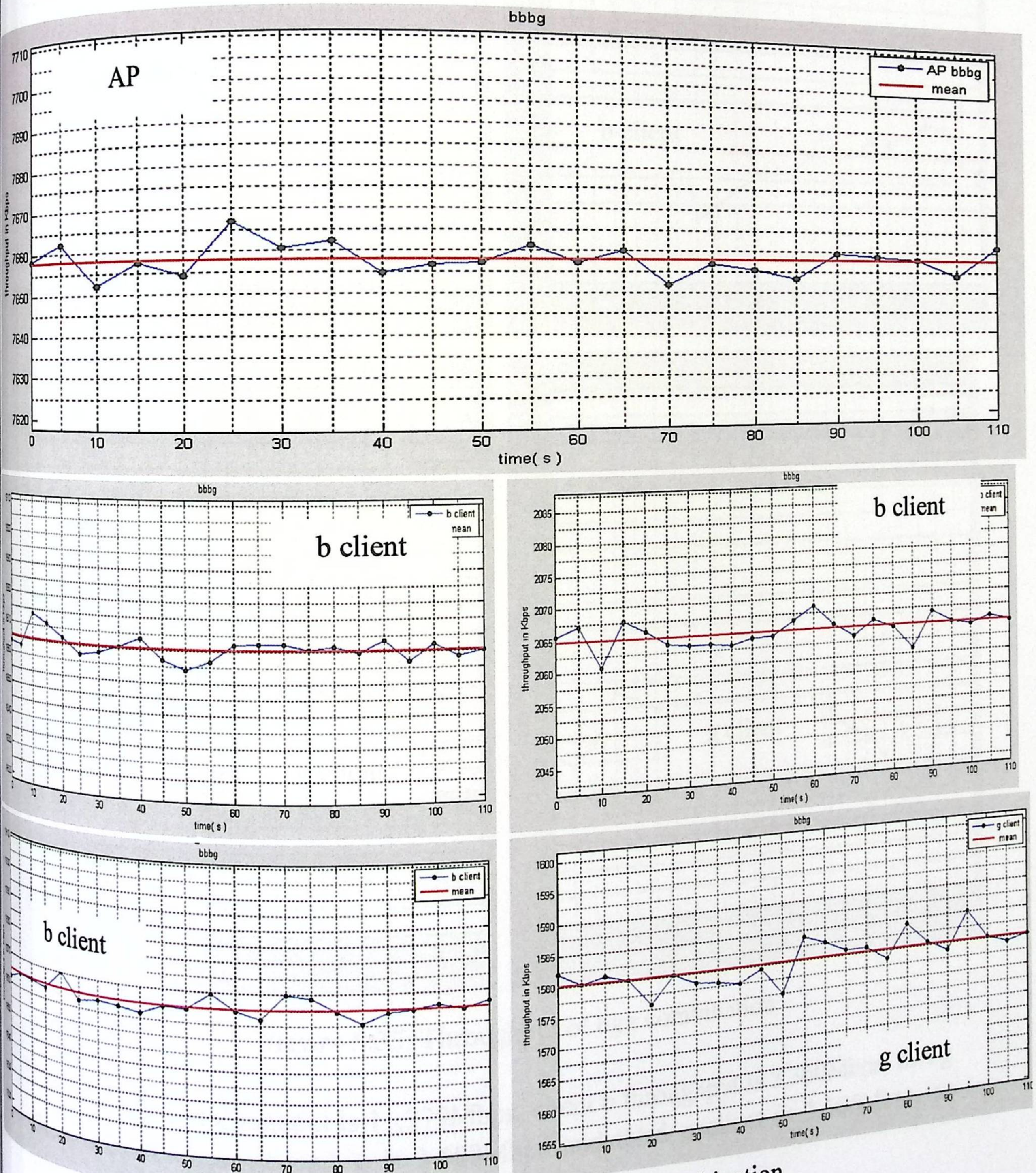


Figure 5.34: Throughput of bbbg combination

In bgg combination throughput of each g client is higher than b client, throughput of b client is 2.592Mbps and two g clients are 5.244Mbps and 3.442Mbpsand AP throughput is 11.400Mbps

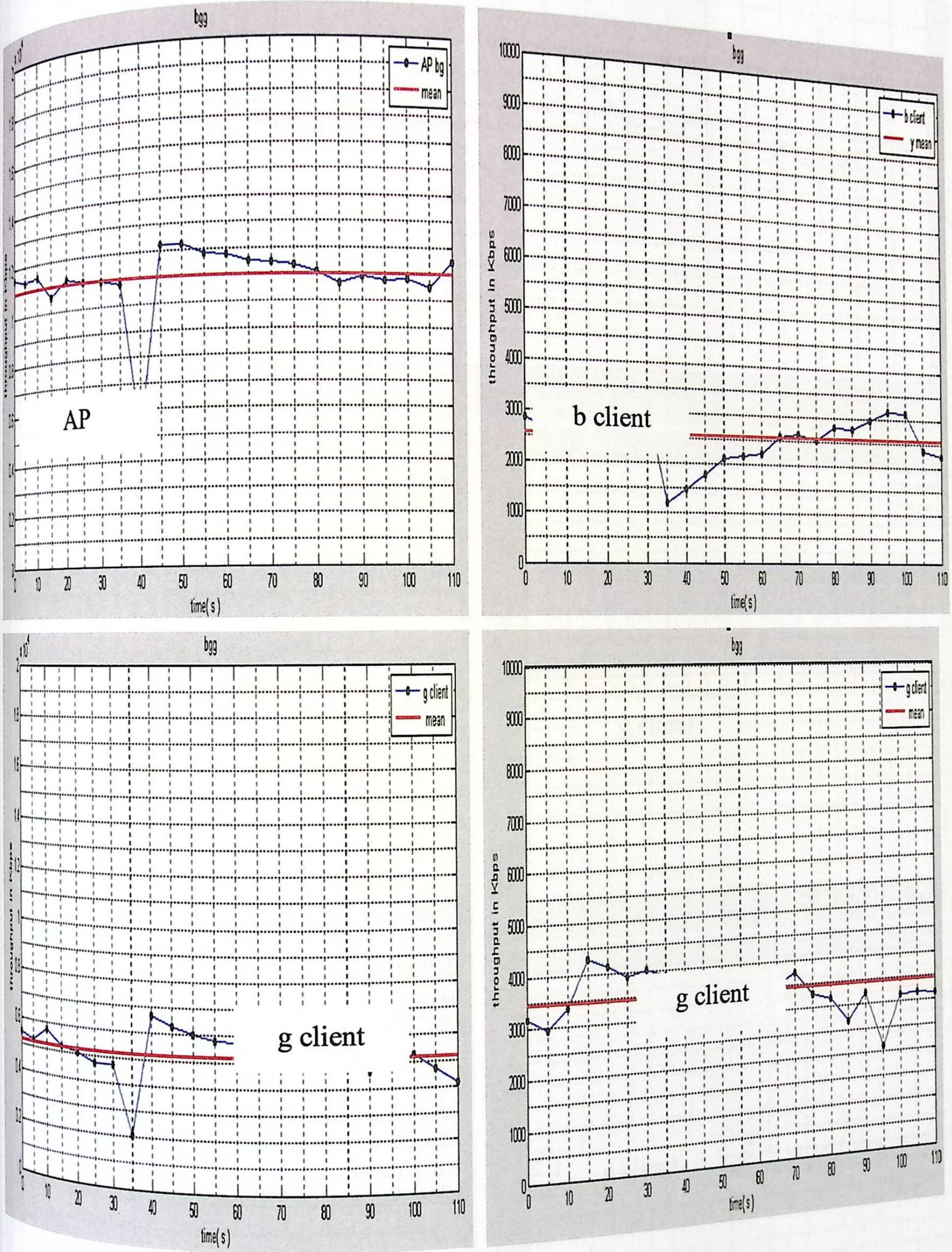


Figure 5.35: Throughput of bgg combination

In bggg, AP throughput is 11.379Mbps, client b throughput is 2.360Mbps, first g client is 3.610Mbps, second g is 3.688Mbps and third g client is 3.566Mbps, as shown.

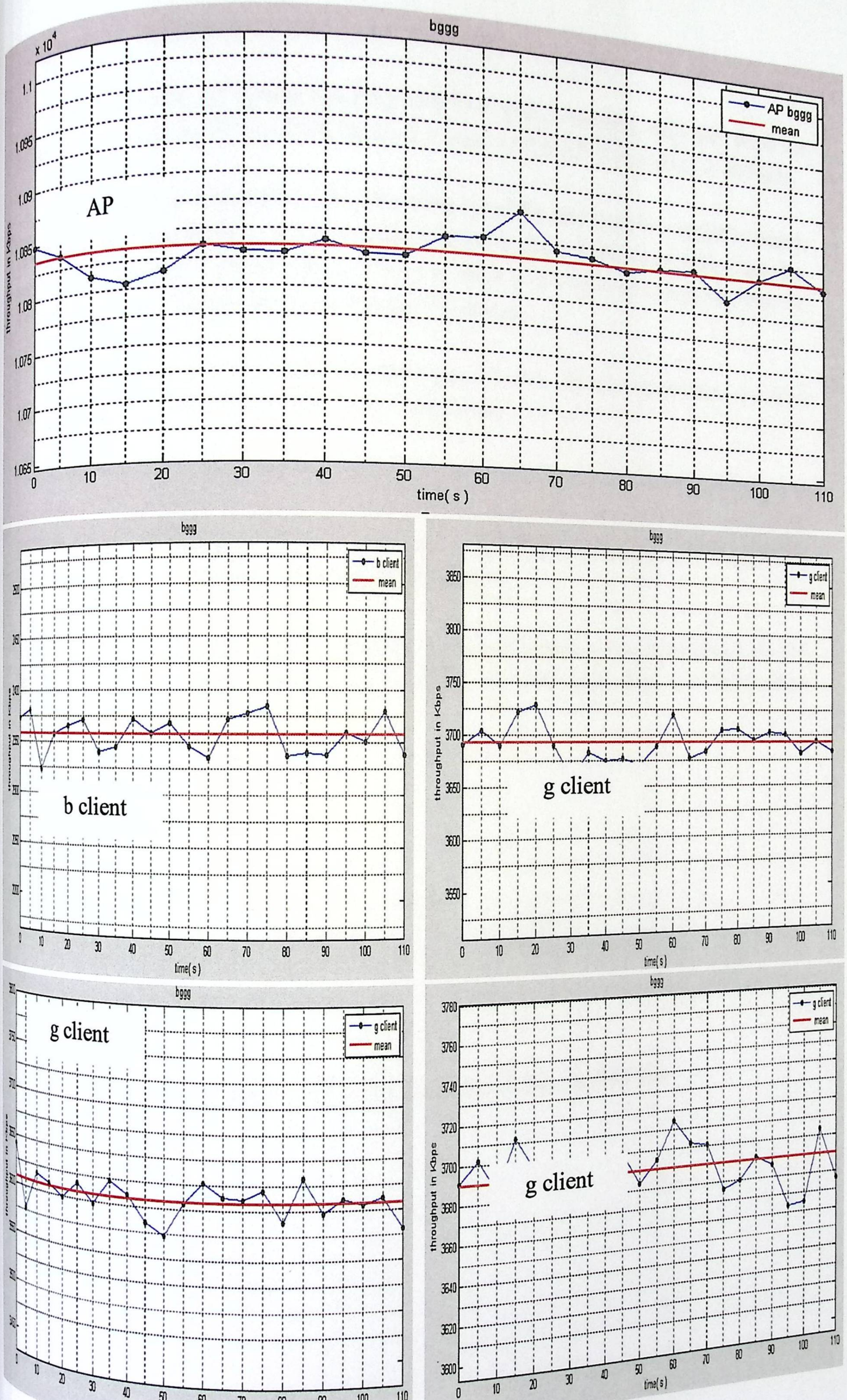


Figure 5.36: Throughput of bggg combination

5.6.3. Combinations between b and n clients

n clients in this AP mode operates with two spatial streams, and since there are at least one b client in all combination in this section; the AP is operating in 20 MHz.

The n client is operates in 20 MHz channel width and uses two spatial streams, when the AP is transmits or receives data to/from n client it uses two spatial streams, but when it transmit or receive data to/from b client it is uses only one spatial streams; since b clients are operate by using one spatial stream.

In this section the combinations between b and n clients, when there are three and four clients are bbn, bnn, bbbn, bbnn and bnnn.

When there is one b client is adding to bn combination, the new combination in this case is bbn; since b client has lower throughput than n client that reduces AP throughput to 7.812Mbps, first b client has 2.730Mbps throughput, the second has 3.046Mbps, and n client has 1.875Mbps throughput.

Throughput of n client is the lowest on in bbn combination, since there are two low throughput b clients that force n client to wait until they are finish there transmitting, as shown below.

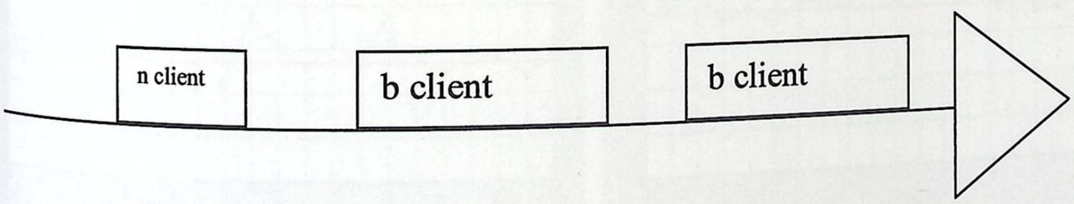


Figure 5.37: Specification of bbn combination

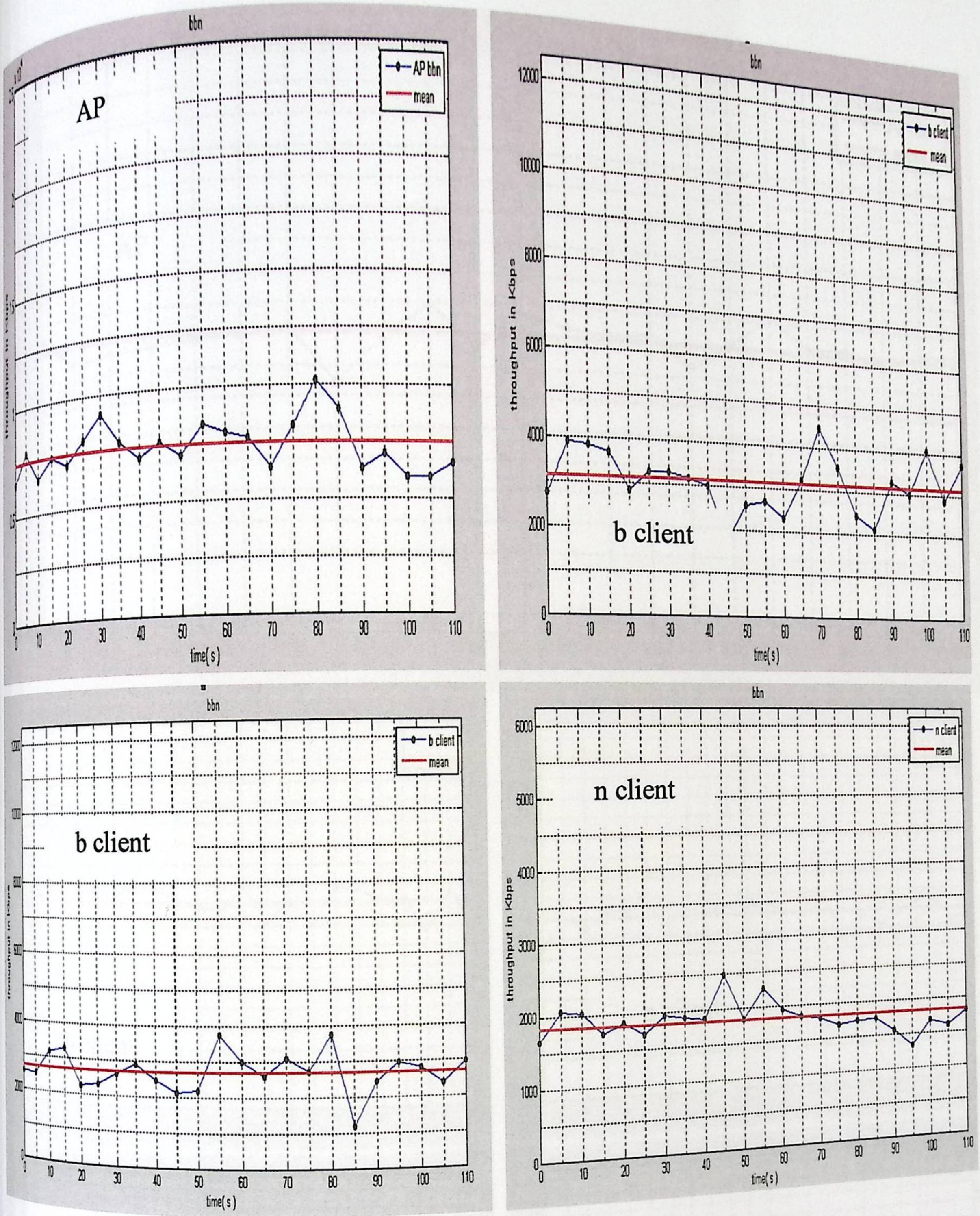


Figure 5.38 : Throughput of bbn combination

Comparing this result with bbb combination, by replacing one b client by one n client throughput of the AP is increases; since n client operates at high data throughput and that make AP to wait shorter time in the transmitting cycle than in bbb combination.

By adding another b client to bbn, the new combination is bbbn, adding more client that is work at low data throughput will reduce AP throughput. In bbbn the AP throughput is 6.840Mbps, as shown in figure 5.39. Throughput of each b clients is higher than n client throughput.

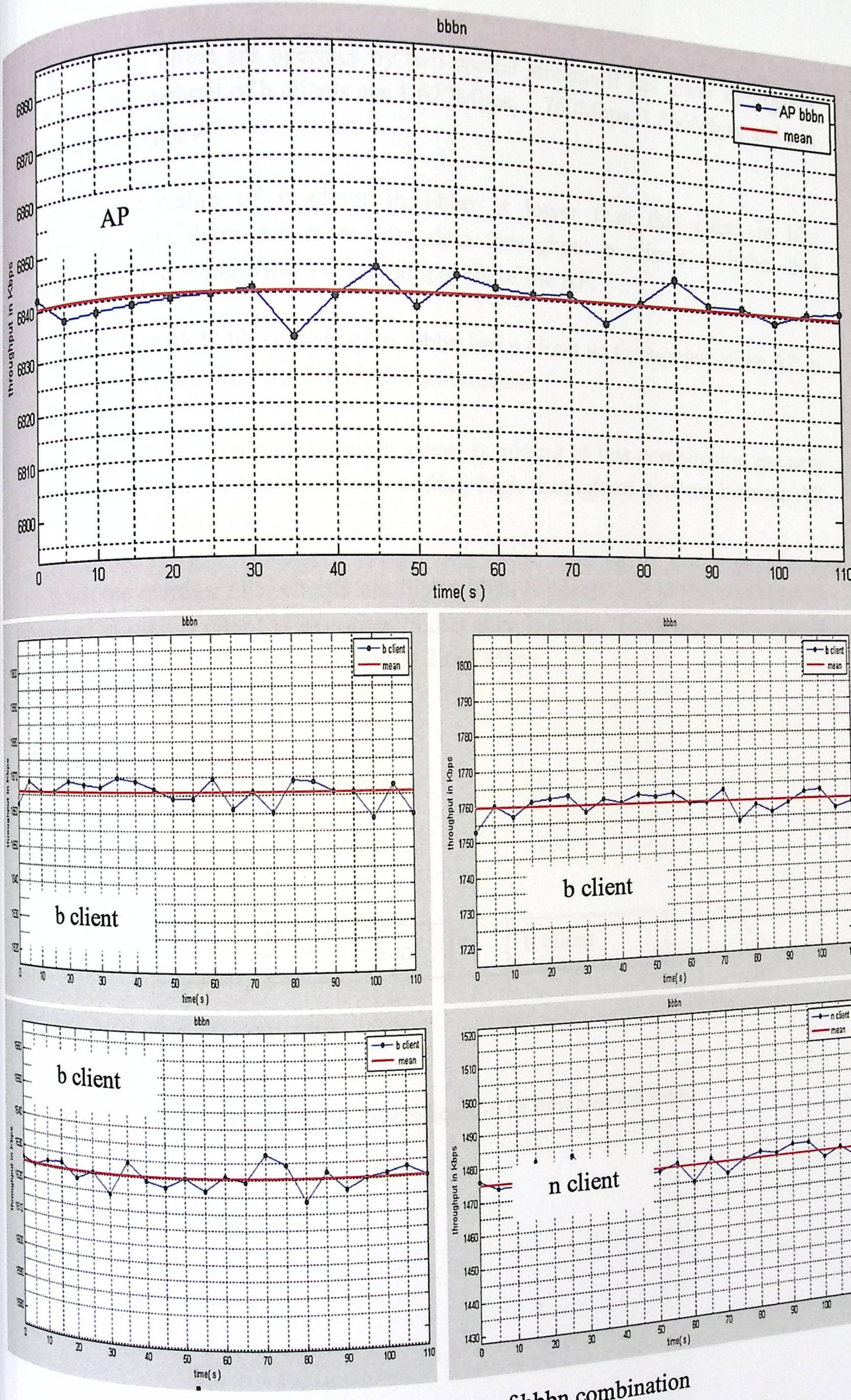


Figure 5.39 : Throughput of bbbn combination

Instead of n client are operates by two spatial streams it has lower throughput than b client, throughput of b clients are 1.627Mbps, 1.760Mbps, 1.866Mbps, and n is 1.475 Mbps throughput.

Throughput value of n client in bbbn is lower than this client in bbn combination, since there are more low data throughput b clients in bbbn, that increased time of complete the transmitting cycle of the AP.

Comparing with bbbb combination, bbbn has n client so throughput of the AP in bbbn combination is higher than in bbbb combination.

Again in bn combination, if one n client is adding to this combination the new combination of client is becomes bnn, adding high throughput n client increase AP throughput to 10.562Mbps.

When the number of n clients are higher than b clients like in this combination throughput in each n client is becomes higher than b client. Throughput of n clients are 3.780Mbps, 4.180Mbps and b client is 2.602Mbps.

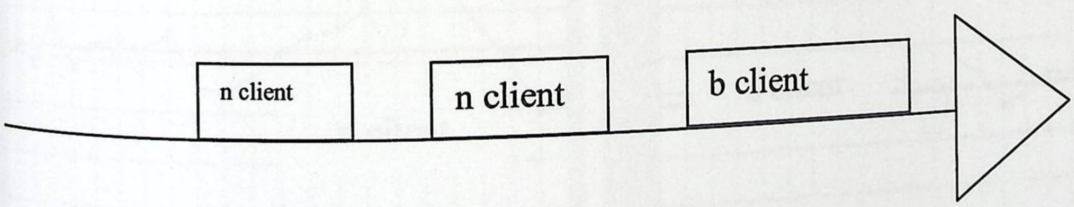


Figure 5.40 : Specification of bnn combination

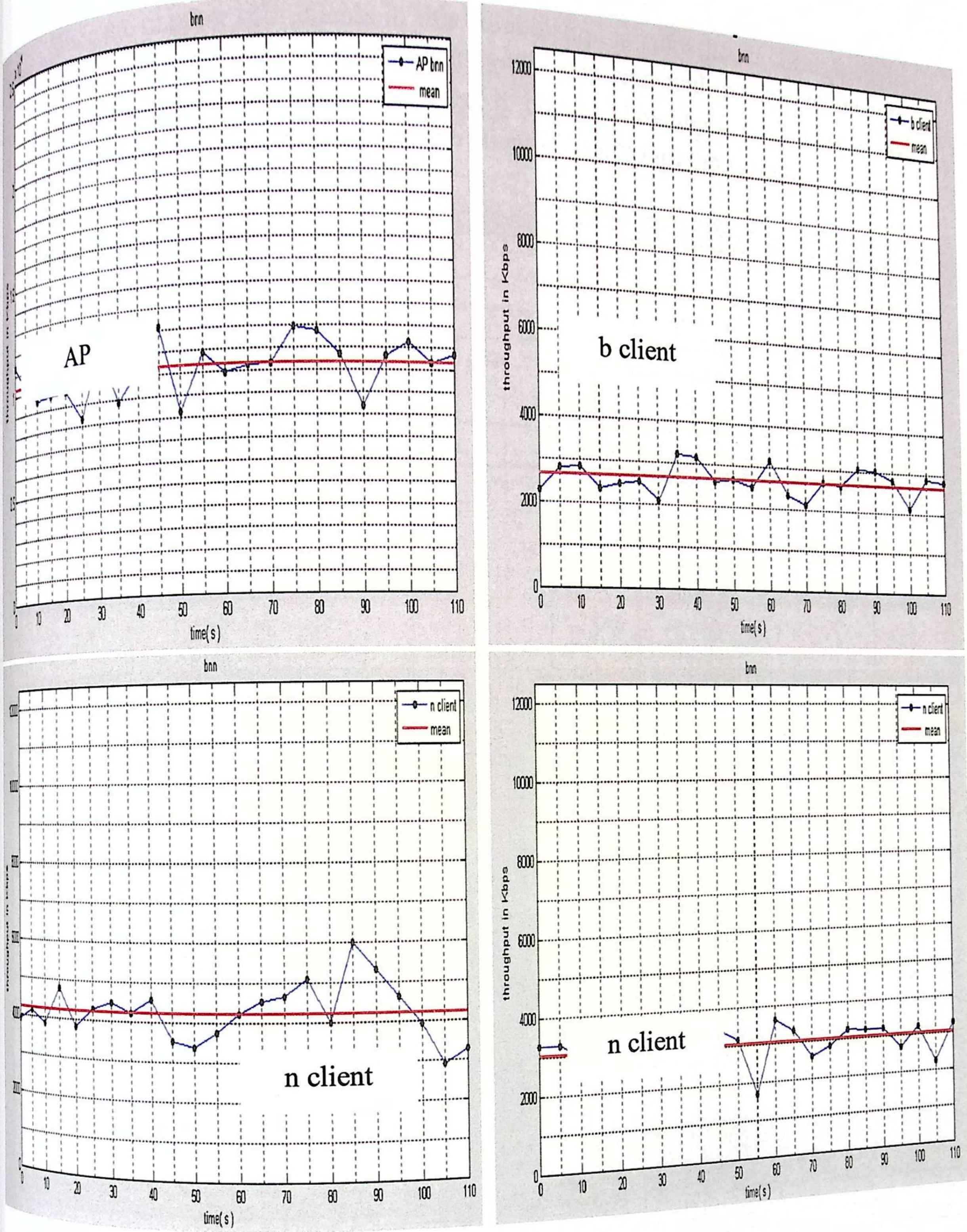


Figure 5.41 : Throughput of bnn combination

Comparing this combination with nnn combination, replacing one n client in nnn by b client reduces throughput of the AP, because b client is operates at low data throughput than n client and also when we add b clients force other n clients in the combinations to operate with 20MHz channel instead of 40MHz in nnn combination.

In bnnn combination, adding another n client increases AP throughput to 10.888Mbps, which is higher than bnn combination throughput value.

Since the number of n clients in this combination is more than b client; b client in bnnn combination reduced data throughput comparing with nnnn combination, each n client has higher data rate than b client. Throughput of n clients are 3.011Mbps, 3.017Mbps, 2.767Mbps and b client is 2.040Mbps throughput.

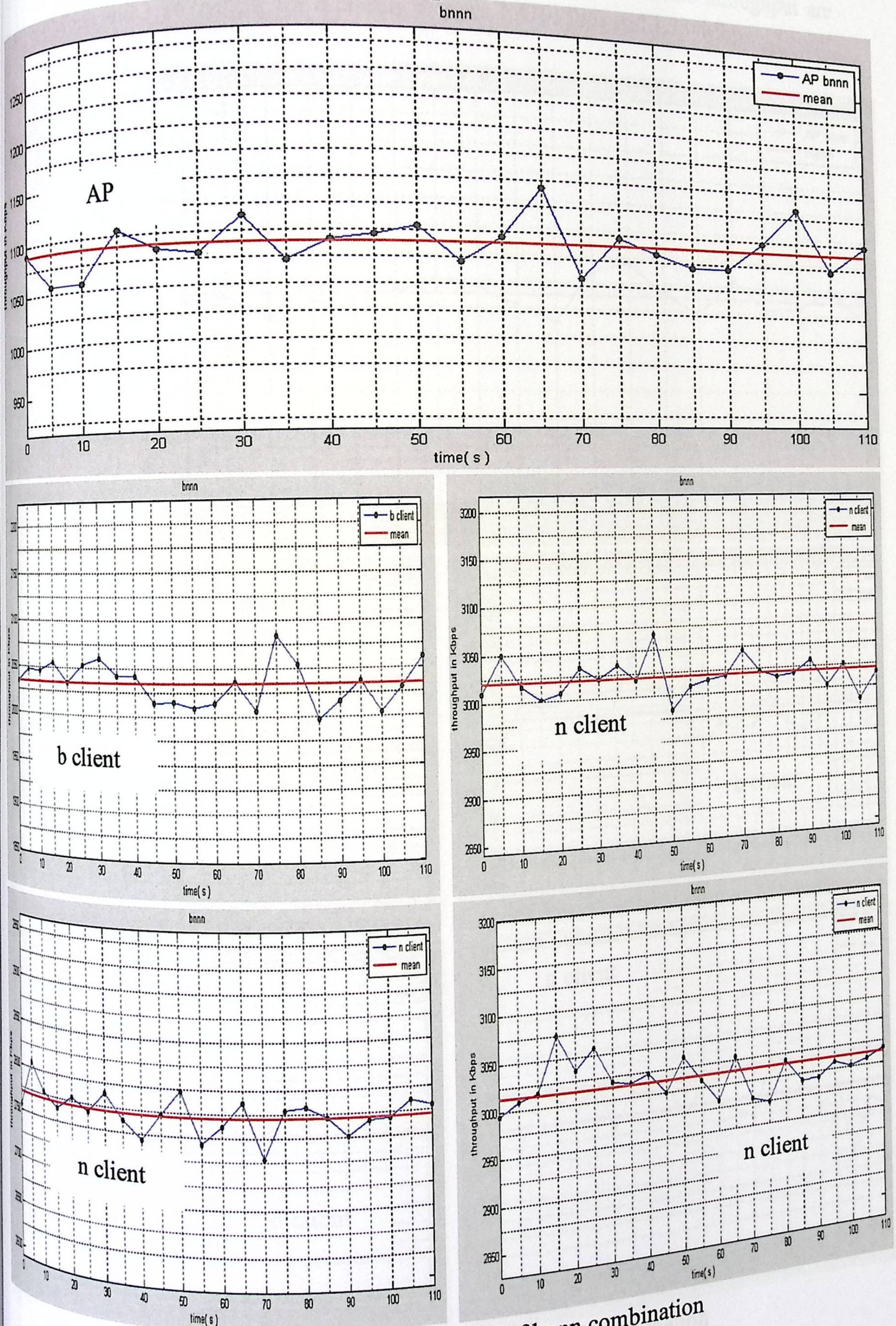


Figure 5.42 : Throughput of bnnn combination

In bbnn the number of b and n clients are equal, in this combination throughput of the AP is 7.840Mbps which is higher than bbbn and lower than bnnn which has more n clients, as shown in figure 5.43

Throughput of n clients are higher than b clients, the n clients throughput are 1.960Mbps and 3.167Mbps, for b clients that are 1.410Mbps and 1.334Mbps.

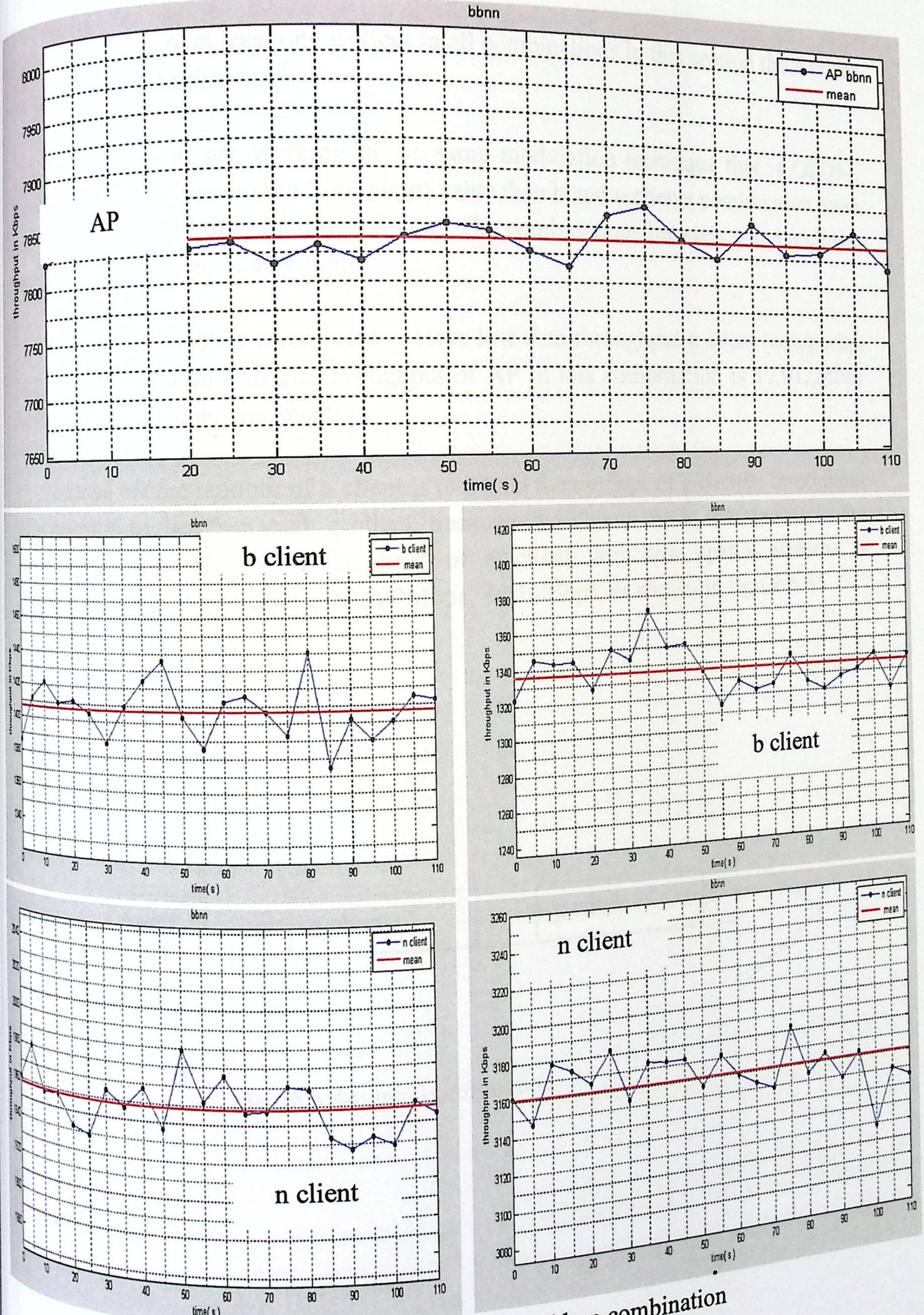


Figure 5.43 : Throughput of bbnn combination

Since n client operates at higher data throughput than g client; so all combination between b and n clients combinations has higher throughput value in b and g combinations.

5.6.4. Combinations between g and n clients.

Since there are at least one g client in all combinations in this section the n client is works in 20MHz channel.

g and n clients are working in the same modulation technique that is OFDM, because that it has higher data throughput value than b and n clients combination there are work in different modulation technique The combinations between g and n clients are ggn, gnn, gggn, ggnn and gnnn.

In ggn combination when there is more low data throughput g client (comparing with n client) is adding to gn, throughput of AP in this combination is 17.912Mbps which is lower than gn combination.

Instead off the number of n client is less than the number of g clients; throughput of n client is higher than each g client, because two clients mode are operate in the same OFDM modulation. Throughput of n client with tow spatial streams is 8.480Mbps and two g clients are 4.520Mbps, 4.650Mbps, as shown in figure 5.45

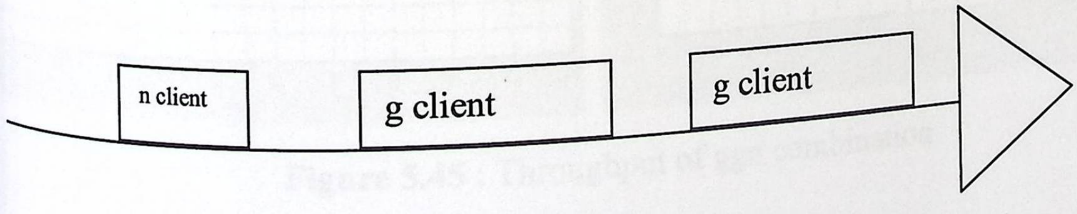


Figure 5.44: ggn combination

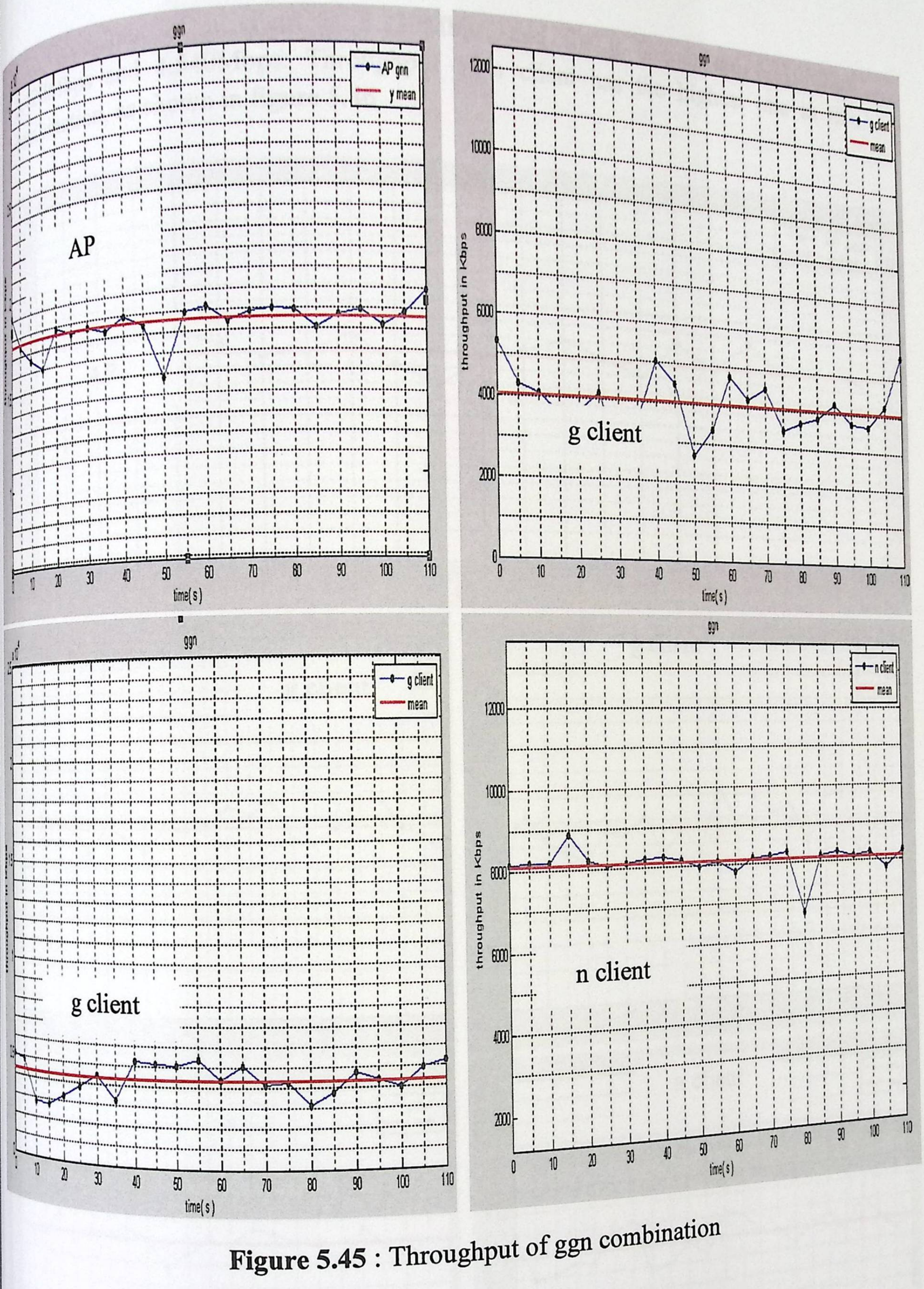


Figure 5.45 : Throughput of ggn combination

Comparing with ggg, n client in ggn increases throughput of the AP; since it is operates with two spatial streams. Throughput of ggn is lower than gn combination since there are more low throughput g clients.

In gggn combination, there are another g client is added; so the AP throughput has lower throughput value than in ggn combination. Throughput of the AP in this case is 17.520Mbps.

Throughput of n client is 5.239Mbps, and for g clients are 4.316Mbps, 3.420Mbps and 4.540Mbps. Throughput of n client has the highest one in this combination, as shown in figure 5.46

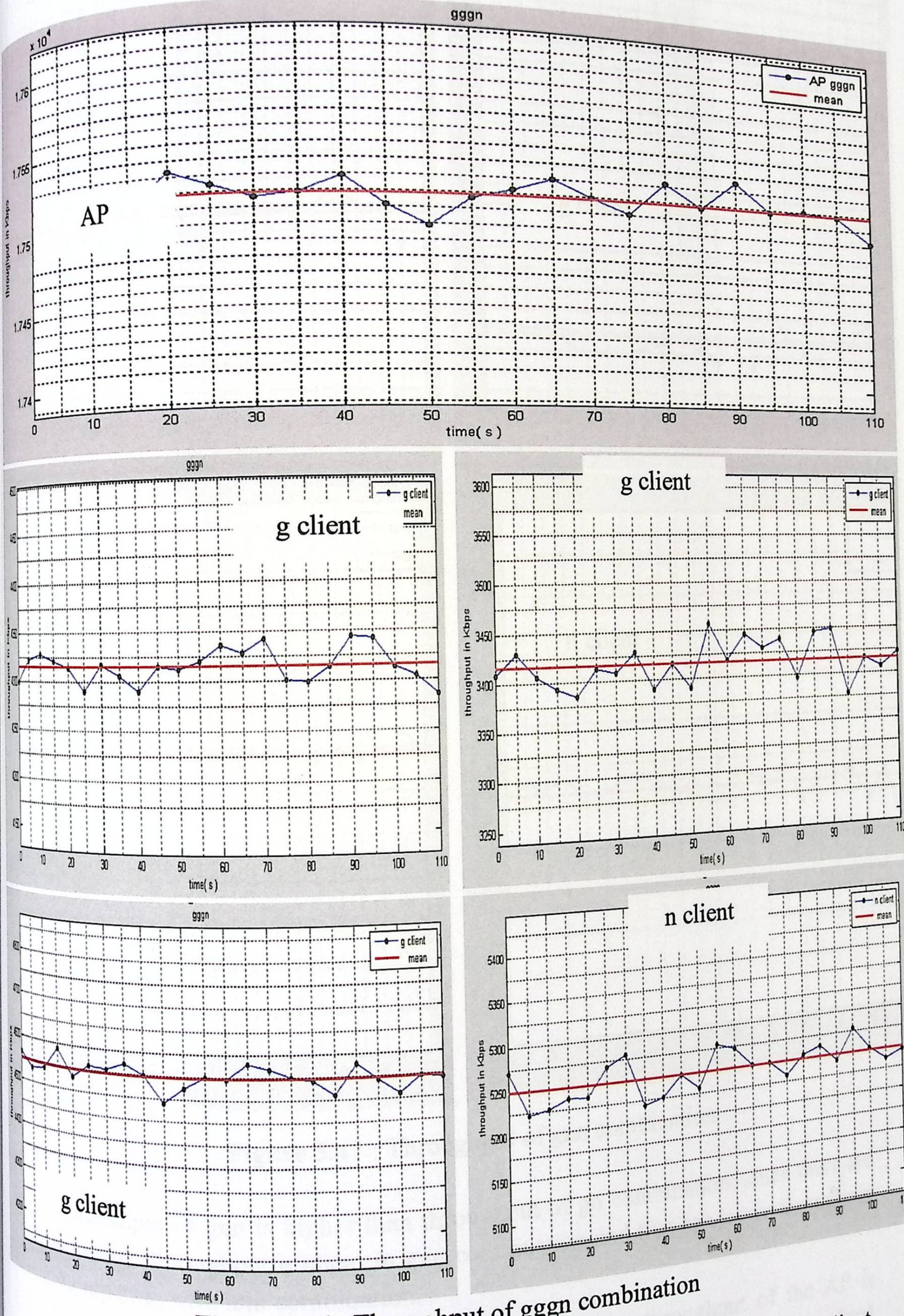


Figure 5.46 : Throughput of gggn combination

In combination gnn throughput of each n clients is higher than g client. Throughputs of n clients are 6.732Mbps and 7.356Mbps and for g client is 3.906Mbps and the AP throughput is 19.200Mbps, as shown in figure 5.47

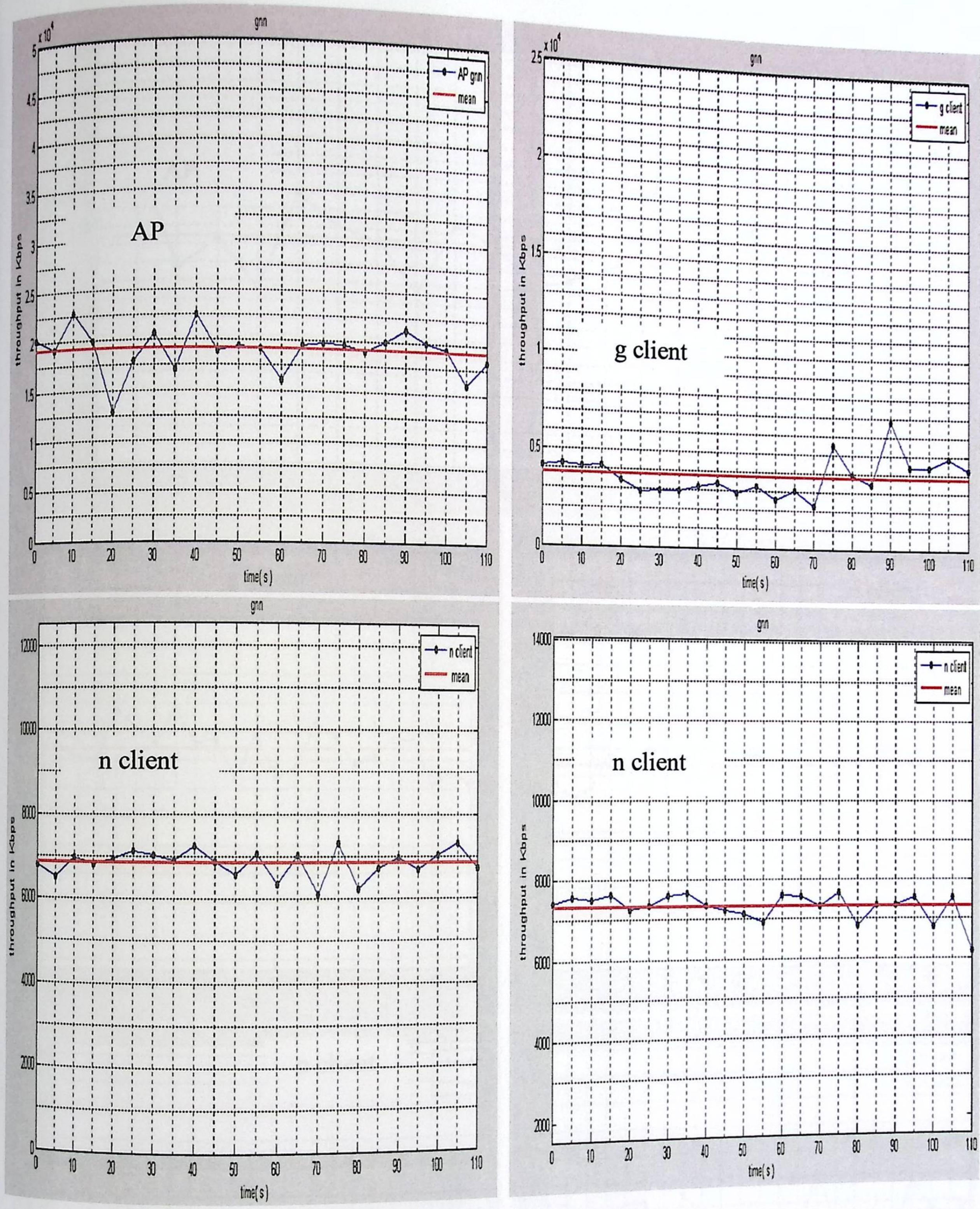


Figure 5.47 : Throughput of gnn combination

Throughput of gnn is higher than throughput of gn combination; since there are one more high throughput n client in gnn combination and that has lower throughput value comparing with nnn combination.

In gnnn combination by adding more one n client, throughput of the AP is increased to 19.360Mbps, adding more n clients increases AP throughput. Throughput of g client is 3.600Mbps and three n clients are 4800Mbps, 4800Mbps and 5.840Mbps, as shown.

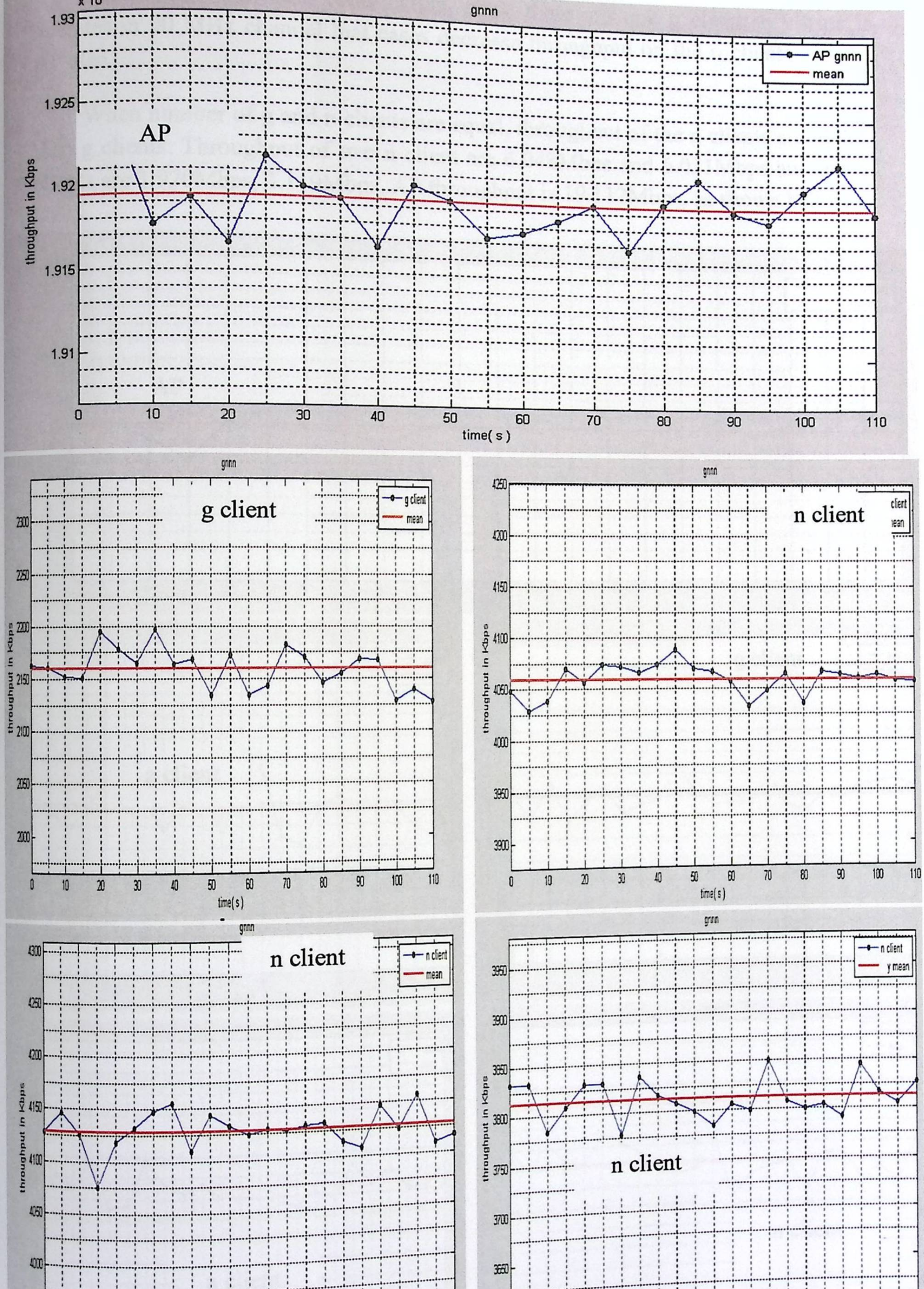


Figure 5.48 : Throughput of gnnn combination

Comparing with nnnn combination, since there are one g client; n clients is operates in 20 MHz channel that cases decrease throughput on the n clients and the AP also.

When number of g and n clients are equal, throughput of the n clients are higher than g clients. Throughput of two n client are 6.048Mbps and 6.031Mbps and two g clients are 3.920Mbps, 3.119Mbps, AP throughput is 19.112Mbps, as shown below.

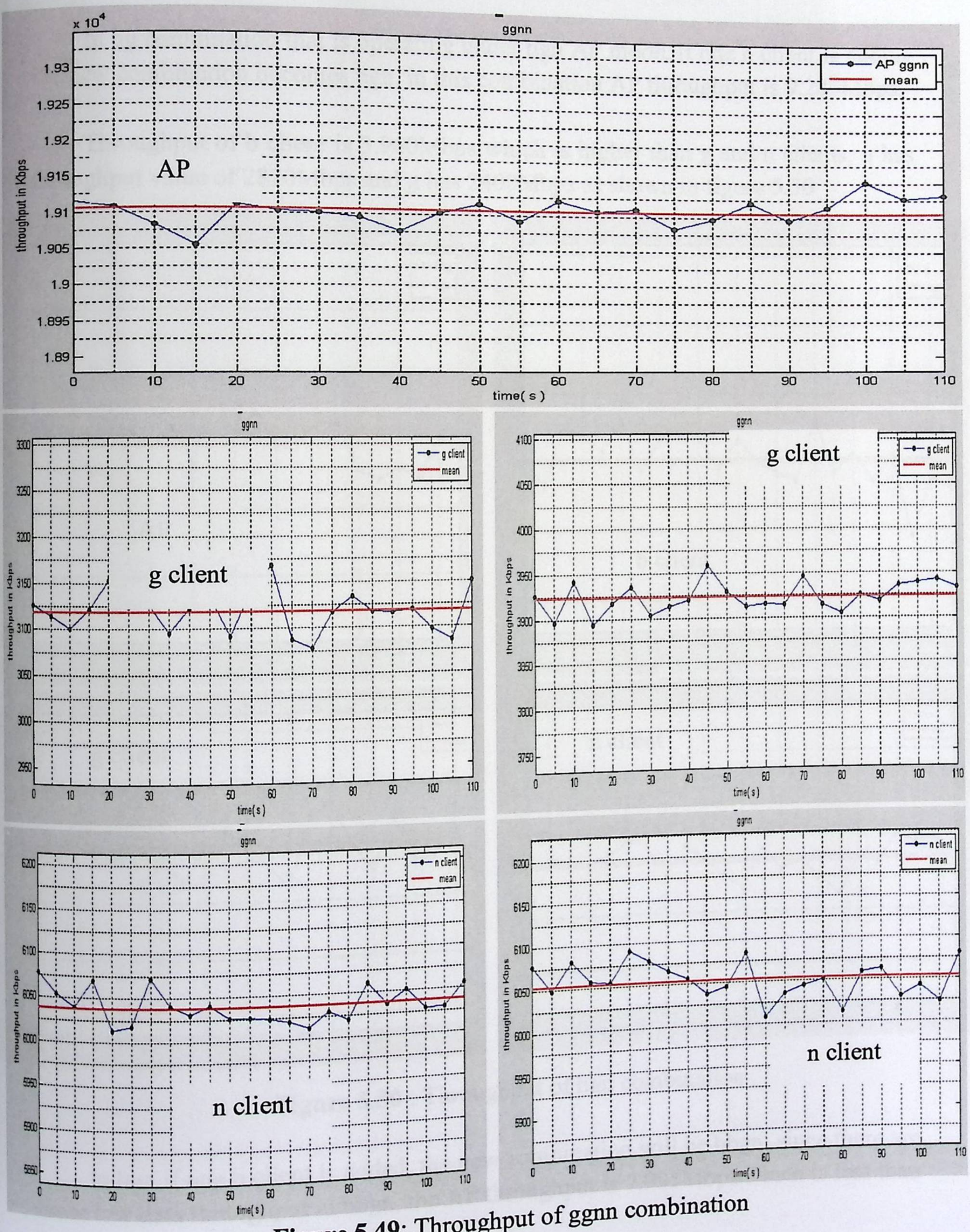


Figure 5.49: Throughput of ggnn combination

5.6.5. Combinations that contain b, g and n technologies.

Combinations in this section when there are three and four clients are bgn, bbgn, bggn and bgnn.

The AP in this section operates at 20MHz channel width, since there is b and g clients in all four combination in this section.

In bg combination that is operating under bgn AP mode, if one n client is adding the new combination becomes bgn, in this combination AP throughput is 9.280Mbps.

Throughput of b client is 3.960Mbps which is higher than g and n clients, n has throughput value of 2820Mbps and g has 2400Mbps as shown in figure 5.50

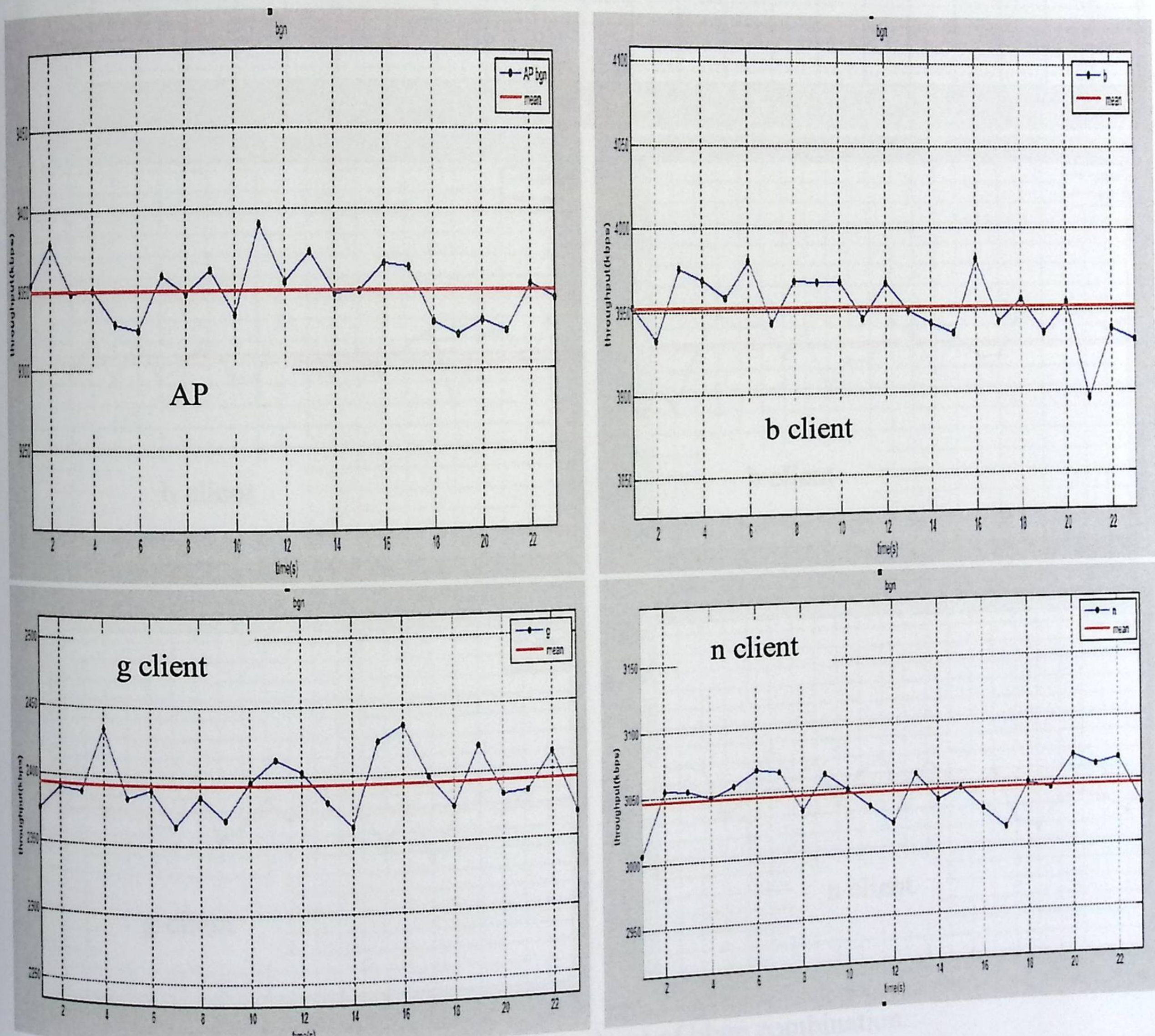


Figure 5.50 : Throughput of bgn combination

In bgn if one b client is added, the new combination will be bbgn, since there are more low data throughput in bbgn, the AP throughput is 7.995Mbps which is less than in bgn combination.

Throughput of n client in this combination is the highest one, it has 2.221Mbps throughput, g client has 2.545Mbps, and two b clients have the lowest throughput value which are 1.484Mbps and a.656Mbps, as shown in figure 5.51 below.

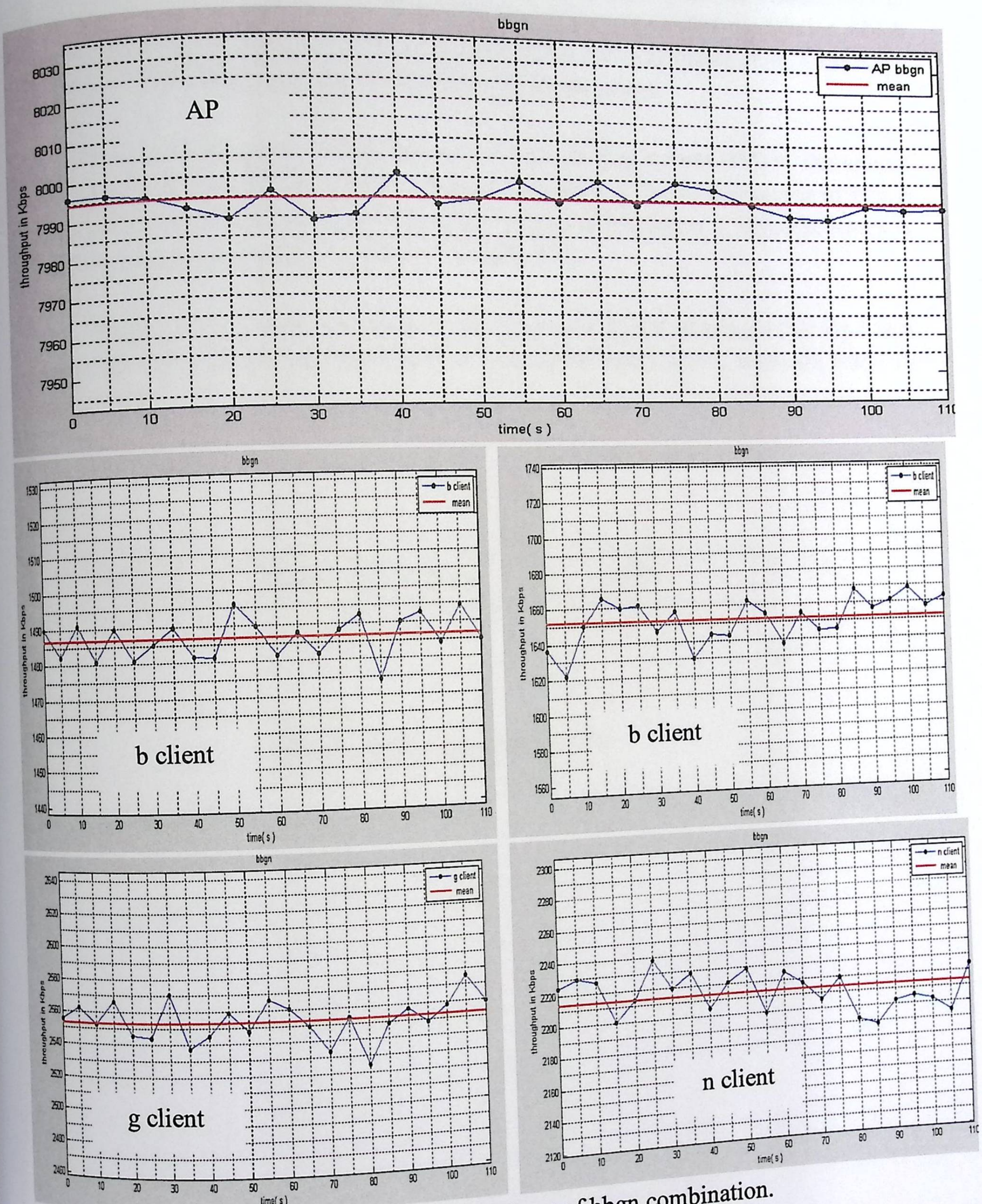


Figure 5.51 : Throughput of bbgn combination.

Although in bbgn combination number of b client are more than g and n clients, b client has lowest throughput than other types of clients, on the other hand when number of b clients is higher than g or n clients such as these combinations bbbg, bbbn, bbg, bbn in this combination each b client has higher throughput value than g and n clients type, since in combination that contain b, g and n, the g and n are operate in the same modulation; the AP give g and n clients more data than b clients.

In bbgn combination, if one b client is replace by g client, the combination in this case is bggn, since there are three clients that are use OFDM modulation which are two g clients and one n client; throughput of the AP is increased from 7.995Mbps in bbgn to 9.910Mbps in bggn combination, as shown below.

Most AP throughput is distributes to the clients that are use OFDM, throughput of n clients is 2.825Mbps which is higher than each g client, throughput of two g clients are 2.540Mbps and 2.687Mbps, throughput of b client is 1.733mbps which is the lowest throughput value, as shown in figure 5.53

There are three clients operate in the same modulation technique that are one n client and two g clients, that have shorter time period than b client, as shown below in figure 5.52

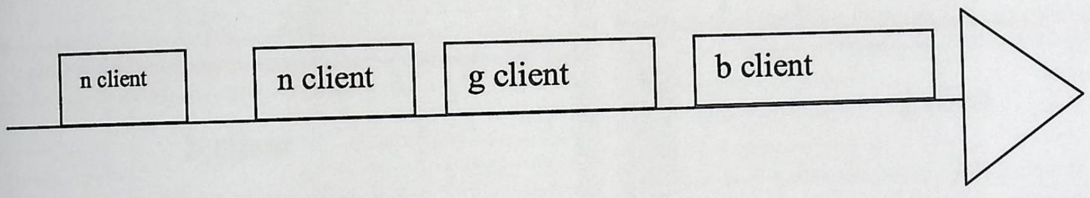


Figure 5.52: bggn combination

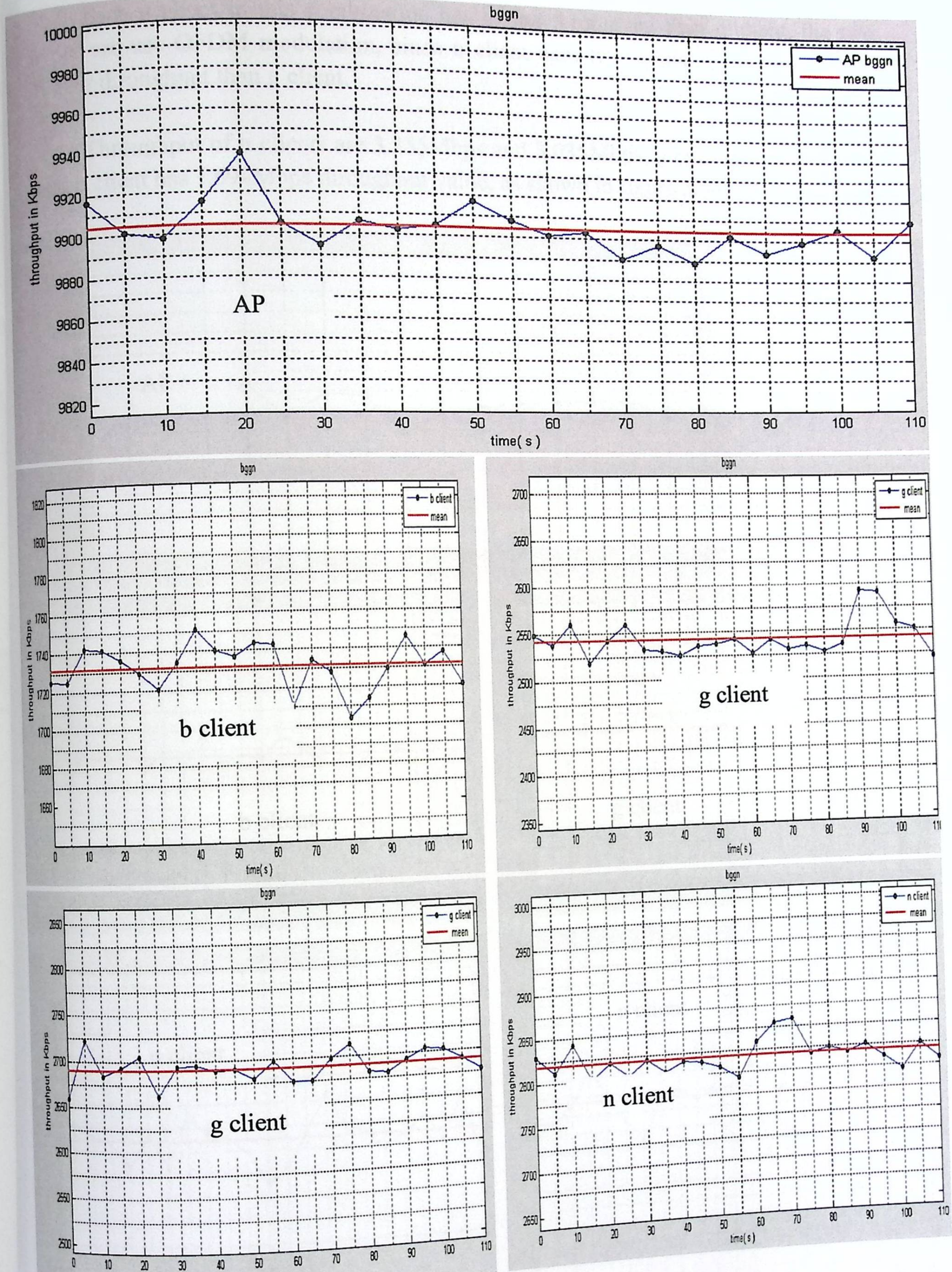


Figure 5.53 : Throughput of bggn combination

In bgnn, there are three clients use OFDM as in bggn combination, and since in bgnn there are more n clients than in bggn combination; bgnn has more AP throughput. The AP throughput in this combination is 10.648Mbps.

Each n client in this combination has higher throughput than g client, the two types are use OFDM modulation, since n client uses two spatial streams; so it has higher throughput than g client.

Throughput of n clients are 3.385Mbps and 3.035Mbps, g client has 2.475Mbps and b client has 1.694Mbps throughput value, as shown in figure 5.54.

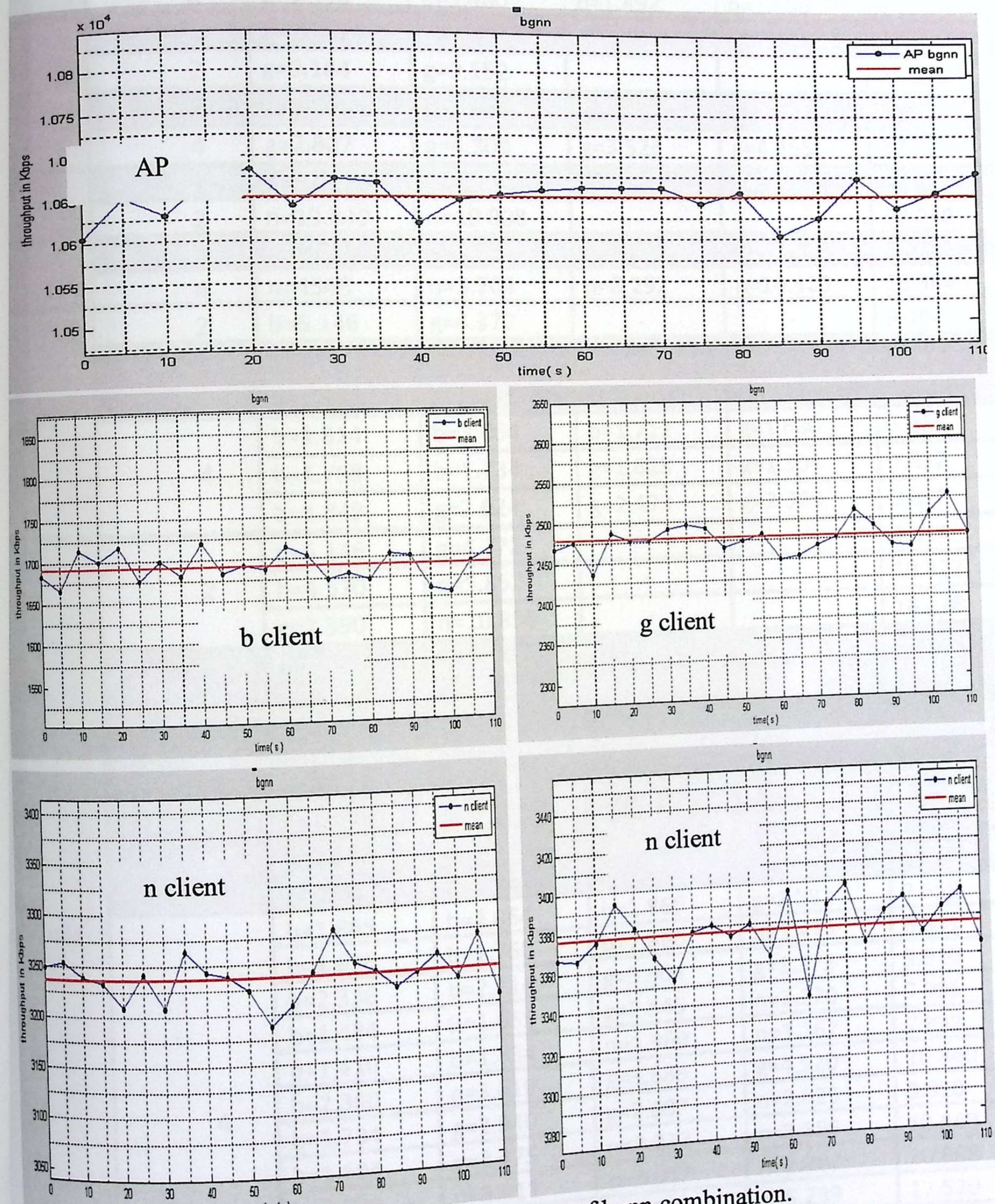


Figure 5.54 : Throughput of bgnn combination.

The table 5.2 below lists all clients combinations in this project, as shown

Each n client in this combination has higher throughput than g client, the two types are use OFDM modulation, since n client uses two spatial streams; so it has higher throughput than g client.

Throughput of n clients are 3.385Mbps and 3.035Mbps, g client has 2.475Mbps and b client has 1.694Mbps throughput value, as shown in figure 5.54.

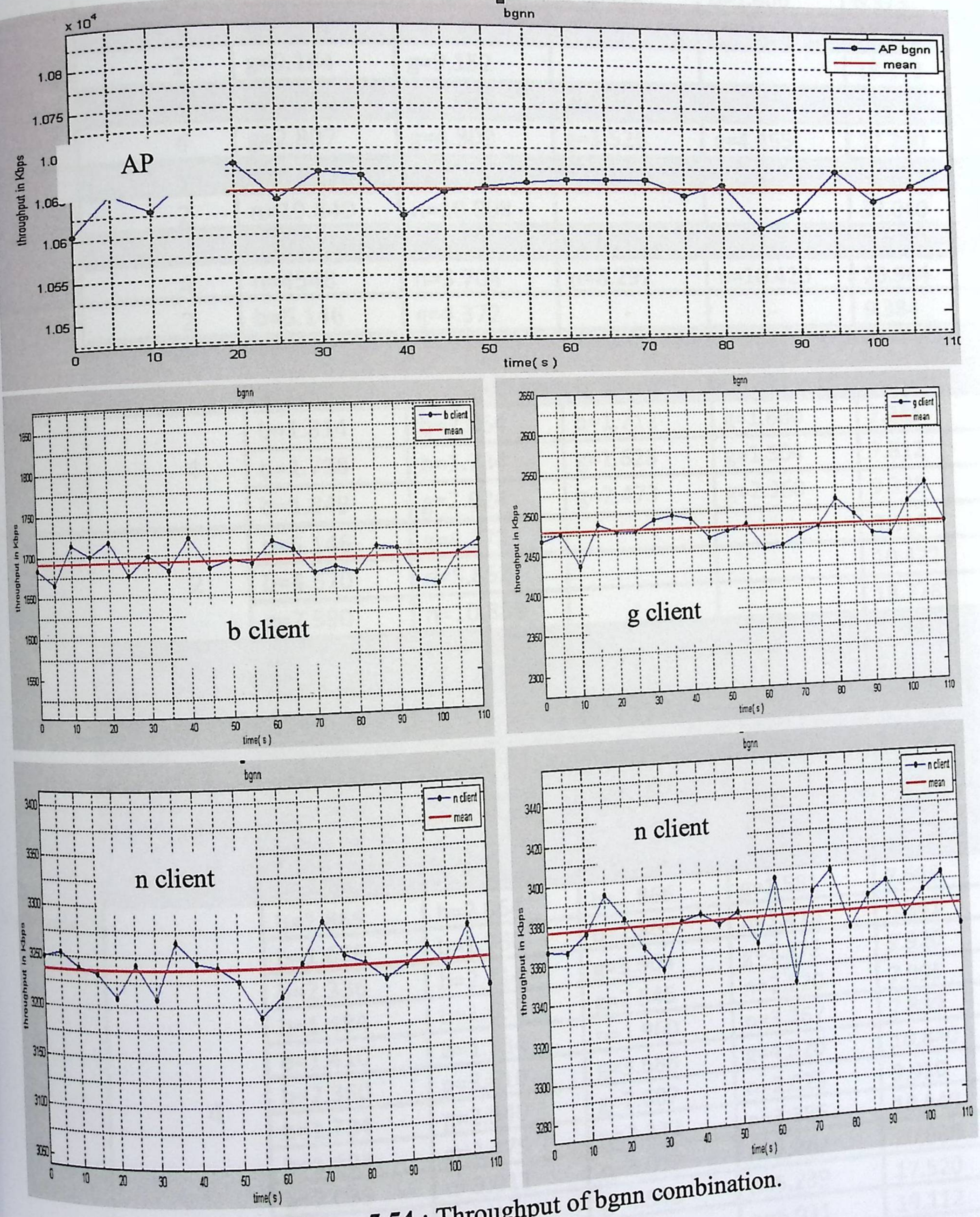


Figure 5.54 : Throughput of bgnn combination.

The table 5.2 below lists all clients combinations in this project, as shown

Table 5.2 : All clients combinations results in Mbps

AP mode	Number of clients	Client one mode	Client two mode	Client three mode	Client four mode	AP Throughput
B only	1	b=6.863	-	-	-	6.880
	2	b=3.404	b=3.412	-	-	6.854
	3	b=2.233	b=2.247	b=2.212	-	6.695
	4	b=1.390	b=1.480	b=1.492	b=1.606	6.373
g only	1	g=18.12	-	-	-	18.360
	2	g=9.184	g=9.152	-	-	18.128
	3	g=8.968	g=4.664	g=4.442	-	18.080
	4	g=2.807	g=4.809	g=3.526	g=4.455	17.200
n only	1	n=33.240	-	-	-	33.632
	2	n=19.840	n=10.008	-	-	32.040
	3	n=9.875	n=9.835	n=9.800	-	29.752
	4	n=4548	n=3.704	n=8.292	n=10.420	26.964
b\g mix	2	b=5.146	g=4.372	-	-	9.384
	3	b=2.945	b=2.720	g=1.538	-	6.248
		b=2.593	g=7.244	g=3.442	-	11.400
	4	b=1.814	b=2.064	b=1.712	g=1.680	7.285
		b=1.788	b=1.734	g=1.628	g=1.504	7.812
		b=1.849	g=2.624	g=2.473	g=2.360	9.328
b\g\n mix	2	b=5.146	g=4.372	-	-	9.414
		b=4.570	n=5.852	-	-	10.422
		g=7.390	n=10.888	-	-	18.278
	3	b=3.108	b=3.140	g=1.538	-	7.786
		b=2.729	b=3.046	n=1.875	-	7.812
		b=3.370	g=3.902	g=3.816	-	11.080
		b=3.960	g=2.395	n=3.046	-	9.352
		b=2.602	n=3.780	n=4.180	-	10.562
		g=4.520	g=4.650	n=8.480	-	17.912
		g=3.906	n=6.732	n=7.356	-	19.200
	4	b=1.865	b=2.064	b=1.866	g=1.581	7.658
		b=1.626	b=1.760	b=1.866	n=1.475	6.841
		b=2.336	b=2.114	g=3.904	g=1.372	9.920
		b=1.484	b=1.655	g=2.545	n=2.220	7.995
		b=1.410	b=1.334	n=1.960	n=3.167	7.839
		b=2.360	g=3.610	g=3.688	g=4.520	10.840
		b=1.734	g=2.540	g=2.687	n=2.825	9.910
		b=1.694	g=2.475	n=3.232	n=3.385	10.649
		b=2.039	n=3.011	n=3.017	n=2.767	10.888
		g=4.316	g=3.420	g=4.540	n=5.239	17.520
		g=3.920	g=3.119	n=6.048	n=6.031	19.112
		g=2.163	n=3.804	n=4.128	n=4.058	19.200

Chapter 6

Conclusions and future works

6.1. Conclusions.

6.2. Future works.

Chapter six
Conclusions and future works

This chapter contains many conclusions during in our measurement of this oject, and also includes some significant points about the way of continuing more ıd more in this project.

.2. Conclusions.

During in this project there are many results and measurements are obtained, in his section we list some of the most interesting results of them that are:

- In b only, g only and n only AP modes, if the number of clients increased, throughput of the AP will be decreased.
- In combinations that contain equal number of b and g clients; throughput of b client is higher than g client.
- If number of b clients are equal of n clients, throughput of each n clients are higher than each b clients.
- Combinations that contain g and n clients, throughput of n clients are higher than g clients in all combination between them.

6.2. Future works.

There are a lot of ideas that can be utilized to enhance project measurement and results. Here are some of them:

- Measuring the same client's combinations in download scenario and comparing results that obtained to the results in upload scenario.
- Use high performance clients and server especially in combinations that contain n clients.
- Studying the effects between 802.11a and 802.11n technologies in 5GHz band.

References:

[1] "Going Wi-Fi: A Practical Guide to Planning and Building an 802.11 Network" by Janice Reynolds

[2] "what is 802.11 ? – A Word Definition Form the Webopedia Computer Dictionary"

[3] "wireless_sample"
INTRODUCTION TO WIRELESS
NETWORKS

[4] "WHITE PAPER >802.11a"

[5] "IEEE 802.11 a/b/g/n Wi-Fi Standards and Facts"

[6] "ANALYSIS AND MEASUREMNET OF THE THROUGHPUT OF THE WLAN 802.11 OF K M SHAW HALL OF RESIDENCE NIT ROURKELA USING QUALNET"
A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Bachelor of Technology In Electronics and Instrumentaion Engineering
By
DIVYA MEHTA
MEENAKSHI KUMARI

[7] "The 802.11n MIMO-OFDM Standard for Wireless LAN and Beyond"
RICHARD VAN NEE, V.K. JONES, GEERT AWATER, ALLERT VAN ZELST, JAMES GARDNER and GREG STEELE

[8] "Wi-Fi CERTIFIED™ n:
Longer-Range, Faster-Throughput,
Multimedia-Grade Wi-Fi® Networks"

[9] "802.11n: Next-Generation Wireless LAN Technology".

[10] "INTERFERENCE OF 802.11B WLAN AND BLUETOOTH: ANALYSIS AND PERFORMANCE EVALUATION"
International journal of Computer Networks & Communications (IJCNC)
, Vol.2, No.3, May 2010

[11] "IEEE 802.11b Ad Hoc Networks: Performance Measurements"
Giuseppe Anastasi
Dept. of Information Engineering, University of Pisa
Via Diotisalvi 2 - 56122 Pisa, Italy
Eleonora Borgia, Marco Conti, Enrico Gregori
Istituto IIT, National Research Council (CNR)
Via G. Moruzzi - 1 56124 Pisa, Italy

[12] "Understanding Congestion in IEEE 802.11b Wireless Networks"
Amit P. Jardosh Krishna N. Ramachandran Kevin C. Almeroth Elizabeth M. Belding-Royer
Department of Computer Science
University of California, Santa Barbara

[13] "Compatibility between IEEE 802.11b and IEEE 802.11g networks:
Impact on throughput"
Izaskun Pellejero, Fernando Andreu, Asier Barbero, Amaia Lesta
R&D and Technology Department, Strategy and Business Development
EUSKALTEL, S.A.

[14] "TCP/IP Tutorial and Technical Overview"
Lydia Parziale
David T. Britt
Chuck Davis
Jason Forrester
Wei Liu
Carolyn Matthews
Nicolas Rosselot

[15] http://searchnetworking.techtarget.com/definition/spread-spectrum

[16] "Frequency Hopping Spread Spectrum (FHSS) vs. Direct Sequence Spread Spectrum (DSSS) in Broadband Wireless Access (BWA) and Wireless LAN (WLAN)"
by Sorin M. SCHWARTZ

[17] G. Guilder, "Telecosm: How Infinite Bandwidth Will Revolutionize Our World," The Free Press, NY, 2000

[18] "Multi-Carrier and Spread Spectrum Systems"
K. Fazel Marconi Communications GmbH Germany and S. Kaiser German Aerospace Center (DLR)
Germany

[19] "Performance Comparison Of Frequency Hopping And Direct Sequence Spread Spectrum Systems In
The 2.4 GHz Range"
Zoran Spasojevic, John Burns
Aegis Systems Ltd.

[20] "The principles of OFDM"
Multicarrier modulation techniques are rapidly moving from the textbook to the real world of modern communication systems
By Louis Litwin

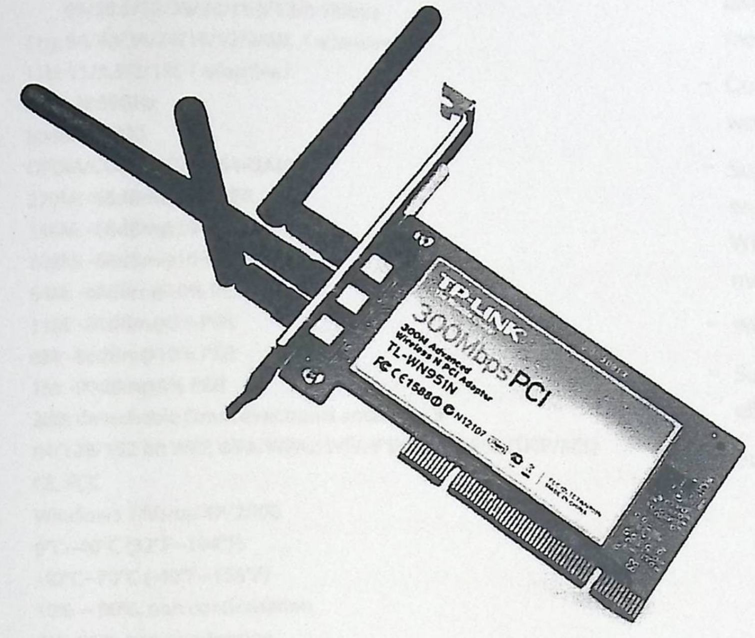
Abbreviation	
WiFi	Wireless Fidelity
LAN	local Area Network
WLAN	Wireless local Area Network
IEEE	Institute Of Electrical And Electronics Engineers
AP	Access Point
PCI	Peripheral Component Interconnect
NIC	Network Interface Controller
Mbps	Megabits Per Second
Gbps	Gigabits Per Second
WIMAX	Worldwide Interoperability For Microwave Access
GSM	Global System For Mobile Communications
SSID	Service Set Identifier
MS	Mobile Station
PDA	Personal Digital Assistant
ISO	International Organization For Standardization
GHz	Giga Hertz
OFDM	Orthogonal Frequency Division Multiplexing
QoS	Quality Of Service
MIMO	Multiple-Input And Multiple-Output
PHY	Physical layer
BSS	Basic service set
VoWiFi	Voice Over *Wireless Fidelity*
VoIP	Voice over Internet Protocol
UNII	Unlicensed Band
FCC	Federal Communications Commission
QAM	Quadrature Amplitude Modulation
ISM	International Solidarity Movement
CSMA\CA	Carrier Sense Multiple Access With Collision Avoidance
MAC	Media Access Control Address
IR	Infrared
CCK	Content Construction Kit
DQPSK	Differential Quadrature Phase Shift Keying
BPSK	Binary Phase Shift Keying
A-MSDU	Aggregated Mac Service Data Unit
MPDU	MAC Protocol Data Unit
ACK	Acknowledgement
RF	Radio Frequency
CTS	Clear To Sent
RTS	Ready To Sent
DCF	Distributed Coordination Function
CSMA\CD	Carrier Sense Multiple Access With Collision Detection
SIFS	Short Inter Frame Space
DIFS	Distributed Inter-Frame Spacing
CRC	Cyclic Redundancy Check
BO	Back Off Interval

CSMA\CA	Carrier Sense Multiple Access With Collision Avoidance
CW	Contention Windows
PLCP-p	Physical Layer Convergence Protocol preamble
PLCP-h	Physical Layer Convergence Protocol header
IFS	Inter-Frame Spacing
TCP\IP	Transmission Control Protocol Internet Protocol
SNA	Systems Network Architecture
OSI	Open System Interconnection
IP	Internet Protocol
UDP	User Datagram Protocol
ICMP	Internet Control Message Protocol
TCP	Transmission Control Protocol
ARP	Address Resolution Protocol
RARP	Reverse Address Resolution Protocol
FTP	File Transfer Protocol
IGMP	Internet Group Management Protocol
ATM	Asynchronous Transfer Mode
FDDI	Fiber Distributed Data Interface
ISI	Inter Symbol Interference
FDM	Frequency Division Multiplexing
NTSC	National Television Systems Committee
FM	Frequency Modulation
DFT	Discrete Fourier Transform
IDFT	Inverse Discrete Fourier Transform
FFT	Fast Fourier Transform
IFFT	Inverse Fast Fourier Transform
QPSK	Quadrature Phase-Shift Keying
ISI	Inter Symbol Interference
PAPR	Peak-to-Average Power Ratio
PN	Pseudo Noise Code
CDMA	Code Division Multiple Access
PSK	Phase Shift Keying
FHSS	Frequency Hopping Spread Spectrum
DSSS	Direct Sequence Spread Spectrum
BWA	Broadband Wireless Access
SS	Spread Spectrum
SNR	Signal To Noise Ratio

Appendix

TP-LINK®

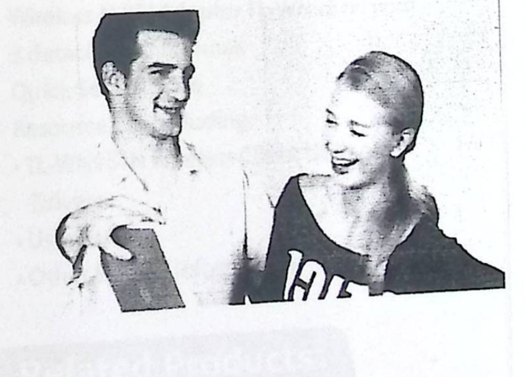
Wireless N PCI Adapter
TL-WN951N



300Mbps wireless transmission rate with 3 antennas, brings smooth wireless N experience

MIMO, CCA™ technology, brings competitive performance in 11n routers

QSS, Quick Secure Setup, complies with WPS for effortless wireless security setup



Description:

The TL-WN951N Wireless N PCI Adapter complies with IEEE 802.11n, IEEE 802.11g, and IEEE 802.11b standards. Wireless transmission rates can reach up to 300Mbps. The PCI Card with three external detachable Omni-directional antennas works well with other 11g and 11n protocol wireless products and adopts MIMO as well as SST™ technology which can bring a faster, wider, and more stable wireless experience. This product can also simultaneously operate bandwidth intensive applications using a lot of bandwidth which are sensitive to interruption. When using multiple bandwidth intensive applications, the most sensitive of these applications can be given priority over the others to be allocated more bandwidth in order to assure quality.

www.tp-link.com

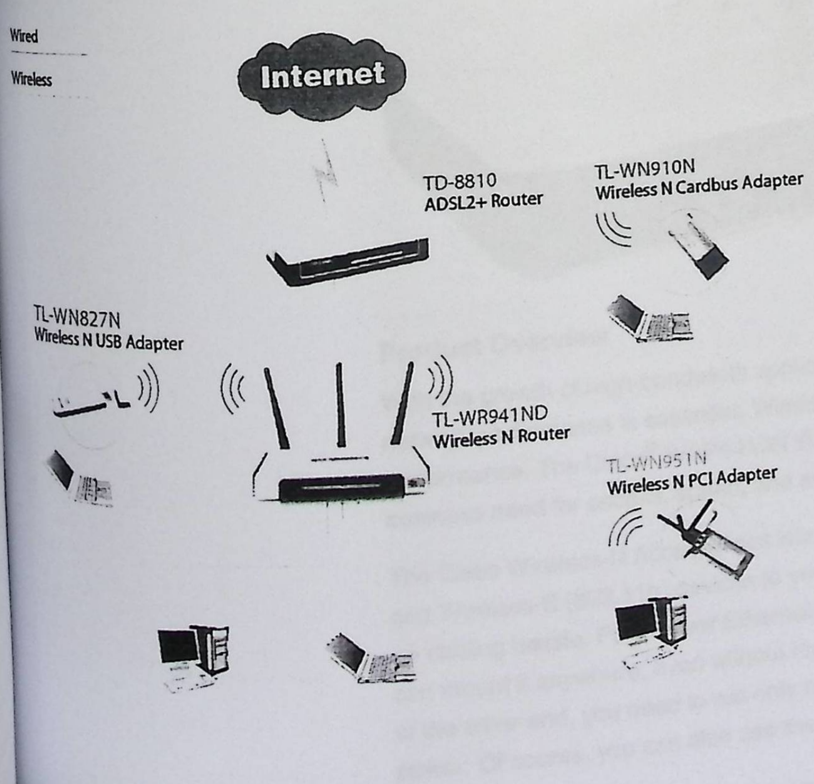
Specifications:

Standards	IEEE 802.11n, IEEE 802.11g, IEEE 802.11b, CSMA/CA with ACK
Interface	32-bit PCI
Wireless Signal Rates With Automatic Fallback	11n: 270/243/216/162/108/81/54/27Mbps 135/121.5/108/81/54/40.5/27/13.5Mbps 130/117/104/78/52/39/26/13Mbps 65/58.5/52/39/26/19.5/13/6.5Mbps 11g: 54/48/36/24/18/12/9/6M (adaptive) 11b: 11/5.5/2/1M (adaptive)
Frequency Range	2.4-2.4835GHz
Wireless Transmit Power	20dBm(MAX)
Modulation Type	OFDM/CCK/16-QAM/64-QAM
Receiver Sensitivity	270M: -68dBm@10% PER 130M: -68dBm@10% PER 108M: -68dBm@10% PER 54M: -68dBm@10% PER 11M: -85dBm@8% PER 6M: -88dBm@10% PER 1M: -90dBm@8% PER
Antenna	2dBi detachable Omni directional antenna x 3
Security	64/128/152 bit WEP, WPA/WPA2, WPA-PSK/WPA2-PSK (TKIP/AES)
Certifications	CE, FCC
Support Operating System	Windows 7/Vsita/XP/2000
Operating temperature	0°C~40°C (32°F~104°F)
Storage temperature	-40°C~70°C (-40°F~158°F)
Relative humidity	10% ~ 90%, non condensation
Storage Humidity	5%~95% non-condensing
Dimensions	133 × 121 × 22 (mm) 5.2 × 4.8 × 0.9 (in.)

Features:

- Provides 32-bit PCI connector
- Provides Infrastructure and Ad-Hoc modes
- 300M wireless transmission rate, adopts MIMO, SST™, CCA™ technology, allows for faster speed, further wireless coverage, more stable performance
- Quick Secure Setup, complies with WPS for worry free wireless security
- Supports 64/128/152 strength WEP encryptions, as well as WPA/WPA2 and WPA-PSK/WPA2-PSK encryptions and mechanisms
- Web-site Configuration and monitoring
- Supports Roaming technology, guarantees efficient wireless connections.
- Supports Windows 7/Vsita/XP/2000

Diagram:



Package:

- Wireless N PCI Adapter TL-WN951N with 3 detachable antennas
- Quick Setup Guide
- Resource CD, including:
  - TL-WN951N Wireless Client Utility and Drivers
  - User Guide
  - Other Helpful Information

Related Products:

- Wireless N Router TL-WR941ND
- Wireless N Cardbus Adapter TL-WN910N
- 54M Wireless ADSL2+ Router TD-W8920G

www.tp-link.com

Cisco WAP4410N Wireless-N Access Point: PoE/Advanced Security
Cisco Small Business Access Points

Advanced, High-Performance Wireless Access for the Small Business

Highlights

- Supports high-bandwidth applications with the 802.11n standard; backward compatible with 802.11b and g devices
- Connects to Power over Ethernet devices, simplifying installation and eliminating the need for and cost of installing external power supplies
- Protects business information with enhanced security, including rogue access point detection, advanced encryption, and select access filters
- Simplifies installation and configuration with easy-to-use web interface

Figure 1. Cisco WAP4410N Wireless-N Access Point: PoE/Advanced Security

Product Overview

With the growth of high-bandwidth applications, such as storage and video, in the workplace, network performance is essential. Wireless technology is no longer lagging behind wired performance. The Cisco® WAP4410N Wireless-N Access Point (Figure 1) answers the growing business need for access, speed, and security.

The Cisco Wireless-N Access Point lets you connect Wireless-N (802.11n), Wireless-G (802.11g), and Wireless-B (802.11b) devices to your wired network, so you can add PCs to the network with no cabling hassle. Power over Ethernet (PoE) support makes the access point easy to install - you can mount it anywhere, even without ready access to a power plug. With appropriate PoE support at the other end, you need to run only one cable to the access point to deliver both data and power. Of course, you can also use the included AC adapter if power is available nearby.

Cisco WAP4410N Wireless-N Access Point: PoE/Advanced Security
Cisco Small Business Access Points

Advanced, High-Performance Wireless Access for the Small Business

Highlights

- Supports high-bandwidth applications with the 802.11n standard; backward compatible with 802.11b and g devices
- Connects to Power over Ethernet devices, simplifying installation and eliminating the need for and cost of installing external power supplies
- Protects business information with enhanced security, including rogue access point detection, advanced encryption, and select access filters
- Simplifies installation and configuration with easy-to-use web interface

Figure 1. Cisco WAP4410N Wireless-N Access Point: PoE/Advanced Security

Product Overview

With the growth of high-bandwidth applications, such as storage and video, in the workplace, network performance is essential. Wireless technology is no longer lagging behind wired performance. The Cisco® WAP4410N Wireless-N Access Point (Figure 1) answers the growing business need for access, speed, and security.

The Cisco Wireless-N Access Point lets you connect Wireless-N (802.11n), Wireless-G (802.11g), and Wireless-B (802.11b) devices to your wired network, so you can add PCs to the network with no cabling hassle. Power over Ethernet (PoE) support makes the access point easy to install - you can mount it anywhere, even without ready access to a power plug. With appropriate PoE support at the other end, you need to run only one cable to the access point to deliver both data and power. Of course, you can also use the included AC adapter if power is available nearby.

Moreover, the integrated quality of service (QoS) features provide consistent voice and video quality on both the wired and wireless networks, enabling the deployment of business-quality voice over IP (VoIP) and video applications.

To protect your data and privacy, the Cisco Wireless-N Access Point supports the industrial-strength wireless security of Wi-Fi Protected Access (WPA), encoding all your wireless transmissions with powerful encryption. The MAC address filter lets you decide exactly who has access to your wireless network, and advanced logging keeps you apprised of access attempts. The rogue access point detection capability notifies the administrator when an unauthorized access point is detected in the airspace. The WPS (Wi-Fi Protected Setup) feature facilitates simple and secure deployment of security in the wireless network. Configuration is a snap with the web browser-based configuration utility.

The Cisco WAP4410N Wireless-N Access Point is the best way to add wireless access to your existing business network.

Features

- Draft 802.11n wireless networking delivers greater throughput and extended range, maximizing the number of wireless clients per access point for your small business
- Easy installation and configuration via a web interface
- Adjustable and removable dipole antennas with multiple-input, multiple-output (MIMO) 3x3 diversity
- Gigabit Ethernet LAN interface
- Supports PoE and external DC power
- HTTP Redirect facilitates the display of a splash page on initial user access
- IPv6 host support for managing the access point over IPv6
- Multiple basic service set identifier (BSSID) support allows the creation of multiple secure wireless workgroups for users and guests
- Service set identifier (SSID) to VLAN mapping maintains application security and quality across wireless and wired
- WPS allows for simple and secure deployment of the wireless network
- Logging via syslog, email, or local log
- Wi-Fi Multimedia (WMM) wireless QoS support

Specifications

Table 1 lists the specifications, package contents, and minimum requirements for the Cisco WAP4410N Wireless-N Access Point.

Table 1. Specifications for the Cisco WAP4410N Wireless-N Access Point: PoE/Advanced Security

Specifications	
Standards	Draft IEEE 802.11n, IEEE 802.11g, IEEE 802.11b, IEEE 802.3, IEEE 802.3u, IEEE 802.3af (Power over Ethernet), 802.1x (security authentication), 802.11i security WPA/WPA2, WMM
Ports	Ethernet, Power
Buttons	Reset
Cabling type	Unshielded twisted pair (UTP) Category 5e or higher
LEDs	Power, Ethernet, Wireless, PoE

Moreover, the integrated quality of service (QoS) features provide consistent voice and video quality on both the wired and wireless networks, enabling the deployment of business-quality voice over IP (VoIP) and video applications.

To protect your data and privacy, the Cisco Wireless-N Access Point supports the industrial-strength wireless security of Wi-Fi Protected Access (WPA), encoding all your wireless transmissions with powerful encryption. The MAC address filter lets you decide exactly who has access to your wireless network, and advanced logging keeps you apprised of access attempts. The rogue access point detection capability notifies the administrator when an unauthorized access point is detected in the airspace. The WPS (Wi-Fi Protected Setup) feature facilitates simple and secure deployment of security in the wireless network. Configuration is a snap with the web browser-based configuration utility.

The Cisco WAP4410N Wireless-N Access Point is the best way to add wireless access to your existing business network.

Features

- Draft 802.11n wireless networking delivers greater throughput and extended range, maximizing the number of wireless clients per access point for your small business
- Easy installation and configuration via a web interface
- Adjustable and removable dipole antennas with multiple-input, multiple-output (MIMO) 3x3 diversity
- Gigabit Ethernet LAN interface
- Supports PoE and external DC power
- HTTP Redirect facilitates the display of a splash page on initial user access
- IPv6 host support for managing the access point over IPv6
- Multiple basic service set identifier (BSSID) support allows the creation of multiple secure wireless workgroups for users and guests
- Service set identifier (SSID) to VLAN mapping maintains application security and quality across wireless and wired
- WPS allows for simple and secure deployment of the wireless network
- Logging via syslog, email, or local log
- Wi-Fi Multimedia (WMM) wireless QoS support

Specifications

Table 1 lists the specifications, package contents, and minimum requirements for the Cisco WAP4410N Wireless-N Access Point.

Table 1. Specifications for the Cisco WAP4410N Wireless-N Access Point: PoE/Advanced Security

Specifications	
Standards	Draft IEEE 802.11n, IEEE 802.11g, IEEE 802.11b, IEEE 802.3, IEEE 802.3u, IEEE 802.3af (Power over Ethernet), 802.1x (security authentication), 802.11i security WPA/WPA2, WMM
Ports	Ethernet, Power
Buttons	Reset
Cabling type	Unshielded twisted pair (UTP) Category 5e or higher
LEDs	Power, Ethernet, Wireless, PoE

Operating system	Linux
Setup/Configuration	
Web user interface	Built-in web user interface for easy browser-based configuration (HTTP/HTTPS)
Management	
Simple Network Management Protocol (SNMP) version	SNMP version 1, 2c
Event logging	• Event logging • Email logging • Remote syslog
Web firmware upgrade	Firmware upgradeable through web browser
Diagnostics.	Flash, RAM, LAN, WLAN
Dynamic Host Configuration Protocol (DHCP)	DHCP client
HTTP Redirect	Redirects initial user access to an external web server to display company logo or network usage policy
IPv6 host	• Support for management and control of access point over IPv6 • Supports RFC2460 (IPv6 protocol) and RFC4294 (IPv6 node requirements)
Network Capabilities	
Multiple BSSID	Supports up to 4 BSSIDs, allowing the creation of multiple virtual access points
VLANs	Supports 802.1q - up to 4 VLANs
SSID to VLAN mapping	Supports mapping of SSIDs to VLANs to securely separate workgroups across wireless and wired domains
Spanning Tree	Supports 802.1d Spanning Tree Protocol to prevent loops when using wireless distribution system (WDS) links as redundant links in a distribution system
Operating modes	Access point mode, point-to-point bridge mode, point-to-multipoint bridge mode, repeater mode, wireless client mode
Load balancing	Allows bandwidth control with user-defined CPU usage ratios
Auto-channel selection	On boot-up, the access point selects the least congested channel
802.11d regulatory domain	Enables the access point to provide radio channel settings for client devices, facilitating easy client access as they move across regulatory domains
Security	
WEP/WPA/WPA2	Wired Equivalent Privacy (WEP) 64-bit/128-bit, WPA-Pre-Shared Key (WPA-PSK), WPA2-PSK, WPA-ENT, WPA2-ENT
Access control	Wireless connection control: MAC-based
SSID broadcast	SSID broadcast enable/disable
Client isolation	Supports wireless client isolation between and within SSIDs
802.1X	Wireless clients can be authenticated through IEEE 802.1X
802.1X supplicant	Supports 802.1X supplicant on the Ethernet port to allow the access point to authenticate itself to the network
RADIUS server	Up to 2 RADIUS servers can be configured for redundancy purposes
WPS	Supports WPS, a WI-FI Alliance specification for simple and secure setup of a wireless network
Rogue access point detection	New access points detected that have not been categorized as known are logged as rogue access points, allowing the administrator to clamp down on unapproved devices in the network
Quality of Service	
QoS	• 4 queues • 802.1p VLAN priority • WMM wireless priority • Mapping of 802.1p VLAN priority to WMM wireless priority to maintain end-to-end QoS
Wireless	
Spec/modulation	Radio and modulation type: 802.11b/DSSS, 802.11g/OFDM, 802.11n/OFDM
Channels	Operating channels: 11 North America, 13 most of Europe (ETSI and Japan)

Internal antennas	None
External antennas	3 (omnidirectional)
Transmit power	Transmit power @ normal temp range for FCC: 802.11b: 16 dBm @ 1TX, 19 dBm @ 2TX, 20.5 dBm @ 3TX 802.11g: 13 dBm @ 1TX, 16 dBm @ 2TX, 17.5 dBm @ 3TX 802.11n: 17 dBm @ 1TX @ MCS0~5/8~13, 13 dBm @ 1TX @ MCS6/14, 11 dBm @ 1TX @ MCS7/15, 20 dBm @ 2TX@MCS0~5/8~13, 16 dBm @ 2TX @ MCS6/14, 14 dBm @ 2TX @ MCS7/15, 21.5 dBm @ 3TX@MCS0~5/8~13, 17.5 dBm @ 3TX @ MCS6/14, 15.5 dBm @ 3TX @ MCS7/15 Transmit power @ normal temp range for ETSI: 11b/g/n: 13 dBm @ 1TX, 16 dBm @ 2TX, 17.5 dBm @ 3TX
Antenna gain in dBi	2
Receiver sensitivity	802.11.n: 300 Mbps at -69dBm 802.11.g: 54 Mbps at -73dBm 802.11.b: 11 Mbps at -88dBm
Environmental	
Dimensions **W x H x D**	6.69 x 6.69 x 1.60 in. (170 x 170 x 40.7 mm)
Weight	0.86 lb (39 kg)
Power	• 12V 1A DC input, and IEEE 802.3af compliant PoE • Max power draw: 10.1W
Certification	FCC, CE, IC
Operating temperature	32°to 104℉ (0°to 40℃)
Storage temperature	-4°to 158℉ (-20°to 70℃)
Operating humidity	10% to 85%, noncondensing
Storage humidity	5% to 90%, noncondensing
Package Contents	
• Cisco WAP4410N Wireless-N Access Point with PoE • User guide on CD-ROM • Ethernet network cable • Power adapter • Product stands • Registration card	
Minimum Requirements	
• 802.11b, 802.11g, 802.11n wireless adapter with TCP/IP protocol installed per PC • Switch/router with PoE support or PoE injector when used with PoE • Web-based configuration: Java-enabled web browser	
Product Warranty	
3-year limited hardware warranty with return to factory replacement and 90-day limited software warranty.	

Cisco Limited Warranty for Cisco Small Business Series Products

This Cisco Small Business product comes with 3-year limited hardware warranty with return to factory replacement and a 90-day limited software warranty. In addition, Cisco offers software application updates for bug fixes and telephone technical support at no charge for the first 12 months following the date of purchase. To download software updates, go to: http://www.cisco.com/go/smallbiz.

Product warranty terms and other information applicable to Cisco products are available at http://www.cisco.com/go/warranty.

For More Information

For more information on Cisco Small Business products and solutions, visit: http://www.cisco.com/smallbusiness.

Americas Headquarters
Cisco Systems, Inc.
San Jose, CA

Asia Pacific Headquarters
Cisco Systems (USA) Pte. Ltd.
Singapore

Europe Headquarters
Cisco Systems International BV
Amsterdam, The Netherlands

Cisco has more than 200 offices worldwide. Addresses, phone numbers, and fax numbers are listed on the Cisco Website at www.cisco.com/go/offices

For More Information

For more information on Cisco Small Business products and solutions, visit: http://www.cisco.com/smallbusiness.

Americas Headquarters
Cisco Systems, Inc.
San Jose, CA

Asia Pacific Headquarters
Cisco Systems (USA) Pte. Ltd
Singapore

Europe Headquarters
Cisco Systems International BV
Amsterdam, The Netherlands

Cisco has more than 200 offices worldwide. Addresses, phone numbers, and fax numbers are listed on the Cisco Website at www.cisco.com/go/offices.

Printed in USA

C78-501860-00 11/08