A PROPOSAL TO INCREASE BANDWIDTH USAGE

IN A MULTIPLE ACCESS POINT ENVIRONMENT

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ABSTRACT

A PROPOSAL TO INCREASE BANDWIDTH USAGE
IN A MULTIPLE ACCESS POINT ENVIRONMENT

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As the demand for uninterrupted Internet access grows, the popularity of wireless communication increases. However, it is known that wireless communication has some problems compared to conventional wired communication. It is an important issue to balance load among access points in widely used Wireless Local Area Network (WLAN) application. It is impossible to balance load when wireless hosts associate with an access point by just taking into account of classical approach of Received Signal Strength Index (RSSI) and Signal to Noise Ratio (SNR). Some solutions containing a central server, requiring a specific brand of access point or protocol revisions have been proposed previously in order to balance load, but none of them has been favored as a generally accepted solution.

In this study, a proposal which is central server free and requires no modifications to the existing infrastructure is presented. The proposed model is based on dynamically determination of least loaded access point to associate with by running script on each host, in order to balance load and maximize throughput.

Keywords: Wireless Communication, Wireless Local Area Network (WLAN), IEEE 802.11, Load Balancing.

ÖZ

ÇOKLU ERİŞİM NOKTASI BULUNAN ORTAMLARDA
BANT GENİŞLİĞİ KULLANIMINI ARTIRMAYA YÖNELİK BİR ÖNERİ

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Kesintisiz Internet erişimine duyulan talep doğrultusunda kablosuz iletişimin popülaritesi de artmaktadır. Ancak, kablosuz iletişimin klasik kablolu iletişime göre bazı sorunları olduğu bilinmektedir. Geniş uygulama alanı bulunan kablosuz yerel alan ağı uygulamalarında, mevut erişim noktaları arasında yük dağılımı konusu özel bir önem arz etmektedir. Kablosuz bilgisayarların, klasik yaklaşım olan alınan sinyal gücü endeksi (RSSI) ve gürültü oranını (SNR) dikkate alarak erişim noktalarına bağlandığı durumlarda yük dağılımının sağlanması mümkün olmamaktadır. Geçmişte, merkezi bir sunucu üzerinden, belirli bir model kablosuz erişim noktası kullanarak veya protokol değişiklikleri ile yük dağılımı dengeleme çözümleri önerilmiş, ancak genel kabul görmüş bir çözüme ulaşılamamıştır.

Bu çalışmada, merkezi bir sunucu istemeyen ve mevcut altyapıda hiçbir değişiklik gerektirmeyen bir çözüm önerisinde bulunulmuştur. Önerilen model, tüm kablosuz bilgisayarlar üzerinde bağımsız olarak çalışan bir uygulamanın dinamik olarak en az yüklü erişim noktasını tespit ederek ona bağlanmasını ve böylece yük dağılımını ve sonrasında toplam bant genişliği kullanımını artırmayı hedeflemektedir.

Anahtar Kelimeler: Kablosuz İletişim, Kablosuz Yerel Alan Ağı (WLAN), IEEE 802.11, Yük Dağılımı.

In memory of my father, Nihat GERÇEK…

ACKNOWLEDGEMENTS

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AP   -   Access Point

BAROG   -   Better Access Rate Offering to Gateway

BSS   -   Basic Service Set

CSMA/CA   -   Carrier Sense Multiple Access / Collision Avoidance

CSMA/CD   -   Carrier Sense Multiple Access / Collision Detection

DCF   -   Distributed Coordination Function

DSSS   -   Direct Sequence Spread Spectrum

ESS   -   Extended Service Set

ESSID   -   Extended Service Set ID

FHSS   -   Frequency Hopping Spread Spectrum

GW   -   Gateway

HBDTM   -   Host Based Dynamic Throughput Maximizing Model

IBSS   -   Independent Basic Service Set

ICMP   -   Internet Control Message Protocol

IEEE   -   Institute of Electrical and Electronics Engineers

ISM Band   -   Industrial, Scientific and Medical Purpose Band

kbps   -   Kilo Bit Per Second

kBps   -   Kilo Byte Per Second

LBU   -   Host with Low Bandwidth Usage Characteristics

MAC   -   Medium Access Control

MANET   -   Mobile Ad-Hoc Network

Mbps   -   Mega Bit Per Second

MSS   -   Maximum Segment Size

OFDM   -   Orthogonal Frequency Division Multiplexing

OSI   -   Open Systems Interconnection

PCF   -   Point Coordination Function

RSSI   -   Received Signal Strength Index

RTT   -   Round Trip Time

SNR   -   Signal to Noise Ratio

SSID	-	Service Set ID
WiMAX	-	Worldwide Interoperability for Microwave Access
WLAN	-	Wireless Local Area Network
WMAN	-	Wireless Metropolitan Area Network
WPAN	-	Wireless Personal Area Network

CHAPTER 1

INTRODUCTION

Rapid developments in computer networks have changed the way of getting and storing information. Today, all kind of business and governmental institutes have their own data communication systems with their branches. They store their business specific data into a central database server and have their distant branches access this information to manage their work via network infrastructure.

However, usage of networking is not left to business specific areas. Today, network of networks, i.e. the Internet, can be accepted as the most popular invention of mankind. All kind of information can be accessed instantly if you are connected to the Internet. Modern people access the Internet not only for entertainment, but also for business and social interactions. Consequently, people want the Internet to be accessible even if they are moving and that leads to increase in popularity of wireless networking.

Wireless networking is based on a simple idea: If an antenna is attached to an electric circuit, its electromagnetic waves can be received by a receiver located some distance away [1]. Daily life becomes easier by means of wireless networking. Ranging coverage area of centimeters to kilometers, today, wireless network supported devices become vital for people.

Wireless networking implementation can be divided into three popular sub-groups. Depending on coverage areas, there are Wireless Personal Area Network (WPAN), Wireless Local Area Network (WLAN) and Wireless Metropolitan Area Network (WMAN). These three wireless networking types have different bandwidth, latency, frequency and media access methods. Availability of a base station and number of

hops required for hosts to communicate one another also define types of wireless networks [2].

Wireless networking has some disadvantages as well as several advantages. Coverage area and bandwidth limitations are WMAN and WPAN specific problems. Handoff latency, performance anomaly and load balancing can be listed as popular problems which arouse interest among researchers, taking WLAN into consideration.

Handoff is one of the key operations in WLAN. Due to working characteristic of wireless networking, the host connects to the access point (AP) which has the highest Received Signal Strength Index (RSSI) and Signal to Noise Ratio (SNR) parameters. If user moves, the received signal becomes weak. Consequently, host probes area and tries to find another AP promising better RSSI. If it succeeds, host de-associates from current AP and then associates to the new one. This process is known as handoff or handover [3]. Since classical TCP has been designed for wired networking, TCP does not have a handoff prediction mechanism [4]. Even handoff occurs in milliseconds, TCP assumes that congestion has occurred, so congestion window should be set to slow start phase. This decision leads to unnecessary decrease in window size that means a drop in total throughput.

Load balancing is the second problem seen in WLAN. Handoff from one AP to another due to mobility may result in some AP to be overloaded. Typical RSSI and SNR based approach also results in un-balanced load among available APs. Strength of received signal does not give any information about the load of an AP. AP with the highest RSSI may be over-loaded while AP with relatively lower RSSI could be idle. On the other hand, initially associating to the idle AP at first association phase does not warranty working always in balanced AP environment. Load status of AP may change because of volatility in bandwidth usage and association de-association of other hosts.

Another problem has arisen from unfairness behavior of Distributed Coordination Function (DCF), which is the most popular media access method in wireless networking. If bit rate of one wireless host decreases, all wireless hosts are affected

by this decrease [5]. Due to low bit rate of access, slower host captures channel for a longer period, which causes drop in total throughputs [6].

Much effort has been made in order to solve these problems. Techniques to lower AP search phase by decreasing scanning duration [7], caching of accessible AP with selective scanning mechanism to shorten total handoff time [8], detaching handoff decision, which is the most time consuming part of whole procedure, from handoff mechanism [9], guessing handoff time to rapidly execute handoff process [4], freezing congestion window to prevent restarting from slow-start phase at handoff [10], splitting TCP connection using an intermediary to have seamless handoff and using a proxy to have fast recovery of lost packets [11] have been proposed to decrease handoff delay and prevent drop in total throughput.

In order to solve anomaly related problems, grouping hosts according to access rates and application of different backoff window to each group [5], implementation of adaptive backoff principle with link adaptation to minimize waiting period [12] and dynamic and distributed packet aggregation models [13] have been proposed.

For load balancing problem, AP producer's own solution which is based on rejection of host association by over-loaded AP itself [14], designing new AP with two transceivers, one for communicating with other APs about load status of each [15], designing new protocol or protocol revisions to convey load information to hosts [16], monitoring bandwidth usage of each hosts together with load of each AP and redistributing hosts among APs by using a central server [17], using probe delay as an indicator of load on AP [18], running an agent on AP to manage load [19] have been suggested as solutions to load balancing problem.

Although these efforts have defined the problems and suggested some solutions, none of them has been accepted as a standard by IEEE 802.11 working group. A separate group IEEE 802.21 is expected to standardize handoff procedure by defining a media independent handoff mechanism [20]. IEEE 802.11 group has some improvement in QoS based load balancing studies, but it has not been finalized yet [21]. Especially for load balancing problem, it will be favorable to design a model which is applicable to existing infrastructure and easy to implement.

In this study, "a novel load balancing and throughput maximizing approach" will be presented. Instead of classical idea of balancing load among available APs, in such a way that all APs have same degree of load, this study suggests different idea: The load should be distributed among available APs according to their bridging capacity taking into account of both interfaces i.e. Radio and Ethernet. Whenever the proposed model runs, some parts of load in the over-loaded AP will be transferred to relatively less loaded (free capacity) APs, and finally the load of APs will converge to a degree proportional to the capacity of each AP. In this definition, the load transfer is done by disassociation of hosts with low bandwidth usage characteristic from over-loaded AP and their association to less loaded one. All analysis and decision making procedures are carried out at host level by an agent running on each hosts, being fully decentralized and autonomous.

This model also considers wired networking side of AP. If running in Extended Service Set (ESS) mode and APs are used to connect wireless hosts to wired infrastructure, both interfaces of AP (Radio and Ethernet) should be considered together in balancing load. According to the model, if hosts with low bandwidth usage characteristics (LBU) currently associated to the over-loaded AP or AP with limited Ethernet interface uplink rate is transferred to less loaded one, other hosts already associated at previous AP may increase their bit rates, while switched LBU hosts continue with same or better bit rate at new AP. This process results in increase of total throughput. The system runs as follows: LBU host analyzes traffic while associated to the current AP, then consecutively associates to all other APs and checks traffic again. Finally it decides to associate with less loaded or better access rate offering AP. It uses an add-on running on wireless agent of operating system and continuously monitor environment. For this reason, the model is named as "Host Based Dynamic Throughput Maximizing Model – HBDTM Model". This approach is superior to previous studies:

- HBDTM Model requires no central server. Decision maker algorithms run on all hosts. Since no extra server is required, there is no complex system to manage.
- HBDTM Model is a software based solution. Therefore it can be applied to an environment having different brands of AP.

- HBDTM Model requires no modification on any protocol or frame used in wireless communication, which results in no deviation from standards set by IEEE 802.11 working group.

- HBDTM Model relies on checking real time bandwidth usage state by analyzing access rate to wired infrastructure through Ethernet interface also. Therefore it is more accurate to estimate load when compared to previous studies of examining probe delay time. Probe delay time data gives no information about access rate to gateway at Ethernet interface, but information about radio interface. HBDTM Model decides which AP has better access rate considering both interfaces of it, resulting in balanced load among APs for maximized throughput.

In order to prove model, a test bed similar to simulation designed by Jabri et al. [17] has been used. But, in contrary to their implementation, it is preferred to make real world testing. By using real world test environment, it is intended to see not only contribution of the model to load balancing effort, but also practicability of the model.

This thesis is arranged as follows: In Chapter 2 basic information about wireless networking is given. Wireless specific problems and solution proposals are explained in Chapter 3. In Chapter 4 HBDTM model's technical layout is explicated. Implementation and test results are given in Chapter 5 and conclusions with future work is presented in Chapter 6.

CHAPTER 2

BASICS OF WIRELESS NETWORKING

2.1. Network Concepts

Interconnecting computing devices via appropriate links forms basic description of networking. Link in this description refers to the media carrying information sent from one device to another [22]. In general, network is divided into two groups: Telecommunication network and data communication network [22]. Telecommunication network has circuit-switched layout and has specification of accessibility by any user. Data communication network, also called computer network, is the second type of networks. It is composed of computers, modems, routers, switches, hubs and passive devices (cabling etc.) which today are well known thanks to network of computers networks, i.e. the Internet.

Computer networks may use the existing telecommunication layout and its circuit switching technology. However, packet switching network, especially designed for data communication as an alternative to telecommunication technology, is more efficient when compared to circuit switching network [2]. Main difference between circuit switching and packet switching technology is just the matter of dedication of certain amount of available bandwidth to user requests. In circuit switching technology, available bandwidth is divided into number of hosts and even if a host does not use network resources by sending or receiving data frames, its allocated bandwidth can not be used by any other hosts. In contrary, sharing of available bandwidth is the key word in the packet switched network since there is no dedicated bandwidth allocation in this technology [2].

As regards computer networks, a simple but necessary differentiation should also be mentioned: Size and form of network. Basic computer networking requires computers, connecting infrastructure (cables, patch panels, patch and drop cables)

and network active devices, such as switches, hubs and routers. For this type of network, depending on the standard of cable used, 10 / 100 / 1000 Mbps of link speed can be reached. Any network containing at least these kinds of devices is called Local Area Network – LAN. If Layer 3 networking is not required (a closed system with hosts connected to a switch or a hub but no desire to connect to any other network infrastructure), a router may not be installed. If at least two LANs wish to share resources supplied from any of them, they must be connected via router devices running on each side. In this formation, the existing telecommunication layout or fiber/optic or wireless router devices can be used. This kind of networks is called Wide Area Network – WAN. There is one more type in this classification, called Metropolitan Area Network (MAN), which is not too popular. It defines special WAN running in geographically limited area.

Starting from definition, some technical details regarding to networking idea have been given. However, the most important part of computer networks has not yet been mentioned: How computers talk to each other? A protocol architecture accepted by everybody allows devices from different vendors to interoperate [22]. That's why, a layered communication protocol, Open Systems Interconnection (OSI) Reference Model, has been developed by International Standards Organization – ISO.

2.2. OSI Reference Model

According to OSI Reference Model, from physical medium (cable) to application program running on computer, each phase has been defined and classified. As stated in the standard, there are seven different layers in OSI Reference Model. Layer 1 is "Physical Layer" dealing with electrical signals coming from physical medium to upper layer and upper layer to physical medium. Bits exist at this layer. The Physical Layer running on network interface should have ability to communicate with the physical medium connected. Physical medium can be copper, fiber/optic or radio frequency.

Layer 2 is called "Data Link Layer". It has two components: "Logical Link Control" (LLC) and "Medium Access Control" (MAC) acting as flow control and data transfer control between Layer 3 and Layer 1. Hosts are identified according to their Layer 2 specific address - MAC address. Ordinary switch devices perform according to their

automatically pre-filled MAC address table. Transferred pieces are called frame at Layer 2.

IP becomes important in Layer 3. The task of "Network Layer" is to route data. At this layer datagrams are sent, each having source and destination IP addresses. Layer 4, "Transport Layer", deals with host to host data transfer. It multiplexes and de-multiplexes messages coming from the neighboring layers. The Transport Layer can be connection oriented (TCP) or connectionless (UDP) depending on the type of segment.

Layer 5 is called "Session Layer" and monitors and synchronizes information exchange [22]. Services managing data compression, data encryption and data description run at this layer. Layer 6, "Presentation Layer", serves end users to provide a common language [22]. Last layer in the model is called "Application Layer" and is responsible for supporting network applications, such as FTP, HTTP, POP3, etc [2]. The corresponding layers on each system communicate on a peer-to-peer protocol interface bound to those layers [22]. Layers of OSI Reference Model, interactions of corresponding layers with each other and passage of a network application from one host to another are seen in Figure 2.1.
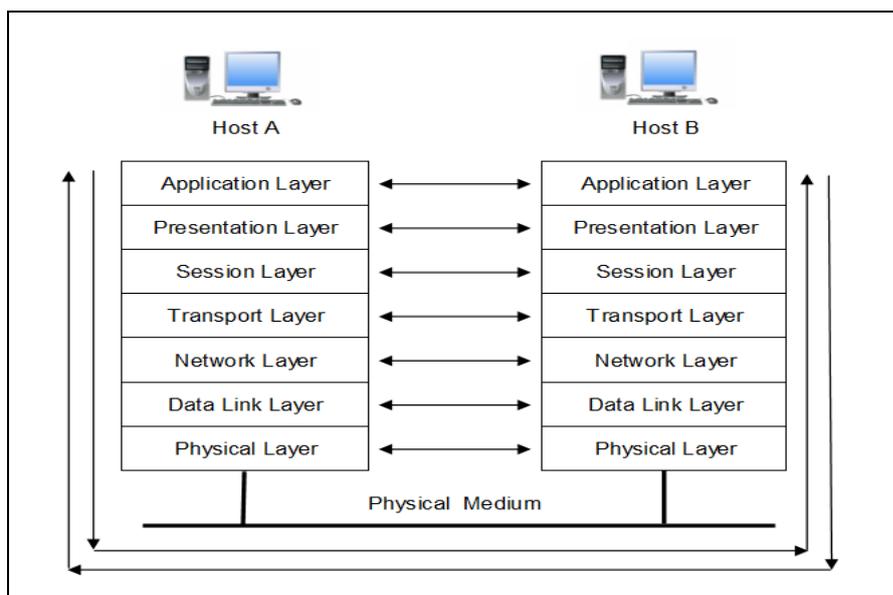
Figure 2.1: OSI Reference Model and Message Passage

Although OSI Reference Model is a detailed and competent model, its application to real world has some differences. Internet Protocol Stack, the backbone of today's networking idea including the Internet, is actually based on OSI Reference Model but has only 5 layers. Layer 5 and 6 are left to programmers to implement them in network user programs which means that they will still exist in application layer [2].

Computers with different operating systems, switches and routers produced by different vendors, and application written by different programmers communicate with each other, thanks to OSI Reference Model and Internet Protocol Stack.

2.3. Wireless Communication

As stated previously, the wireless communication is based on a fact that if an antenna is attached to an electric circuit, its electromagnetic waves can be received by a receiver located some distance away [1]. Frequency and wavelength of electromagnetic waves are two basic actors in this kind of communication. Higher frequency results in lower wavelength and lower frequency results in higher wavelength due to equality of their multiplication to a constant value (speed of light in test environment - vacuum). Frequency band term has evolved from this approach. Each frequency band has an associated bandwidth value (measure of data carried) which actually has some amount of frequency space in it [23]. If it is intended to carry more data on such a wireless link, higher frequency band should be chosen. For this reason, depending on usage area and bandwidth requests, different products satisfying different standards exist in market. But allocating frequency is not bandwidth aware only. Governments allocate some intervals of frequency band for public usage. This usage is license free and called as ISM which comes from abbreviation of Industrial, Scientific and Medical terms. Wireless devices such as cordless phones and wireless mice use ISM band.

There is one more important term to define wireless communication: Spread Spectrum. It explains the way of transmission. Frequency Hopping Spread Spectrum (FHSS), Direct Sequence Spread Spectrum (DSSS) and Orthogonal Frequency Division Multiplexing (OFDM) are three popular techniques. The implementation of these techniques varies according to standards set by sub-groups of IEEE 802 initiative.

2.4. Types of Wireless Network

IEEE 802 LAN/MAN Standards Committee works for the standardization of LAN and MAN rules [24]. Although there are 11 active working groups under IEEE 802, groups dealing with wireless networking can be listed as 11, 15, 16, 18, 21 and 22. The first three are popular groups, and has wide area of application of standards. 802.18 deals with radio regulatory while 802.21 works to standardize media independent handoff systems. 802.22 is the last group working for wireless networking technology standards. It aims to define air interface using same spectrum as in TV broadcast services [25].

2.4.1. 802.11 WLAN

The 11th working group of IEEE 802 defines standard for wireless LAN applications. It is infrastructure-based, single or multi hop computer networks having data rate of 11 to 54 Mbps. An AP, running in bridge or router mode helps computers equipped with WLAN interfaces to communicate with each other or access wired infrastructure. Three sub-standards of 802.11, namely a, b and g defines data rate, coverage area and operating frequency. 802.11a operates at 5.1-5.8 GHz with data rate of 54 Mbps and indoor coverage area of about 30m. 802.11b, one of the popular standards, operates at 2.4-2.485GHz and has maximum data rate of 11 Mbps. Its coverage area is very similar to 802.11a. Last one, the most popular of them has caught attention of computer producers. 802.11g operates in same frequency with 802.11b, but has 54 Mbps of data rate and about 100 meters of indoor coverage area [2].

There are two types of WLAN based on existence of infrastructure. Both types have their own service set types which logically group devices. Infrastructure-based type network is also called Basic Service Set (BSS) Network. In this network AP helps each host to communicate with each other [26]. Each host sends its data to other host through AP. If it is required to have a larger wireless network, it can be created by linking BSSs by means of a backbone network, forming Extended Service Set (ESS) Network [23]. This kind of network is also installed in order to carry wireless hosts to wired network resources. Figure 2.2 shows typical BSS and ESS infrastructure.
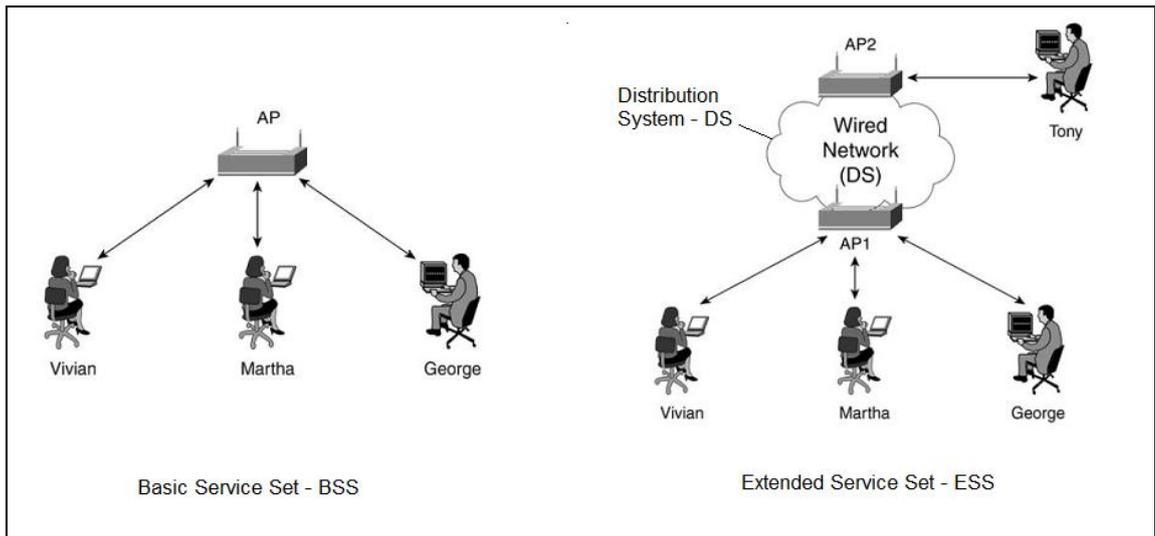
Figure 2.2: Typical BSS and ESS [26]

Another type of WLAN is an infrastructure-free network. In this type of WLAN, the wireless hosts communicate directly with each other without requiring an AP as seen in the Figure 2.3. This kind of network is called as Independent Basic Service Set (IBSS) or Ad-Hoc Network [23]. If the wireless hosts are mobile, these networks may be called mobile ad-hoc networks (MANETs). Such networks are formed for military and meteorological purposes in which information is gathered from specific area via this layout.
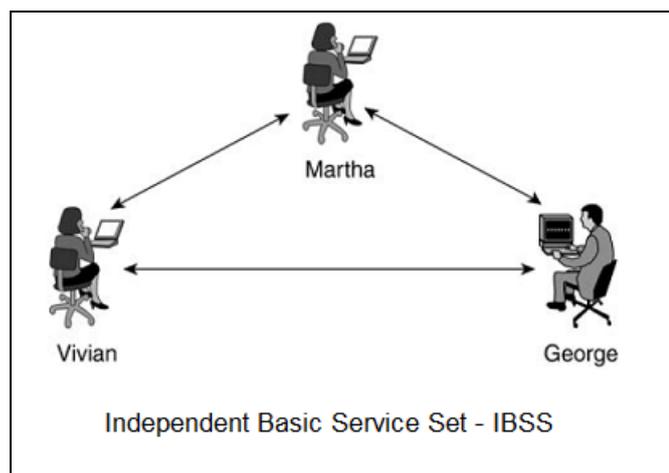
Figure 2.3: Typical IBSS [26]

Implementation of 802.11 results in some deviations from the definitions given above. The wireless mesh networks, one of the networks formed by 802.11 standards, are known as multi-hop, infrastructure–based networks. Nodes in wireless

mesh network may use existing infrastructure or another host as relay server to communicate with the system.

2.4.2. 802.15 WPAN

Wireless Personal Area Network has characteristics of short range, low cost, infrastructure-free wireless communication with ability to form network among devices having 802.15 interfaces, such as Bluetooth devices ranging from laptops, small personal printers, cellular phones, earphones etc. Bluetooth supported devices have coverage area of 10 cm to 10 meters. That's why it is used among devices within personal area [27].

2.4.3. 802.16 WMAN

WMAN stands for "Wireless Metropolitan Area Networks". Its air interface - physical layer- is defined by 802.16 standards. Currently accepted specifications of WMAN are based on December 2005 802.16e amendment [28]. It has add-ons on 802.16a standard for mobility. It is an infrastructure-based wireless network having 15 Mbps of data rate within coverage area of 50 km [29]. Brand of WMAN is WiMAX. It stands for "Worldwide Interoperability for Microwave Access". WiMAX has been designed to offer worldwide access for mobile users. It focuses especially on ubiquitous access to the Internet in city center while moving. A base station with coverage area of around 50 km is used for wireless hosts equipped with WiMAX interface to access the Internet.

2.5. Technology Underlying Wireless Networking

2.5.1. Transmission Techniques

The most important and second widely used computer networking system is based on wireless networking idea. Similar to IEEE 802.3 –Ethernet, IEEE 802.11 uses same OSI layer as infrastructure. In 802.11 protocol stack, the Physical Layer has different transmission techniques, ranging from low bandwidth promising infrared to higher bandwidth supported FHSS, DSSS and OFDM.

As seen in Figure 2.4, together with infrared, FHSS and DSSS are two techniques used in base IEEE 802.11. These techniques make use of ISM band and have ability to transmit 1 to 2 Mbps of data. For higher data transmission rate as required in

802.11a/b/g, two other techniques are used: OFDM and High-Rate DSSS (HR-DSSS).
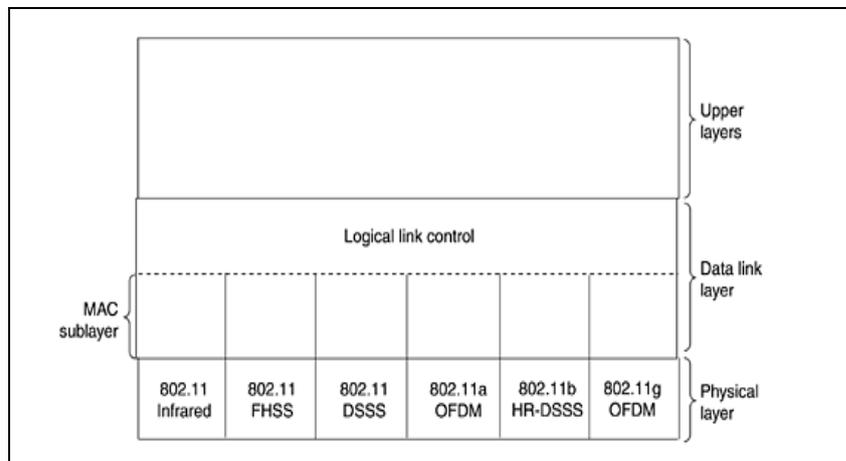
Figure 2.4: Part of the 802.11 Protocol Stacks [1]

FHSS uses 79 channels each of which is 1 MHz wide. Although it has low bandwidth, its ability to change of frequency rapidly during transmission makes this technique favorable when multipath fading problem exists. DSSS also supports $1-2$ Mbps data rate transmission with the advantage of running in low SNR environment. It takes 1 Mbps of data from upper layer and transfers it to 11 MHz chip stream [26].

802.11a has special transmission technique, i.e. OFDM. It uses 5 GHz ISM band width to deliver 54 Mbps of data. OFDM divides available channels into sub-channels and encodes a portion of the signal across each sub channel [23]. Totally 52 frequencies are defined and 48 of them are used for transmission while the remaining 4 are for synchronization in OFDM technique [1].

802.11b uses HR-DSSS. It is similar to DSSS but differs in chips/sec rate. It uses 11 million chips per second to transmit up to 11 Mbps of data. As in 802.11a, 802.11g uses OFDM as the spread spectrum model, but it operates at 2.4 GHz ISM band with 802.11b promising 54 Mbps of data transfer rate [1].

2.5.2. Media Access Models

The wireless networks use different types of media access models. As used in Ethernet (802.3), WLAN (802.11) also uses CSMA – Carrier Sense Multiple Access

model. But unlike CSMA/CD (with collision detection) as in Ethernet, the WLAN uses collision avoidance specification of this model (CSMA/CA). CSMA/CA is applied to 802.11 with operation mode of Distributed Coordination Function (DCF). It checks the media and waits for the media to be free, then sends data. In case of collusion, it waits for a time of exponential backoff period. All kinds of WLAN implementations should support DCF [1].

However, there is another operation mode, namely Point Coordination Function (PCF), designed for special request. It is used when collusion free communication is required. A special host or AP generally coordinates access of each host.

Another technology, Inter Frame Spacing has also important role in coordinating access to media. It controls when to access media after media let free. There are four different methods in this area: Short Inter Frame Space (SIFS), DCF Inter Frame Space (DIFS), PCF Inter Space (PIFS) and Extended Inter Frame Space (EIFS).

DIFS is the minimum time required to access media when contention is not important. However, if contention-free access is important, then time required to access media calculated accordingly in PIFS [23]. In SIFS, QoS based approach exists. Data with higher importance access to media earlier when compared to other technologies. Last one, EIFS is used by host to inform about a bad frame [1].

2.5.3. Physical Layer Implementation

The wireless network uses traditional OSI model but it differs in implementation of Physical Layer. In the wireless network, electromagnetic waves are used as physical medium. As seen in Figure 2.5, two sub-layers Physical Layer Convergence Procedure (PLCP) and Physical Medium Dependant (PMD) play active role in communication. PLCP listens to the media and supports clear channel assessment. It works between MAC and PMD. PMD is actually the real layer which conducts wireless communication [26].
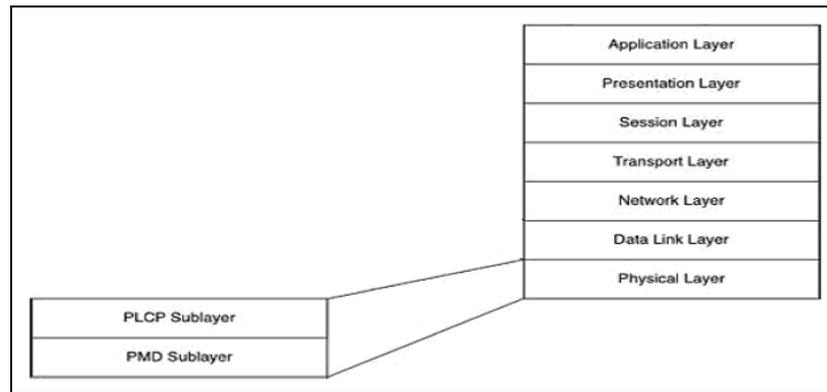
Figure 2.5: Physical Sub-Layers in OSI Reference Model [26]

2.5.4. Association and Handoff in 802.11 WLAN

In infrastructure-based WLAN, an AP is used to serve physical layer to all associated wireless hosts. AP, being either a router or a bridge, helps mobile wireless hosts to access wired infrastructure. Association and disassociations due to mobility requires special management frames to be sent and received by two parties of link. In IEEE 802.11, following management frames are defined [8]:

- Authentication frame: the wireless host sends an authentication frame to AP containing ID information. In open system authentication, AP either accepts or refuses wireless host by sending a reply to authentication frame.
- Association request frame: wireless hosts send authentication request frame to AP which contains wireless host specific information and SSID of AP to connect.
- Association response frame: If AP decides to be associated with wireless host, it answers its association request frame with information of association ID, supported data rates etc.
- Re-association request/response frames are used if roaming occurs.
- De-association frame informs system about termination of association.
- Beacon frame: AP periodically sends a beacon frame to inform wireless hosts of its presence with timestamp, SSID, etc.
- Probe request/response frame: Wireless host sends a probe frame to get information about other hosts or existence of another AP in coverage area and responded by them using probe response frame.

The first association follows these steps: Mobile host tries to find an AP that it can connect. This is done by the MAC layer scanning function. It can be done in two different ways: active or passive. In the passive scanning, the wireless host listens to the wireless medium for beacon frames. It has timing and advertising information. Using this information, the wireless host can select best AP to connect. In this way, the wireless host listens to each channel. In the active scanning, the wireless host sends a probe request frame to wireless medium. This frame has destination address of broadcast. After sending frame, the wireless host starts probe timer and waits for probe response. If no response is received in preset duration which is device dependent variable, the scanning starts again in next channel. If any probe response is received in preset duration, the scanning is finished and the authentication procedure is started [8].

Since the wireless communication is based on electromagnetic waves, some portion of which can reflect from surfaces such as wall or furniture and takes another path to receiver. This kind of signal is called as obscure signal [2]. Problem arisen from obscure signals is called multipath propagation. In order to prevent this problem, the wireless interface at mobile host listens to only the strongest signal, in case same signals come from different paths. In selecting best AP, only criteria for a host are receiving highest signal strength and having lower noise from AP. These criteria are called Received Signal Strength Index (RSSI) and Signal to Noise Ratio (SNR).

Connection quality of the wireless hosts may be affected by mobility itself. As hosts move freely, it's RSSI and SNR may start to decrease. But there is an acceptable level for RSSI. If it is under this level, the procedure mentioned above is restarted, resulting in first disassociation and then re-association. This procedure is called as handoff of handover [3]. During handoff, user feels nothing but TCP connection is lost and re-established. All procedure is carried out by wireless interface card and agent running on operating system. The handoff procedure should be a seamless operation with both low latency and low packet loss [30].

There are two types of handoff: Vertical and horizontal. Mobility induces mobile hosts to use different base stations according to RSSI, SNR and coverage area criteria. When RSSI and SNR start to drop, host tries to find another base station to

associate with as mentioned in Section 2.5.4. Mobile hosts with multiple technological wireless interfaces such as infrared, wireless, cellular and satellite may handoff to different technological base stations to have better RSSI and SNR values. Such environment with different technological wireless base stations is called "wireless overlay network" as seen in Figure 2.6. Base station with higher coverage area offers limited bandwidth while base station with lower coverage area offers higher bandwidth in wireless overlay network. Handoff occurred in this kind of environment between different technological base stations is called "vertical handoff". Vertical handoff from current base station with lower coverage area to other with higher coverage area is called upward vertical handoff and vice versa [31].
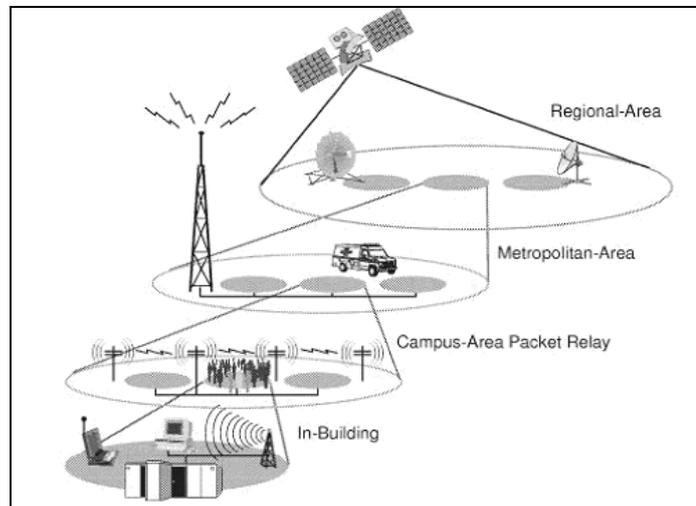
Figure 2.6: Wireless Overlay Networks [31]

In contrary to vertical handoff, horizontal handoff occurs between base stations of same wireless technologies. Disassociation from currently associated AP to another one with better RSSI and SNR is an example for this kind of handoff. Both types of handoff are shown in Figure 2.7.
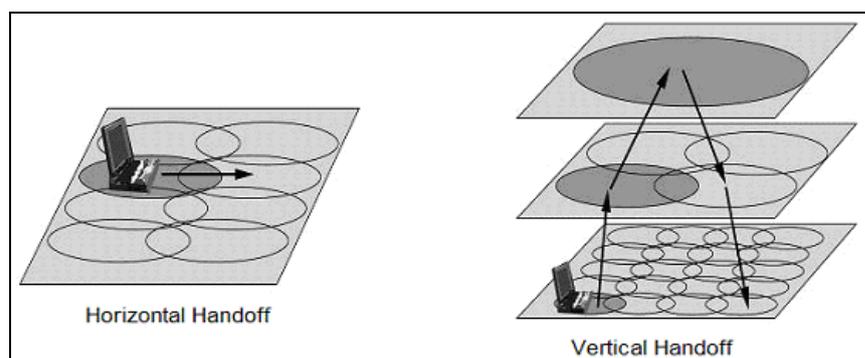
Figure 2.7: Horizontal Handoff vs. Vertical Handoff [31]

CHAPTER 3

PROBLEMS SPECIFIC TO WIRELESS NETWORK

3.1. Wireless vs. Wired Communication

The wireless communication has different characteristics when compared to the wired communication. Although both of them use OSI Reference Model, their applications differ in physical layer as stated in previous chapter. For example in wired communication, there is no received signal strength problem. If infrastructure has been established considering IEEE 802.3 cable length standard, it makes no sense to be closer or far to network active devices. All hosts work as desired thanks to fixed infrastructure.

However, in the wireless communication, "ability to move" is the reason of the difference. If a wireless host moves, its received signal strength will drop dramatically, resulting in making handoff to another AP. At this point, the criteria to choose correct AP are RSSI and SNR of such AP. There is no piece of information about load of AP either in RSSI or in SNR. This information shortage results in some of APs over-loaded while others less loaded. Hosts associated to over-loaded AP not only get less bandwidth but also lower other hosts bandwidth usage amount. This problem results in loss of total throughput.

Another difference between wired and wireless communication is the application of TCP congestion control mechanism. TCP uses a sliding window mechanism to accomplish reliable, in-order delivery with flow/congestion control. In classical TCP congestion control mechanism there are two major phases: slow start and congestion avoidance. In slow start phase, transmission window size is set to Maximum Segment Size (MSS) of 1 and doubles in every round trip time (RTT) i.e. exponential growth. After transmission window size reaches to predefined threshold, congestion avoidance starts and MSS increases 1 MSS in every RTT (means linearly). In case of

timeout, threshold is set to one half of transmission window, when the congestion window is set to 1 MSS, the procedure starts again [2]. Figure 3.1 shows these stages.
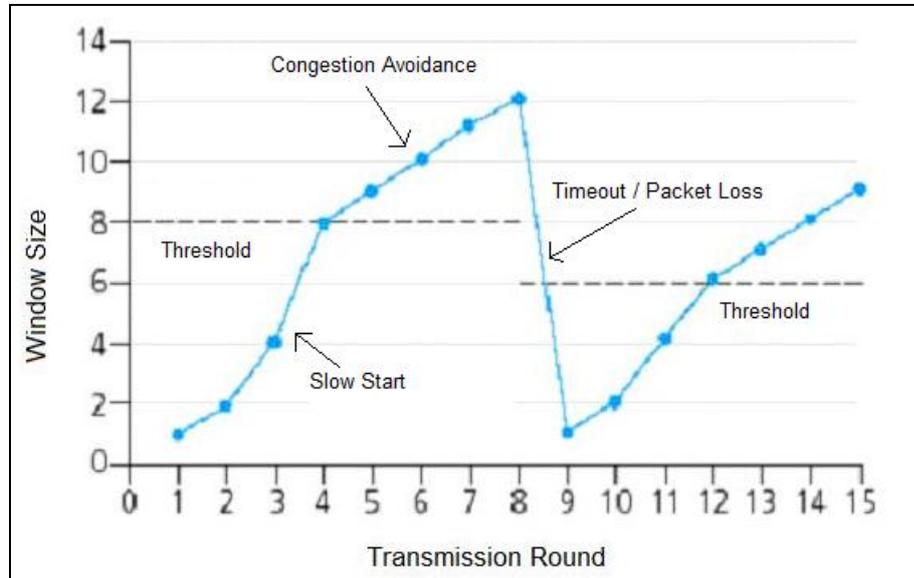
Figure 3.1: TCP Congestion Windows (Adopted from [2])

In the wired communication, packet loss occurs only if there is congestion. TCP controls and recovers this problem by "congestion control mechanism". It is done by re-sizing window size. But majority of packet losses in wireless networking are from high bit error rate of wireless links and temporary disconnections. After disconnection, the wireless connectivity can be re-established, but for classical TCP even a single packet loss may result in congestion window to restart the slow-start phase [11]. This problem causes poor TCP performance.

3.2. Problems Related to Wireless Communication

Different characteristics of the wireless communication give rise to some problems which can actually be classified into 3 sub-groups: handoff related problems, unfair load balancing and slower hosts longer channel capture.

3.2.1. Handoff Related Problems and Efforts

When to handoff and how to select the most feasible AP to associate has not yet been defined in IEEE 802.11. It is expected that IEEE 802.21 standard will solve handoff problem and interoperability in heterogeneous networks. This working group focuses

on media independent handoff services, but is currently at development stage [18]. Besides, many of researchers have tried to solve handoff specific problems. Solutions to these problems may be grouped into two parts; managing handoff procedure and managing TCP congestion control mechanism.

As stated in previous chapter, when the wireless host moves, RSSI and SNR ratios start to decrease. As a natural reaction defined in wireless agent, it tries to find another AP with better ratios. When a better AP is found, the de-association and re-association procedures are realized. During handoff procedures, wireless host leaves network and then turns back.

It has been analyzed that handoff procedure is completed in three phases: detection, search and execution [7]. In the detection phase, request to handoff is decided by wireless agent. In the search phase, possible AP with acceptably higher RSSI and SNR is tried to find. At last phase i.e. execution, disassociation from current AP and association with the new one is carried out. According to the detailed analysis, detection and search phases are main contributors to total handoff procedure [7].

3.2.1.1. Managing Handoff Procedure

Manodham et al. propose a novel AP with two transceivers one for communicating with neighbor APs [15]. According to the authors, 90% of delay occurs in Layer 2 operations (detection and search). If AP initiates handoff by gathering information from neighboring APs via second transceiver but not the host itself, time consuming phase can be skipped [15]. They also suggest that if handoff is initiated by AP the load between APs can be balanced as well. Main problem with this approach is the need of designing new APs while leaving old ones un-usable.

Jae-Woo So proposes a new handoff model, applicable only to the wireless hosts equipped with different technological interfaces [32]. For this reason, his model is applicable to only vertical handoff procedure. According to the author, traditional model of break-before-make leads to packet loss. However, if prospective interface tries to associate before current interface disassociate, no packet loss occurs. Author calls this model as "make-before-break" [32]. Problem of this model is its

applicability to only vertical handoff, but not horizontal handoff in classical wireless hosts equipped with only one interface.

Similar to So, Chen et al. propose a new model for seamless handoff with low latency and low packet loss [30]. In this model, a tunnel with one end in mobile host while other in a newly designed handoff server is used. According to these authors, if all Application Layer communications are bound to this tunnel which has two virtual and two fixed IP addresses at both ends, physically connected interface can be assigned to this tunnel interface during the handoff procedure. This idea keeps two ends intact and helps remain transparent to handoff process. For the horizontal handoff scenario, two different IP addresses can be used to bind to same 802.11 interfaces and connected to a virtual IP address of a tunnel interface [30]. This model can be accepted as a solution to TCP congestion control mechanism specific problem seen in wireless communication.

Shin et al. tries to minimize handoff delay by using so-called "selective scanning with caching mechanism" [8]. They propose that if mobile host keeps data about which channels are used by surrounding APs, only these channels may be scanned in active scanning procedure which may be needed by handoff requests. Furthermore, if second best AP other than currently associated one is recorded in a table, handoff request may be answered by using this table, omitting search phase of handoff procedure. Authors show that this model drops average handoff duration of 343 ms to 129 ms if only selective scanning is used; and to 3 ms if caching with selective scanning is used.

3.2.1.2. Managing TCP's Congestion Control Mechanism

The matter of freezing TCP in handoff has aroused interest among all researchers. The main idea is not decreasing handoff duration but freezing TCP connection during handoff procedure. Goff et al. propose a novel idea [10]. Freeze-TCP approach relies on sending advertisement of zero window size just before a temporary disconnection i.e. handoff. The period which is in advance of the connection is called a warning period and it should be equal to 1 RTT. By receiving zero window size from receiver, the sender assumes that no congestion occurred but receiver buffer is full, and there is no need to change window size. None-zero

window size is advertised after reconnection (successful handoff) by the receiver and traffic starts again with the previous window size.

Lee et al. criticize Freeze-TCP model [33]. According to them, during handoff, sending zero window size just before 0.5 or 1 RTT is difficult to guess. They propose a novel method to enhance Freeze-TCP model. Namely "Path Recovery Notification TCP-PRN" model says that when reconnection is done, Special ACK (SACK) containing PRN and TCP SACK option has been sent. This ACK forces sender to resent lost packets because of handoff. This model does not rely on accurate prediction of handoff time; instead it relies on its special ACK.

Qu and Zhang propose a new model regarding QoS performance in wireless networking [4]. This model has ability to detect possible handoff and to prepare wireless host to take necessary actions. They intended to add a new entity to Q-TCP (QoS object option-based TCP). In this scenario, every time entity detects a possible handoff, a warning message is send to Q-TCP and then a zero window probe is sent to the corresponding node. Both sides (sender and receiver) then freeze their timer up to the end of handoff process, which results in no change in congestion window size. Actually this model also uses the theory underlying Freeze-TCP approach.

3.2.2. Load Balancing Problems and Efforts

As stated above, classical approach in IEEE 802.11 WLAN is based on association to highest RSSI and SNR offering AP at initial connection. If the wireless host moves, it's RSSI and SNR starts to decrease. This time the wireless host tries to find an AP offering better RSSI by active/passive scanning operation. When it finds an acceptable AP, it starts association procedure. Association to an AP without considering its current load by a function or algorithm results in one AP working in over-loaded state while others in idle. However, the application of workstation distribution among APs by taking into account of load is a difficult task because of movement ability of workstations [16]. Researchers try to define problem and offer some solutions to this problem. The solutions may be grouped into four approaches; AP-based approaches, central server-based approaches, host-based approaches and other approaches.

3.2.2.1. AP Based Approaches

Beside proprietary solutions of AP producers, some thought that if handoff is done by AP but not by host itself, the load balancing could be reached. Manodham et al. support this idea by defining a novel AP with two transceivers additional one for communicating with neighboring APs which is used not only for deciding handoff time but also analyzing load [15].

Velayos et al. change the definition of load balancing in the wireless hosts [19]. They argue that, load metric should be throughput since number of hosts gives no idea about load of AP. They suggest that agent running on AP should monitor network status. Agents send and receive information regarding load of AP to neighboring APs and select the best candidate host to handoff. Their model is a new approach especially in defining load. However, programming agent for each brand name of devices is not a feasible result.

3.2.2.2. Central Server Based Approaches

Bejerano et al. analyze the definition of load balancing [33]. They claim that in order to maximize the overall system throughput, the users may be shifted to idle or lightly loaded APs. They suggest that, at the end of this process, each AP may have offer associated hosts maximal data rate. However, they criticize this system in view of fairness issue. Term "max-min fairness" is used to describe the idea behind this approach: if there is no way to increase bandwidth for a specific host without decreasing allocated bandwidth of others it is the point of "max-min fairness". They have also come up with a theory that in a fractional-association, "min-max load balanced association" gives "max-min fairness". They design an algorithm to fulfill max-min fairness in the light of min-max load balancing. Using algorithm and collected information, the network operation center (NOC) designs balanced load and inform connected hosts about new ideal associations.

In 2008, Jabri et al. propose a central load balancing server, which downloads some parameters from APs and then using a special algorithm tries to find the best host distribution among APs [17]. They especially focus on balancing load in order to have optimized QoS. The algorithm checks load distribution if (1) a new hosts enters into area, (2) host leaves network or (3) application requirements of host change.

3.2.2.3. Host Based Approaches

Chen et al. propose another idea in the wireless load balancing [18]. They suggest that, probe delay (PD) data can be an indicator of load on AP. Especially if more than one probe is analyzed, i.e. Mean Probe Delay (MPD), it can be a more accurate indicator. According to them, backoff time, which is a unique random time interval requested by the hosts in case sending a frame to busy media to wait for, gives valuable information. It is known that major variance in frame transmission comes from this waiting duration. Due to exponential backoff time usage of 802.11, if traffic is heavier, transmission delay will be longer. Probe request and probe response frames which follow DCF procedure mentioned in Section 2.5.2 are used by active scanning function. Probe responses are examined and AP over some SNR threshold is selected as candidate. Then minimum PD of it is chosen as least loaded AP to associate with.

3.2.2.4. Other Approaches

Some solutions to load balancing need to be run on both AP and wireless hosts. Although there are no many examples in this approach, it has some advantages as well. Since it does not require a central server it seems feasible, but management of APs is a challenging issue. Sheu and Wu tried to design an algorithm i.e. Dynamic Load Balancing Algorithm (DLBA) in 1999 running on both AP and wireless host [34]. They propose that Variation of Average of RSSI (VAR) and Variation of Number of Stations associated per APs (VSN) should be used as indicators in DLBA. According to their analysis and simulations, in a load balanced network, both VSN and VAR should be minimized in order to have fair traffic load among different AP sets.

Papanikos and Logothetis analyzed load balancing issue in WLAN in 2002 [16]. They suggest that the wireless host should be associated according to the number of connected workstations and mean RSSI value. Since standard protocols do not have information about either number of workstations connected or mean of RSSI, protocol modifications of beacon and additional features in probe response are required. This model also based on sharing nearly same amount of wireless hosts among APs.

3.2.3. Wireless Anomaly Problem and Efforts

If both IEEE 802.11b and IEEE 802.11g supported devices operate in the same area, an unexpected anomaly can exist. This problem can also be seen in pure IEEE 802.11b operated areas due to signal fading. As stated by Heusse et al. if a host uses lower bit rate when compared to others, performance of all hosts may degrade [6]. Reason for this anomaly is that slower host is capturing channel longer during data transmission. Bad time sharing among wireless workstations which is caused by DCF, results in this anomaly. Two approaches have been developed, in order to solve this problem: Packet aggregation/fragmentation and contention window adaptation.

Tahiry et al. analyzed the problem and propose a Performance Anomaly Solution (PAS) [13]. According to their approach, dynamic and distributed packet aggregation will overcome problem and it will be applicable to not only single hop wireless networks but also multi-hop wireless networks as well. Their idea is based on the fact that if same transmission time is given to all hosts, more packets can be sent in this period.

Li et al. propose changes in contention window to solve this problem in 2007 [12]. Their idea is based on application of classical CSMA/CA access model. According to the model, every host listens to the media and, if it is not busy, it sends its data to receiver. But if media is busy, it waits for a random exponential backoff time. After this period, if media is free, it sends its data. The model says that "adaptively minimizing contention window" can overcome this anomaly.

Chetoui et al. indicate that multiple backoff window can be a solution for this problem [5]. The model proposes that if hosts are grouped according to their access rates and different backoff windows (contention window size) are assigned to each group, then the problem can be solved.

CHAPTER 4

HOST BASED DYNAMIC THROUGHPUT MAXIMIZING (HBDTM) MODEL

Many researchers try to find generally accepted solution to load balancing problem for highly dynamic wireless networking environments where handoffs occur frequently as mentioned in Section 3.2. The difficulty arises from capability of host to change associated AP without user intervention as it moves. Movement of hosts result in some APs over-loaded while others remain idle. If load is distributed dynamically among available APs, then total throughput may be maximized even if frequent handoffs occur.

In fact, there is no common consensus on the definition of load. Some suggest that load should be number of associated hosts per AP. This value should be equal per AP in order to have load balancing in the environment [16]. However, associating with an AP does not mean generating certain amount of data traffic. An AP with higher number of associated hosts may have little data traffic when compared to other AP with less number of hosts which all associated hosts may be downloading some files. Velayos et al. give another definition for load, taking into account of this criterion [19]. According to them, the load should be "throughput in a certain amount of time". This definition seems more acceptable and has aroused great interest among researchers. Because if you consider throughput as the indicator of load, then the data passed over AP can define status of AP correctly. Since Physical Layer implementation of OSI Reference Model for the wireless communication is based on "listen before send", i.e. CSMA/CA, the generated data traffic by hosts fills media but not hosts existence only. This fact supports definition of Velayos et al.

Balancing load among APs is a challenging issue. Chen et al. propose a solution which works only at association phase [18]. But balancing load should be considered

not only during host's initial association phase, but also during its normal data transfer. In other words, connecting to a less loaded AP does not warranty living in balanced load environment. Since user preferences may change rapidly, the bandwidth usage per host varies as well. Therefore, the load of AP should periodically be checked and necessary actions should be taken. This idea necessitates existence of a central server to manage this process. Bejerano et al. [35] and Jabri et al. [17] propose solutions having a central server, while Manodham et al. [15] and Velayos et al. [19] suggest that solutions should be AP-centric, i.e. AP should manage load balancing process.
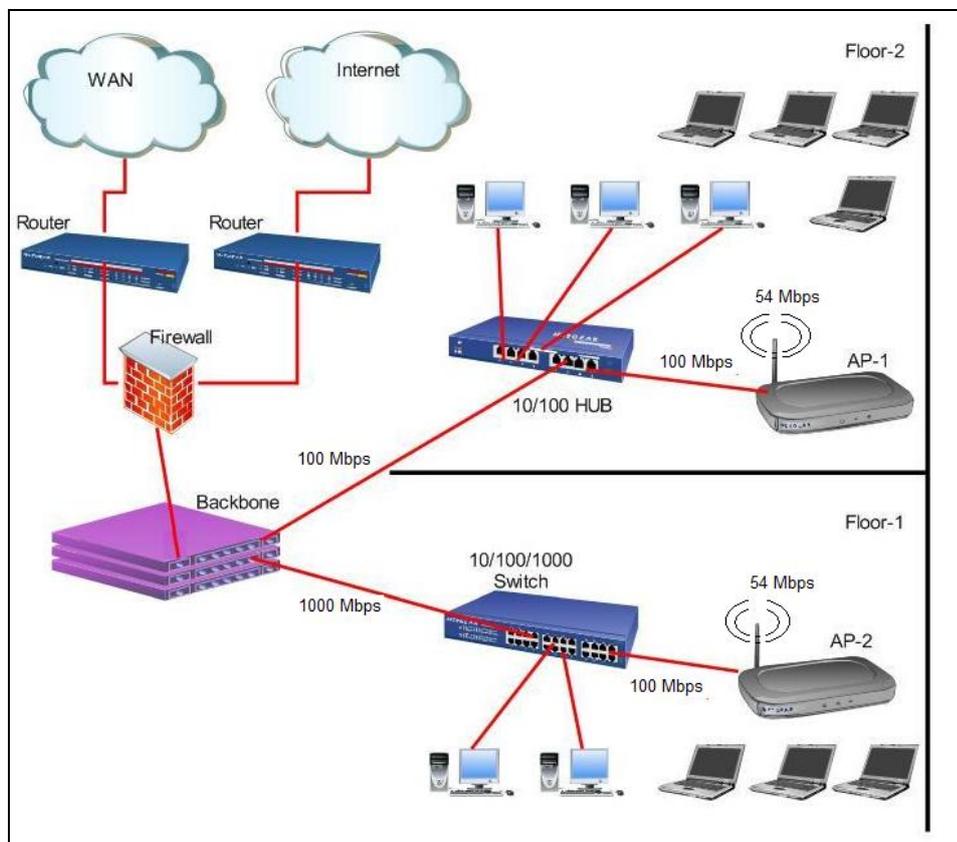
Figure 4.1: Typical Network Infrastructure with APs
Connected to Backbone via Different Uplink Speeds.

All of the researches suggest that load should be distributed among APs either using a central server or using an AP-centric solution. These works consider only radio interface of AP and disregard Ethernet interface. Yet, the connection to wired infrastructure via Ethernet interface also determines performance of AP. For example, consider two APs both serving 54 Mbps access rate to associated hosts at its radio interface. If one of them has limited rate at Ethernet connection due to

collisions, while other with 100 Mbps of rate, second AP may serve better service to its associated hosts. Figure 4.1 shows such an infrastructure.

Same problem can be seen frequently. Imagine two neighboring cafés serving customers for access to the Internet via their APs. Assume that some customers are in the coverage area of both APs, promising 54 Mbps of access rate, without considering their location of seats. If Café A has Internet access rate of 8 Mbps but Café B has only 2 Mbps, customers whose wireless computers associated with AP-A may be more satisfied with the speed of Internet access. Figure 4.2 shows this scenario.
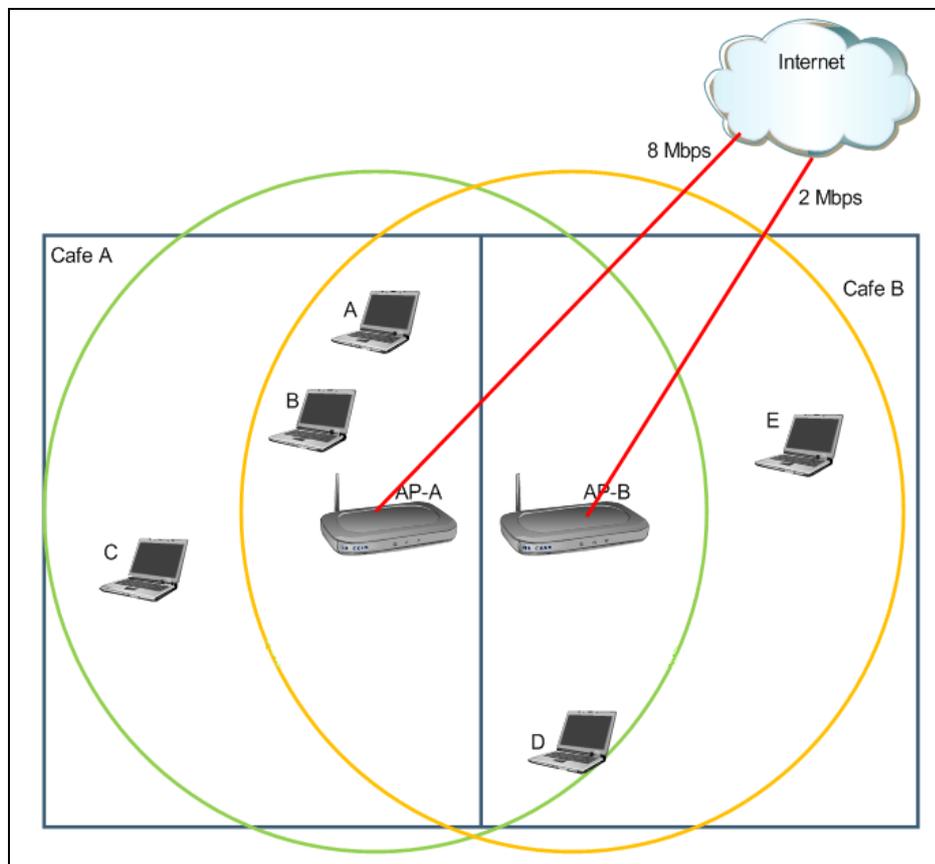
Figure 4.2: Service offered by two neighbor café

According to the scenario, if host D sitting in Café B luckily associates with AP-A, it may have better access rate since AP-A has 8 Mbps of connection speed to the Internet Service Provider (ISP). In contrary, host B sitting in café A may have better access rate if it associates with AP-B, in case neighbor hosts A and C, already associated with AP-A, downloads huge files. In this case, associating with AP with

relatively less uplink speed may offer better performance. This accidental association may result optimized throughput or waste of available bandwidth. However, there is no mechanism for such an association to maximize throughput as seen in Café A and Café B.

Classical association deals only with RSSI and SNR but not load and/or uplink rate of AP. Researchers try to find a solution to load balancing only considering radio interfaces of AP as mentioned before. If there is no central server, the most feasible method i.e. probe delay time data can be used to guess load of AP [18]. However, probe delay means nothing if you can see big picture, i.e. both interfaces of AP as seen in Figure 4.1 and 4.2.

In this study, it is intended to propose a novel load balancing and throughput maximizing approach. The term of "load balancing" in the model reflects the idea that the load should be distributed among available APs according to their bridging capacity by taking into consideration of both interfaces i.e. Radio and Ethernet. For this reason, the model considers both interfaces of AP and proposes better solution when compared to previous works. First of all in the model, in contrary to other approaches, there should not be;

● A central server which makes network more complex,
● AP-centric approach which requires brand name specific solution,
● Protocol change request.

But model must be transparent to wireless agent of operating system and should run on currently installed infrastructure without requiring any change. The proposed system should offer a long lasting solution to load balancing and throughput maximizing problem in such a way that load balancing should not be provided only at initial association but also during normal operation by checking load status of APs periodically.

Table 4.1 shows comparison of the approaches proposed to solve load balancing problem. In the table, first column lists approaches mentioned in Section 3.2.2, while next four columns show way of implementation. Last two columns identify whether

the proposed solution is autonomous and dynamic i.e. balancing load effort is valid only at initial association or during normal operation.

Table 4.1: Comparison of Approaches

Researchers / Approaches	AP Based	Central Server Based	Host Based	Protocol Revision Based	Autonomous	Dynamic
AP producer solution (such as Cisco) [14]	x					x
Manodham et al. approach with two transceiver [15]	x					x
Velayos et al. approach with agent running on APs [19]	x					x
Bejerano et al. approach using central network operating center [33]		x				x
Jabri et al. approach with QoS based load balancing [17]		x				x
Chen et al. approach with mean probe delay analyzing [18]			x		x	
Sheu et al. approach with new algorithm [34]	x		x			x
Papanikos et al. approach with beacon analysis [16]				x		
Approach proposed in this study (HBDTM Model)			x		x	x

One important issue in balancing load observed in previous works is the method of "guessing" load. If a central server or AP centric solution is not used, the host should find a method to estimate load of the AP to associate with. In this study, it has been also intended to find a mechanism to "see" load of AP. For this reason, HBDTM model relies on "visiting" (associating with) each AP to learn load state of AP by living.

4.1. How HBDTM Works

As implies its name, "Host Based Dynamic Throughput Maximizing" is based on dynamically monitoring of bandwidth usage status of all APs and association with "Better Access Rate Offering to Gateway" (BAROG) AP, considering also Ethernet

interface as well as to maximize throughput. It is done by switching "host with low bandwidth usage characteristics" (LBU host) to the next available AP to check load status of it. Through this process, if a BAROG AP is found, the wireless host will make handoff to this AP as a last decision. As it can be inferred from this definition, the model offers fully autonomous and decentralized solution.

The BAROG AP term needs some explanations. As seen in the café example, both interfaces play active role in performance of AP. In order to have balanced load environment together with maximized throughput, both interfaces should be taken into account. For this reason, generated traffic passing through both interfaces should be examined. This definition requires another player in the model. To be able to analyze traffic, a far end node should be determined in such a way that route to it should pass over both interfaces. In other words, a special node located at Ethernet side should be found. This node can be the gateway of the network (backbone as in Figure 4.1), or any web site having ability to answer ICMP requests if gateway is just the AP itself (as in Figure 4.2).

According to the model, if host's bandwidth usage is determined as "low", this host can be selected to make series of temporary handoff to find BAROG AP. Selecting LBU hosts for such an action is an important decision. If a high bandwidth usage host is selected for this purpose, its association with less loaded AP may change its status to over-loaded one. And this process continues with subsequent meaningless series of handoff. As it can be understood from this idea, LBU hosts handoff to a BAROG AP can not change BAROG APs load status. Model says that leave of LBU host from over-loaded or low access rate to gateway offering AP to BAROG AP will make no sense for it, since it is currently not using too much bandwidth resources and its TCP connection will be protected by Freeze TCP approach. At the same time currently associated hosts of new AP will not be disturbed since coming new host is just spending low amount of served bandwidth. But over-loaded or low access rate to gateway offering AP, which was the one associated before, will offer better performance to its clients after this handoff. Finally, if all LBU hosts handoff to BAROG AP, at the end of some series of handoff processes, throughput maximization with load balancing among APs will be reached.

In other words,

- Assume that there are n APs, as AP_1, AP_2, ..., AP_n with capacity of each as C_1, C_2, ..., C_n. Capacity in this definition represents the maximum throughput of an AP considering both interfaces.

- Then total capacity C_t can be calculated accordingly as, $C_t = \sum_{i=1}^{n} C_i$.

- Let T_i represents throughput of a particular AP, then T_t represents the total throughput of the system as, $T_t = \sum_{i=1}^{n} T_i$.

- Let Rq_i represents total bandwidth requested by users from AP_i and Rq_t represents the total request from system.

- If $Rq_i > C_i$, then AP_i cannot satisfy all the requirements in time, and throughput of each user will be less than the requested.

- If $\forall AP_i : Rq_i \leq C_i$, then throughput of each user is equal to his/her request, meaning fair load sharing AP environment.

- If $\exists AP_i : Rq_i > C_i$ and $\exists AP_j : Rq_j < C_j$, then it means there is an unbalanced load sharing among APs in the environment, that is $T_t < C_t$. This is the case where HBDTM works to increase T_t.

- Let $LBU_1, LBU_2, LBU_3, ..., LBU_m$ are hosts with low bandwidth usage characteristics already associated with any AP in the environment.

- Assume that, LBU_k, already associated with AP_i having $Rq_i > C_i$, switches to AP_j having $Rq_j < C_j$. Then, its transfer does not only help balancing load but also may let other hosts associated with AP_i get more bandwidth.

- If LBU_k is transferred to AP_j, T_i of AP_i may not change depending on comparison of Rq_i and C_i, but remaining hosts live in better bandwidth sharing environment. However, T_j increases because the new host requests some amount of bandwidth from AP_j; and AP_j still may have some spare capacity.

- At the end of series of LBU host transfers among APs, balancing load and maximizing T_t leads convergence of T_t to C_t .

In this model all procedures are carried out by host itself. An add-on service running on host's wireless agent will check hosts bandwidth usage and decide whether this host should temporarily handoff to other APs. Since all procedures are carried out by add-on service running on host, there is no need to use a central server in the network topology. Figure 4.3 shows flowchart of the model running on each host.
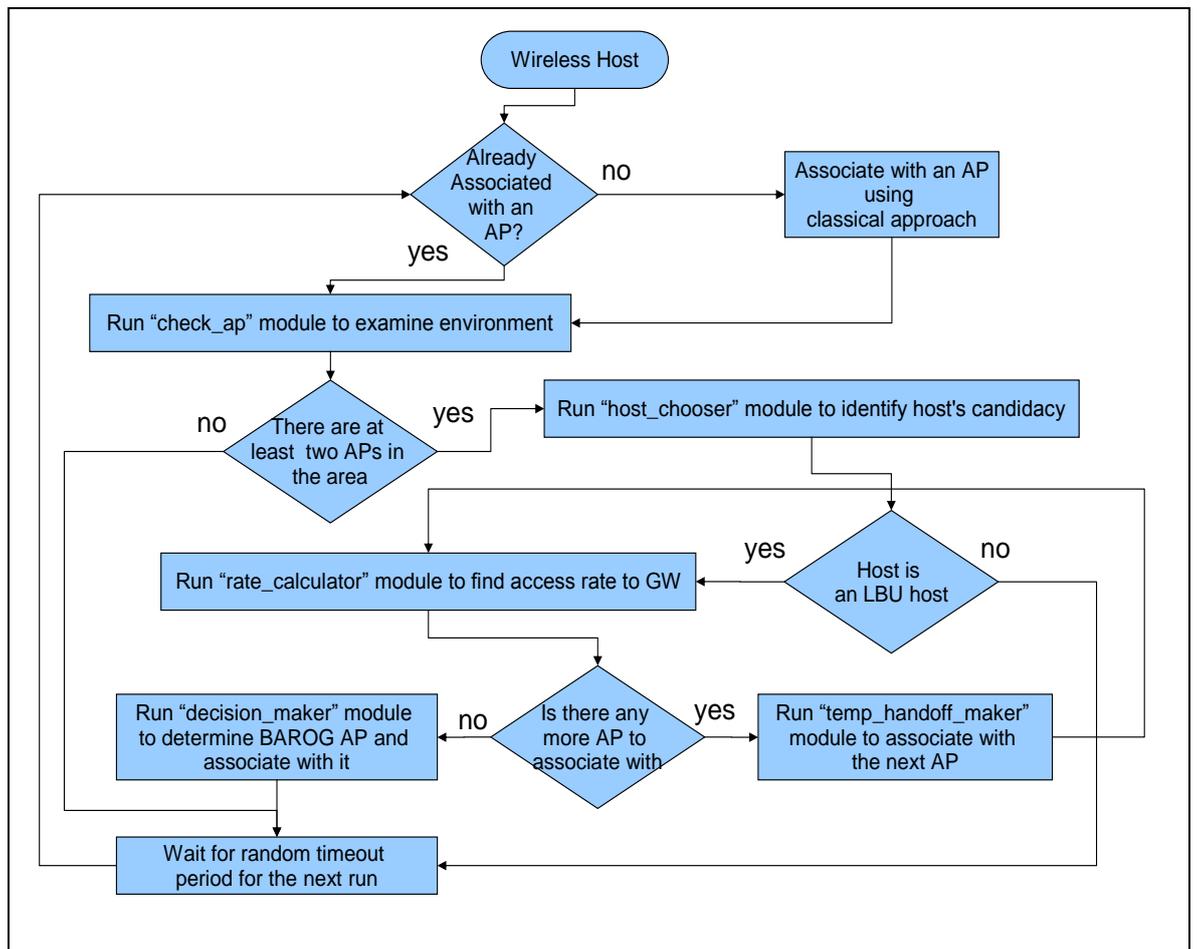
Figure 4.3: Flowchart of HBDTM Model

According to the approach, a service linked to the wireless adapter should run automatically at random timeout periods (120 seconds to 300 second) and run the model described above. The aim of using random timeout periods for the next run of the model is to prevent whole LBU hosts handoff to other APs at the same time. Because if all LBU hosts run the model at the same time and temporarily handoff to

33

next AP together, they all may be associated with a certain AP, resulting in false decision about load status of it.

The model should also consider movement of the host. If host moves, its RSSI and SNR may start to decrease, giving rise to associate with another AP serving better RSSI and SNR. This handoff, caused by nature of wireless communication, may affect load balancing efforts. For this reason, the model should re-run without waiting for timeout period after such handoff to help balancing load.

In order to understand running method of the model, some components mentioned in the flowchart and algorithm needs to be examined. First of all, model requires that bandwidth usage counter module should run independently on minute basis to record wireless interface's bandwidth usage data. In addition to this module, main algorithm calls the following modules:

- Environment Identifier (check_ap)
- LBU Host Chooser (host_choser)
- Access Rate Calculator (rate_calculator)
- Temporary Handoff Maker (temp_handoff_maker)
- Result Analyzer (decision_maker)

4.2. HBDTM Modules

4.2.1. Bandwidth Usage Counter

HBDTM is a central server free solution. Using central server may decrease workload. Since the central server collects data from all hosts and analyze them by considering load at each AP, re-matching of association to fit balanced load can be easily done. In this kind of solutions, the central server acts as decision-maker. However, in HBDTM there is no central server. All hosts have their own decision-maker mechanism running independent of other hosts. Since the model is based on temporary handoff of LBU hosts, every host should check its own traffic usage to decide its own candidacy. Therefore, in every host, there should be a service continuously monitoring its bandwidth usage. The "bandwidth usage counter" performs this work. Proposed algorithm for this aim is as follows:

```
Algorithm-1: Bandwidth usage counter
INPUT: None
OUTPUT: Minute based usage data
BEGIN
        Read value from "previous value file"
        Sum up values of received and transmitted bytes of interface from
                "/proc/net/dev" file
        Subtract two values to find last one minute usage
        Write summed up value to "previous value file" for next run
        Append log file with the value and time data
END
```

4.2.2. Environment Identifier

Environment Identifier module runs to get information about number of APs with RSSI of each in the coverage area.

Since the aim is to balance load in order to maximize throughput, there should be at least two APs serving in the same coverage area. In this model, handoff is not a process just used to change AP in order to have RSSI and SNR over threshold, but a useful device playing active role. In other words, the model says that if a handoff occurs in HBDTM Model, reason for this handoff may not be decrease in received signal strength from currently associated AP but efforts to find BAROG AP. That's why the aim of initial check in the model is to ensure existence of at least two APs with acceptable higher RSSI. The proposed algorithm for this purpose is as follows:

```
Algorithm-2: Environment Identifier
INPUT: None
OUTPUT: Link quality and ESSID of each AP in the coverage area
BEGIN
        Execute active scanning to all channels and
                record ESSIDs of all available APs to a file
        Read each line of file, find ESSID and ask relevant link quality
        Record ESSID and link quality of each AP in another file
END
```

4.2.3. LBU Host Chooser

Which host to play active role is a challenging issue. Since HBDTM requires handoff of LBU host to next available APs, it must be decided which host can be accepted as

"LBU host". In this thesis, it is accepted that classical Internet usage is based on web page browsing. Browsing a page and following links costs about 100 - 125 kbps of bandwidth usage. Therefore, LBU hosts should have usage characteristics of less than 125 kbps. The proposed algorithm for this module is as follows:

Algorithm-3: LBU host chooser
INPUT: Minute based usage data
OUTPUT: Hosts selection
BEGIN
    Read log file updated by "bandwidth usage counter" module
        to get last three minutes usage data
    Calculate average of last three minutes usage.
    If last three minutes average is less than 125 kbps,
        Select host as "LBU host"
    End If
END

4.2.4. Access Rate Calculator

Access rate calculator plays important role in the model. As stated by Bejerano et al., the load of AP can be given in terms of time it takes to complete the transmission of certain amount of traffic [35]. In other words, certain amount of traffic should be created and time required for this purpose should be recorded to have an index value. It can be easily done by sending pre-loaded ICMP packages to the gateway. This module carries out this job. The proposed algorithm for this module is as follows:

Algorithm-4: Access Rate Calculator
INPUT: Name of associated AP
OUTPUT: Access rate per AP list
BEGIN
    Read associated AP from file
    Find GW using network configuration binary
    Send pre-loaded ICMP packages to GW
    Update file with newer access rate data per AP
END

4.2.5. Temporary Handoff Maker

Temporary handoff maker helps host to check load status of next AP in the coverage area. This procedure is carried out by making handoff to next AP, and then by running "access rate calculator" module. The process is repeated up to the last AP in

the area. In other words, this component helps host to associate with each AP in order to see access rate status of each. It differs from classical handoff procedure. Normally, a handoff is expected to occur if RSSI starts to decrease. But this is different. Next AP may offer lower RSSI when compared to previous one. However, if RSSI is over acceptable threshold, the host can work while connected to this lower RSSI AP, considering load sharing and throughput maximization. Proposed algorithm for this purpose is as foolws:

Algorithm-5: Temporary Handoff Maker
INPUT:
OUTPUT:
BEGIN
      Find associated AP
      Read number of AP from file generated by "check_ap" module
      If all APs haven't been associated with
            Read name of AP from file
            Associate with relevant AP by running "iwconfignew" module
            Run "access rate calculator" module to have index value for associated AP
            Update file having access rate index per AP
      End If
END

An important issue regarding handoff execution is keeping TCP's congestion window size at its current state. Since, the model requires subsequent handoff procedures, the host may be affected by restart of slow start phases by loosing TCP connection whenever handoff occurs. Even low traffic usage hosts may face with this problem. According to the idea behind the model, this loss may decrease total throughput. For this reason necessary action should be taken in order to keep congestion window at its current status. As proposed by Goff et al. sending zero window size propagation just before handoff will freeze re-transmit timer of the sender and enters it into a persist mode [10]. After successful handoff, a non-zero window propagation send by receiver will restart transmission of sender at previous window size, resulting in no loss in congestion window. In this model same approach is used. Problem with predicting correct handoff time which has been criticized by Lee et al. [33] and Qu et al. [4] will not be an issue in HBDTM, since handoff is requested by host itself but not a mandatory action activated by decrease in RSSI. Host's intend to handoff can activate precautions before handoff and may keep TCP transmission at its original state. For this reason another module is required.

Algorithm-6 shown below is designed for this reason. In this algorithm, one of the kernel parameters of Linux operating system is changed properly [36].

Algorithm-6: Handoff with Freezing TCP
INPUT: ESSID of next AP
OUTPUT:
BEGIN
       Check availability of given AP
       Set window size to zero by sending "0" to "/proc/sys/net/core/rmem_max" file
       Associate with the AP of given ESSID
       Set window size to previous value (default value is 131071 for Linux)
END

4.2.6. Result Analyzer

Last component deals with analyzing results. After finishing subsequent temporary handoff procedures together with rate calculation at each, host should decide which AP is BAROG AP to associate with. This procedure compares load indexes of all APs, which are calculated by "access rate calculator" and chooses BAROG AP. The following algorithm is used for this purpose.

Algorithm-7: Result Analyzer
INPUT: File generated by Access Rate Calculator module
OUTPUT:
BEGIN
       Sort file generated by "Access Rate Calculator" according to index value
       Find ESSID of lowest index BAROG AP
       If not already associated with this AP
              Associate with it
       End If
END

4.3. Sample Output

When model run manually, its stages can be seen in the screen. According to the bandwidth usage characteristics of host, one of the following outputs is expected to be seen.

For LBU host, the whole procedures defined in the model are carried out and depending on comparison of index values "T" and "K", one of the following outputs can be seen:

Phase-0:Associate with the AP with higher RSSI if not already associated:
➔ Already associated to AP "AP_i"
Phase-1:Check number of AP available and link quality of each:
➔ AP "AP_i" has link quality of "X"
➔ AP "AP_j" has link quality of "Y"
Phase-2:Identify bandwidth usage of host:
➔ Host is selected to make temporary handoff.
➔ It has average of "Z" kBps bandwidth usage for last three minutes.
Phase-3:Calculate access rate to GW through currently associated AP:
➔ Access rate index when associated to AP "AP_i" is "T"
Phase-4:Execute temporary handoff to next AP and re-calculate access rate to GW:
➔ Associated to AP "AP_j"
➔ Access rate index when associated to AP "AP_j" is "K"
Phase-5:Best AP selection and last association:
➔ Currently associated to best AP. No more handoff required.

Phase-0:Associate with the AP with higher RSSI if not already associated:
➔ Already associated to AP "AP_i"
Phase-1:Check number of AP available and link quality of each:
➔ AP "AP_i" has link quality of "X"
➔ AP "AP_j" has link quality of "Y"
Phase-2:Identify bandwidth usage of host:
➔ Host is selected to make temporary handoff.
➔ It has average of "Z" kBps bandwidth usage for last three minutes.
Phase-3:Calculate access rate to GW through currently associated AP:
➔ Access rate index when associated to AP "AP_i" is "K"
Phase-4:Execute temporary handoff to next AP and re-calculate access rate to GW:
➔ Associated to AP "AP_j"
➔ Access rate index when associated to AP "AP_j" is "T"
Phase-5:Best AP selection and last association:
➔ Best AP is "AP_i". Now tries to re-associate with it.
➔ Associated to AP "AP_i".

If host is a non-LBU host, the model output will be as following:

Phase-0:Associate with the AP with higher RSSI if not already associated:
➔ Already associated to AP "AP_i"
Phase-1:Check number of AP available and link quality of each:
➔ AP "AP_i" has link quality of "X"
➔ AP "AP_j" has link quality of "Y
Phase-2:Identify bandwidth usage of host:
➔ Host is not an LBU host…
➔ Skipping remaining procedures.
➔ !!!!!!!!!!END!!!!!!!!!!!

CHAPTER 5

TEST AND DISCUSSION

In order to see operability of HBDTM model, some test procedures have been designed. At this point, the main aim is to show not only functionality of new model but also its contribution to load balancing and throughput maximizing efforts. At test stage, modules given in Section 4.2 have been used.

5.1. Specification of Test Environment

Instead of using network simulator such as "ns", "OPNET" or "OMNET" it has been preferred to see usage of model in real world. All test procedures have been carried out at the open office of Data Processing and Communication Department of Undersecretariat of Customs in Ulus, Ankara. Figure 5.1 shows the test bed environment.
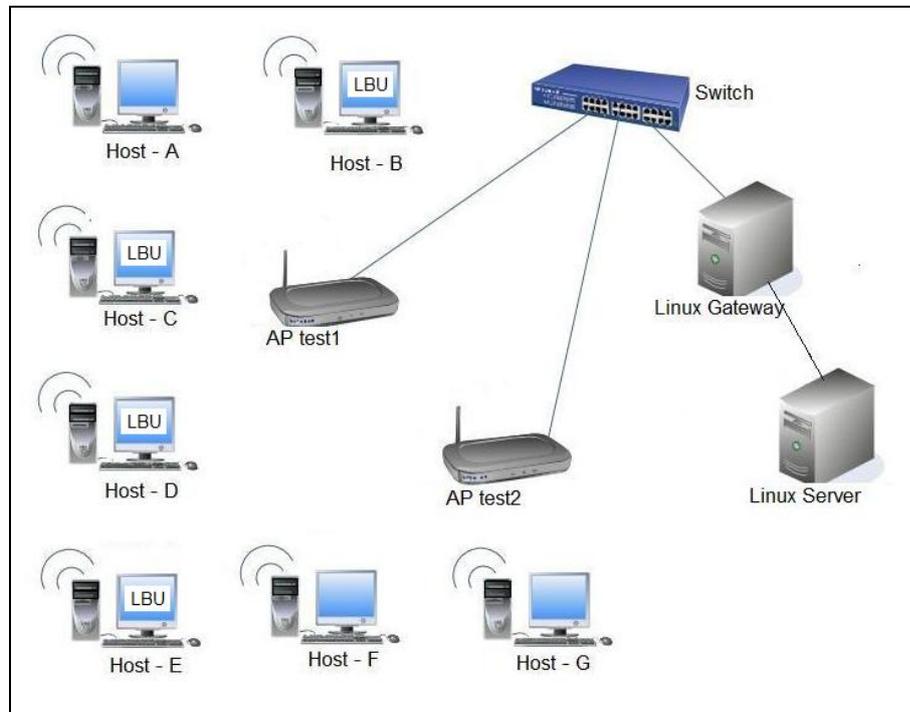
Figure 5.1: Test Bed Design

In the test bed, two APs connected to a switch which had another connection to a PC acting as gateway to another server have been used. Seven hosts equipped with wireless adapters have been associated with two APs manually. Linux gateway with two Ethernet interfaces was used as a router to access to server located out of the LAN. To be able to see usage of model, one AP has been set to have different uplink speed at its connected switch port during the test. In order to minimize outer effects, those may deteriorate test results, necessary cares have been taken. In the area covering test hosts, only test APs have been allowed to operate, but no other. Similarly, in order to be sure that all data communication at each host has been carried out via WLAN interface, Ethernet interfaces have been disabled.

5.1.1. Wireless Hosts and Gateway

At test phase, desktop computers equipped with wireless adapters (ASUS WL-167g USB WLAN Adapter) have been used. All computers were 2.33 GHz CPU speed devices with 2 GB of RAM. They have their own Ethernet interfaces, but these interfaces have been disabled. All communication has been realized through wireless interface. In order to ignore time required to ask IP addresses from DHCP server after handoff, all PC's have been set to have static IP configuration.

Wireless hosts, gateway and server have been chosen to be operated by Linux. Being a General Public License (GPL) powered open source software, having every "thing" as a file and easiness of network connection management compared to MS Windows operating system are some reasons why Linux operating system has been chosen. It is not only easy to have support to manage devices via "man pages" but also lots of Internet web pages are ready to help you. Furthermore, having network usage statistics is as easy as reading a file (/proc/net/dev).

There are lots of Linux distributions, ranging from very small platforms like 10 MB (Tiny Core Linux) to enterprise level support promising platforms (Red Hat Enterprise Linux Advanced Platform, Novel-SUSE Linux Enterprise Server etc.). Some of the well known distributions are Red Hat / Fedora, Ubuntu, Debian, SUSE/openSUSE, Gentoo, Mandriva, CentOS and Slackware. Their differences are mainly based on packet manager program, selected packets, order and location of file, kernel chosen and support type. Some distributions require annual fee-based

support, while others are absolutely free to download and upgrade. Annual fee-based support requires subscription to have upgrades. One of the well known national distribution, Pardus is developed by The Scientific and Technological Research Council of Turkey (TÜBİTAK) and is Gentoo based distribution with its own management programs.

At test phase of the model, Ubuntu Linux Version 9.04 has been chosen as operating system for all of the wireless hosts whose original operating system installed were MS Windows XP. Ubuntu Linux has advantage of ability to run without installation [37]. In other words, it has been prepared to examine its usage without removing current operating system via so-called "live CD". You can start your computer with this CD and if you don't want to install it, you can run it at the memory. But at the gateway and server level, already installed Ubuntu Linux 8.10 Server edition operating system PCs have been used.

5.1.2. APs

Two APs (ASUS Wireless Router WL-520g) having same coverage area have been set up to bridge wireless hosts to wired infrastructure. In the test bed, it has been prepared such that each hosts had ability to associate with both APs as seen in Figure 5.1. Channels of APs have been manually set to 1 and 6 relatively to prevent possible signal interference. When active scanning has been initiated manually at each host, it has been noticed that all APs have more than 30/100 link quality. "Link Quality" term, seen in output of "iwconfig" binary which has been also recorded in the log file created by "bandwidth_usage_counter" module, is an aggregate value containing level of interference, bit or frame error rate, how good the received signal is, some of the timing synchronization value etc. depending totally on the driver of interface [38].

5.1.3. Codes

Using algorithms and idea mentioned in Chapter 4, necessary programs have been coded. At this stage, instead of shell scripting, one of the powerful programming languages Python has been used. Created by Guido von Rossum, Python programming language has some advantages such as, being an object-oriented language, having very clear readable syntax specification, ability to use in

application as a scripting languages, short coding etc. [39]. Since it has also a powerful operating system library (os and sys), shorter codes compared to even classical shell scripting can be written. Codes used during the test are given in Appendix-A.

5.2. Scenarios

First of all, each host has been charged to use some amount of network resources. But in contrary to definition given in Section 4.2.3, hosts have been charged with some over load. In other words, LBU hosts have been set with bandwidth usage of 1000 kbps, instead of 125 kbps as in definition. This modification was used to fill bandwidth of APs with limited number of hosts. During the test, each host has been assigned to one of the following groups:

- LBU host group having average of <1000 kbps (7500 kB/minute)
- Non-LBU host group having average of >1200 kbps (9000 kB/minute)

During the test, the hosts B, C, D and E have been assumed to be LBU hosts, while the hosts A, F and G have been set to be non-LBU hosts.

Two scenarios have been planned in order to test functionality of model. In the first scenario, the number of wireless hosts has been divided into two APs and three hosts have been associated with one AP and remaining four with other AP at initial phase. At this initial association stage, the hosts A, B and D have been associated with AP-test2 (ESSID was "test2"); while others (C, E, F and G) associated with AP-test1 (ESSID was "test1"). Before starting up the test, connected port of AP-test1 has been set to 10Mbps rate by changing parameters of the port. Then the hosts have been started to operate with charged load.

In order to make use of bandwidth served by APs, the hosts send ICMP packets to the server through the gateway PC. LBU hosts have sent 15 kB of preset load to gateway in four separate sessions, i.e. totally 60 kB. While other hosts (non-LBU hosts), at six separate sessions, have sent totally 15x6=90kB. Due to characteristics of ICMP protocol, data sent is received by the sending host again. Therefore, the total bandwidth usage for a certain host is double of the created traffic. In other

words, the total bandwidth usage (transmit + receive) for LBU host is about 120 kB and it is 180 kB for non-LBU hosts.

After assigning loads to each host, the test has been started and the bandwidth usage of each host has been recorded at their own log file. In each log file, data on bandwidth usage has been indicated as sum of data transmitted and received. During the first test, the model has not yet been applied.

For second test, the proposed model with coded programs has been installed into each host and necessary configuration has been completed. Same association as in the first test has been manually arranged. Then the model has been run as a service to check automatically load status of each AP and balance load so as to maximize throughput. But in this second test, timeout period has been set to fix value of 180 seconds, instead of random value. The bandwidth usage of each host has also been recorded. In this second test, screenshot of the model has also been recorded. Sample screenshots are in Appendix-B.

5.3. Test

According to the test results Table 5.1 and Table 5.2 have been generated. In Table 5.1, the first column is duration of the test. In this first test, natural behavior of wireless hosts has been recorded for 30 minutes of test duration. As it can be seen from Table 5.1, no handoff has been recorded during this test. Hosts are charged with previously determined load and their minute based bandwidth usage data has been recorded. Under names of each host, amount of bandwidth usages calculated when associated with AP-test1 or AP-test2 is given in kB/min. As information on bandwidth usage of hosts is taken by reading "/proc/net/dev" file of hosts and the unit of usage is in the form of byte in this file, necessary convertion has been done in module "wlan_usage_counter" to have usage values in the basis of kB/min.

At initial phase (first test), Hosts C, E, F and G have been associated with AP-test1; and the others with AP-test2 as seen in the Table 5.1. Stated in Section 5.2, LBU hosts have been charged with 60 kB of ICMP packets and non-LBUs have been loaded with 90 kB of ICMP packets. In the table, value under name of associated AP shows minute based bandwidth usage created by these loads.

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Table 5.1: Initial Usage of Bandwidth (kB/min)

Time (min)	Host A AP-test1	Host A AP-test2	Host B AP-test1	Host B AP-test2	Host C AP-test1	Host C AP-test2	Host D AP-test1	Host D AP-test2	Host E AP-test1	Host E AP-test2	Host F AP-test1	Host F AP-test2	Host G AP-test1	Host G AP-test2
1		10786		4761	4716			7053	5912		7810		7924	
2		10259		6571	5708			6961	5131		8726		7626	
3		10346		6567	5411			7006	5493		7569		7963	
4		10724		6815	5143			6946	5795		6781		8216	
5		10898		6512	5945			7068	5195		6251		8020	
6		10546		6041	5311			7327	4168		6578		8659	
7		10508		6615	5480			7205	4496		6760		8423	
8		10773		6587	5482			7156	4575		7018		8409	
9		10862		6863	5461			7014	5658		6974		8192	
10		10929		6869	5210			6880	5157		7687		7701	
11		10759		6310	4579			6829	4417		7325		7464	
12		10800		7016	5228			7277	4457		8000		8220	
13		10487		7175	5598			7248	4612		8792		8245	
14		10313		7011	5398			7178	5466		8125		8454	
15		10538		6809	4862			7183	4872		7126		7146	
16		10724		6898	5444			6971	5356		7389		7567	
17		10464		7139	5969			7184	5604		7871		8377	
18		10272		6715	5867			6877	5346		6891		9061	
19		9459		6773	6133			6660	4965		7044		8381	
20		9596		6840	5096			6417	5242		7061		7922	
21		10400		6738	5262			7107	5719		7629		7602	
22		10856		6315	5013			7000	4980		7298		7270	
23		10776		6334	4747			7238	4813		7083		6773	
24		10915		6433	4749			7338	4878		6762		7628	
25		10778		6291	4725			7056	5151		7329		8002	
26		9827		5196	5649			6994	5860		8257		8157	
27		10487		5977	4811			7136	5094		7747		8672	
28		10612		6569	4717			7018	4433		7428		8085	
29		10585		6473	5348			6893	4732		8088		7671	
30		10526		6414	5896			7171	5308		7915		7380	

In Table 5.2, prepared in the same manner with Table 5.1, data on bandwidth usage has been obtained by using HBDTM Model. As seen in the table, Hosts A, F and G are non-LBU hosts. In other words, their usage can not be qualified as "low", but other hosts are LBU hosts and they are faced with subsequent series of handoff to find BAROG AP.

Table 5.2: Usage of Bandwidth with HBDTM Model (kB/min)

Time (min)	Host A		Host B		Host C		Host D		Host E		Host F		Host G	
	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2
1		10828	5090			6407		6209		6963	8508			10620
2		10364		4842	6019			7010	5179		8067			10615
3		10651	4700	5952				7078	4921		7410			10006
4		10730	4679	5708	6977				4968		8335			10543
5		10216	4969	5278				6750	4953		8571			10720
6		10746		6287	5810			7272	5055		8085			10204
7		10591		6770	5698			7145	6149		8614			10413
8		10786		7000	5260	5638				5723	7027			10351
9		10412	6714			6121	5829			6971	8298			10160
10		10832	5850			7144	6130			6892	8558			10786
11		10741	5228			6522		5466		7078	7634			10750
12		10503	5406			5502		7304	5610		7815			10470
13		10758		6716		6679		7228	6092		8544			10820
14		10845		6824		6544		7223	6227		9142			10715
15		10482		6567	6347	6634				5447	9260			10084
16		10617		6209		6674	5865			7095	8086			10622
17		10000		6874		6111	5613			6847	8060			10295
18		9976		6959		6404		5999		7039	8128			10613
19		10444		6967	5932	6162				6463	7089			10194
20		10541		7000	5833	5744				6986	7610			10673
21		10434		7093	6178	4816				7147	8745			10341
22		10439		6811		6033		6502		6602	7142			10301
23		10562	6089		5647			7292		7178	7442			10545
24		10600	5286		5942			6910		7084	7103			10816
25		10349	5545		6977			6261		6909	8147			10292
26		10528	5568			6303		6925		6528	8802			10355
27		10291		6694		6463		6998		7225	9640			10305
28		10560		6739		6610		7055		7038	9132			10089
29		10737		6870	6438	6607			6331		7862			10482
30		10610		6912		5862	5309		5580		7274			10572

Total bandwidth usage on cumulative and minute basis can be seen in Table 5.3 prepared using data given in Table 5.1 and 5.2. As it can be understood from Table 5.3, the cumulative bandwidth usage increases from initial phase value of 1497190 kB to 1627942 kB when HBDTM Model is applied.

Similarly, the following table, Table 5.4, can be prepared when Table 5.1 and 5.2 are analyzed for each AP. In the table, cumulative bandwidth (kB) and minute based (kB/min) usage data are given on the basis of kB and kB/min.

Table 5.3: Total and Minute Based Throughput
with and without HBDTM Model

Time (min)	TOTAL THROUGHPUT (kB)		MINUTE BASED THROUGHPUT (kB/min)	
	Initial	With HBDTM Model	Initial	With HBDTM Model
1	48962	54625	48962	54625
2	99944	106721	50982	52096
3	150299	157439	50355	50718
4	200719	209379	50420	51940
5	250608	260836	49889	51457
6	299238	314295	48630	53459
7	348725	369675	49487	55380
8	398725	421460	50000	51785
9	449749	475965	51024	54505
10	500182	532157	50433	56192
11	547865	585576	47683	53419
12	598863	638186	50998	52610
13	651020	695023	52157	56837
14	702965	752543	51945	57520
15	751501	807364	48536	54821
16	801850	862532	50349	55168
17	854458	916332	52608	53800
18	905487	971450	51029	55118
19	954902	1024701	49415	53251
20	1003076	1079088	48174	54387
21	1053533	1133842	50457	54754
22	1102265	1187672	48732	53830
23	1150029	1242427	47764	54755
24	1198732	1296168	48703	53741
25	1248064	1350648	49332	54480
26	1298004	1405657	49940	55009
27	1347928	1463273	49924	57616
28	1396790	1520496	48862	57223
29	1446580	1575823	49790	55327
30	1497190	1627942	50610	52119

According to the data shown in Table 5.3, the load transfer is achieved at the end of series of handoff, caused by HBDTM. Detailed calculation can be seen in Table 5.4.

Table 5.4: Throughput and Load Ratios of APs

Phase	AP-test1		AP-test2		Total Throughput (kB)
	Throughput (kB)	% Load	Throughput (kB)	% Load	
Initial	774367	51.72	722823	48.28	1497190
With HBDTM Model	530662	32.60	1097280	67.40	1627942

If transferred load ratio has been calculated using data given in Table 5.4, following value could be obtained.

Transferred Load = (774367 − 530662) / 774367 x 100 = 31.47%

By the help of data given in Table 5.3, following graphs in Figure 5.2 and 5.3 are obtained. Graph in Figure 5.2 shows cumulative throughput values initially and after employment of the model. Total throughput increase can be seen in the graph.
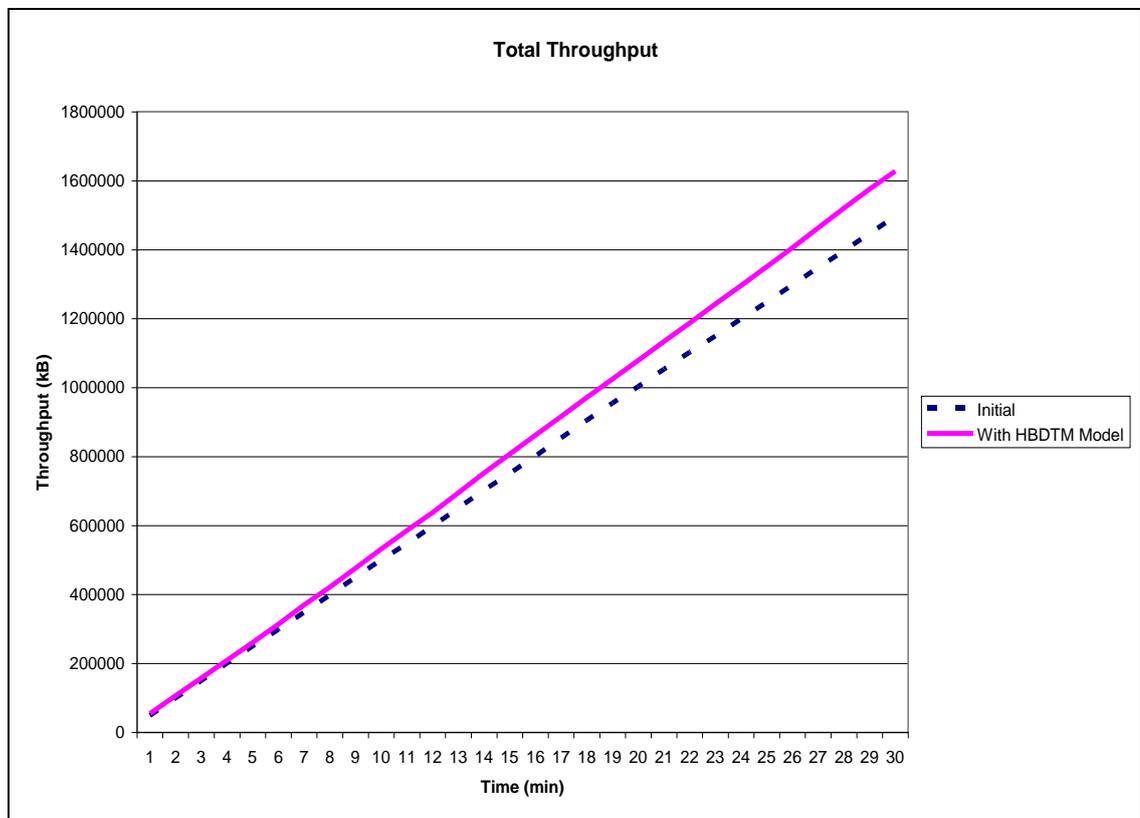

Figure 5.2: Graph Showing Total Throughput Initial and With HBDTM Model
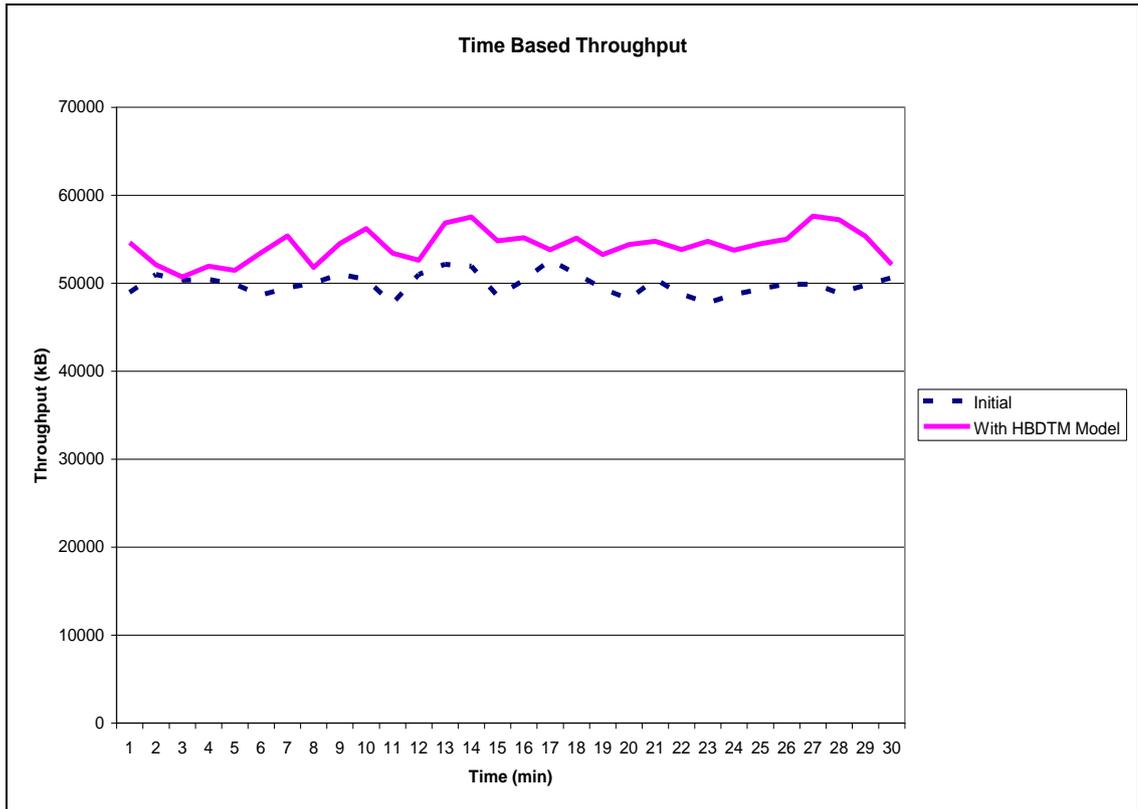
Figure 5.3: Graph Showing Time Based Bandwidth Usage Initial and
With HBDTM Model

Graph drawn in Figure 5.3 shows minute based throughput values. It is seen that, starting from first minute, the model performs as it is expected and lasts to the end of the test.

As it can be seen from the graphs above, HBDTM model runs as it is intended. The total and minute based throughputs increase when the model is applied to the environment having at least two APs. Calculated benefit (contribution of the model) at the end of the test can be calculated as follows:

$$\text{Contribution of the Model} = (1627942 - 1497190) / 1497190 \times 100$$
$$= 8.73 \%$$

Link quality of each host has been also recorded during test. Data on link quality gathered at initial phase are shown in Table 5.5.

Table 5.5: Initial Link Quality of Wireless Connections

Time (min)	Host A		Host B		Host C		Host D		Host E		Host F		Host G	
	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2
1		40		33	36			40	31		35		29	
2		40		32	35			39	29		35		31	
3		37		31	36			36	30		33		31	
4		40		32	35			38	31		32		31	
5		40		31	36			39	30		32		30	
6		40		32	35			39	30		33		31	
7		40		32	36			38	30		32		33	
8		41		32	35			39	30		32		31	
9		39		32	36			38	31		32		31	
10		40		33	36			38	29		33		30	
11		40		32	34			41	30		32		31	
12		39		33	36			38	30		33		31	
13		40		33	36			38	30		34		32	
14		39		32	36			38	30		33		30	
15		40		33	35			39	30		33		30	
16		40		33	35			40	31		33		30	
17		39		32	37			39	30		34		30	
18		38		33	36			37	29		32		31	
19		39		33	36			37	30		32		30	
20		41		33	34			37	31		32		30	
21		38		34	35			39	31		33		32	
22		40		33	36			38	30		33		30	
23		39		32	35			40	31		33		31	
24		40		32	35			39	30		33		32	
25		41		32	36			38	30		33		32	
26		39		31	35			37	30		33		30	
27		40		32	35			38	30		32		31	
28		39		32	35			41	30		35		31	
29		39		33	35			40	31		33		31	
30		35		31	36			37	31		34		30	

Ling quality data obtained after the application of HBDTM Model can be seen in Table 5.6. Both tables (Table 5.5 and Table 5.6) show that all hosts have ability to associate with each AP during the test. Description of "link quality" has been given in Section 5.1.2.

Table 5.6: Link Quality of Wireless Connections
with HBDTM Model

Time (min)	Host A		Host B		Host C		Host D		Host E		Host F		Host G	
	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2	AP-test1	AP-test2
1		40	32			36		39		33	34			35
2		41		34	37			42	30		33			33
3		39	33		37			41	30		33			33
4		40	33		36		51		30		36			33
5		54	34		36			39	31		35			34
6		40		33	37			41	30		35			34
7		40		33	35			41	31		35			34
8		41		34	35		34			49	34			34
9		35	34		35	38				32	37			34
10		41	34		35	35				33	35			34
11		41	33		34		40			33	36			35
12		41	33		35		41	32			51			34
13		41		34	35		41	31			36			35
14		39		32	35		40	32			36			33
15		42		35	34		39			32	37			50
16		40		32	35	36				32	34			34
17		40		32	35	36				31	37			34
18		40		32	36		40			32	35			35
19		40		50	34		36			32	33			35
20		42		33	35		35			32	33			34
21		40		33	37		35			33	35			35
22		41		32		36		41		49	34			36
23		41	33		36			39		32	33			35
24		41	33		37			39		32	35			35
25		40	34		37			39		32	36			35
26		40	33			35		39		33	35			35
27		41		32		35		39		32	33			34
28		40		32		36		40		32	35			35
29		42		33	36		35		30		32			35
30		39		31		34	35		31		33			30

By using data given in Table 5.5 and Table 5.6, average link quality is calculated per AP. It is noticed that average link quality of AP-test1 increases as the model is applied.

Table 5.7: Average Link Quality per AP Initially and with HBDTM Model

Phase	AP-test1	AP-test2
Initial	32.35	36.73
with HBDTM Model	34.71	36.65

By the help of the model, average link quality of APs converged to each other. Initially 32.35/100 value of link quality of AP-test1 has increased to the value of 34.71/100. This means an increase in link quality as following.

$$\text{Link Quality Increase} = (34.71 - 32.35) / 32.25 \times 100$$
$$= 7.29 \%$$

At each model run during the test, if host is an LBU host, preloaded ICMP packets was sent to the gateway in order to get access rate index value while associated with each AP. This traffic has also been included in the test results. According to the test results given in Table 5.2, five hosts have made handoff i.e. executed the model. So, following extra traffic should be included in the total throughput values:

$$\text{Extra Traffic} = 5 \times 30 \text{ minutes} / 180 \text{ seconds timeout} \times 1024 \text{ byte}$$
$$= 5 \times 10 \text{ executions} \times 1 \text{ kB}$$
$$= 50 \text{ kB}$$

When considering total throughput with the contribution of the model (1627942 kB), following value as the cost of the model can be calculated;

$$\text{Cost of the model} = 50 \text{ kB} / 1627942 \text{ kB} \times 100$$
$$= 0.00307 \%$$

5.4. Analysis of Test Results

For implementation of the model, real test bed has been preferred. Testing model in real world has some disadvantages as well as advantages. Natural behavior of the model has been seen during the test. However, some problems, such as un-controllable interference may have an impact on throughput values, i.e. variation in bandwidth usage values, while during the test necessary actions have been taken.

During the test, LBU hosts have been chosen as the hosts with less than 1000 kbps of usage characteristics and period of model run has been set to 180 seconds. However, some parameters have been fixed just for the sake of showing functionality of model.

Test with two scenarios has shown HBDTM model's contribution to throughput maximizing efforts. 8.73% of increase in the bandwidth usage has been reached at the end of the test.

One of the most important results achieved from the test is to get balancing load idea. Calculated by data taken from Table 5.4, 31.47% load of AP-test1 has been transferred to AP-test2 which has 100 Mbps of uplink speed to the wired infrastructure. This transfer has decreased load on AP-test1 from 51.72% to 32.60% and increased load at AP-test2 from 48.28% to 67.40%. With this transfer, load balancing considering capacity of each AP has been reached.

According to the Table 5.5, 5.6 and 5.7, average "link quality" of wireless connections has also increased with the model. Table 5.7 shows that, with the help of the model, AP-test1 has transferred some of the loads to AP-test1, serving remaining associated hosts better link quality. Previously, the average link quality of 32.35/100 has increased to 34.71/100 that means an increase of 7.29%, while it hasn't changed for AP-test2. What it must be understood from this increase is that, by the help of the model, some of the loads initially on AP-test1 has been transferred to less loaded BAROG AP, AP-test2 and remaining hosts at AP-test1 reached to better environment i.e. better link quality.

In the definition of the model, it has been emphasized that, contrary to classical load balancing idea, this model considers both interfaces of AP. As a result of this idea, AP-test1 connected to the port of switch with 10 Mbps speed has been obstructed with load generated by the associated hosts. The model transfers some of the hosts to BAROG AP (AP-test2) not only to offer them better access rate but also to serve the remaining hosts more bandwidth resources. Since the aim of the model is to balance load in order to "maximize throughput", the model runs correctly with supporting results compliant with the idea behind the model.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

Increasing popularity of the wireless communication attracts researchers to propose solutions for wireless specific problems. There are different works considering wireless anomaly, handoff latency and load balancing to support wireless networking idea. Many proposals have been given, especially for load balancing problem, but none of them has been accepted as a standard by IEEE 802.11 Working Group.

In this study, a "novel" approach has been proposed. According to this approach, the host dynamically monitors its bandwidth usage and decides its candidacy for temporary handoff, and then makes series of temporary handoff to all available APs to find the best one to associate with. Associating with this AP does not ensure living in balanced load environment. In other words, disassociation of only one host from over-loaded AP for association with less loaded one cannot finish load balancing process. However, at the end of some series of handoff process, LBU hosts find and associate with the best AP i.e. BAROG AP. At the end of these procedures, throughput maximization with balanced load is reached.

On the other hand, the model's contribution to load balancing and throughput maximizing effort has been proven by the test mentioned in Chapter 5. Calculated value of 31.47% of load has been transferred to less loaded BAROG AP by the help of the model. In other words, thanks to the model, the host decides which AP to associate with in order to have better bandwidth usage, leading balanced load in the environment. As a consequence of this approach, better bandwidth usage characteristics have been reached as seen in Figure 5.2 and 5.3 with 8.73% of increase in total throughput. An increase has been seen not only in total throughput, but also in link quality values. At the end of the test, 7.29% of increase in link quality of previously over-loaded AP has been recorded by the help of load transfer initiated

by the model. Finally, all hosts living either in over-loaded AP or BAROG AP have better bandwidth usage with better link quality leading to increase in total throughput.

At the end of the test it has also been proven that, running only an HBDTM Model agent in a wireless host is enough to have better bandwidth usage in a multiple AP environment where all APs will be loaded with respect to their capacity considering both interfaces. Because of the new idea behind the model, no similar approach mentioned in previous research could be found in order to compare benefit arisen from the application of the model. At the same time, there is no generally accepted test bed design such that every proposed solution in balancing load could be proven. Every researcher uses different test bed and scenario to prove his/her approach. For this reason, figures from previous proposals may vary if they are tried to be proven in different scenarios. However, it is evident that significant benefit can be reached by using autonomous and dynamic HBDTM Model in such a way that, no need to consider brand of APs, security vulnerabilities arising from central server or protocol revisions.

But in an environment with less number of wireless hosts or low traffic usage state where APs are not over-loaded, the model may not be needed in order to balance load. It may also be true for the model to have no effect on balancing load where all available APs are over-loaded. In such cases, the model runs as it is expected, but contribution of the model may not be worth mentioning. Furthermore, the cost of the model is so negligible that in such environments, it may create some extra traffic, but not as mush as it can not overcome.

As future work, the following improvements are needed in the model in order to have better model:

- LBU host should be determined dynamically, i.e. the level defining LBU host should be changed accordingly during operation of the model.
- Functionality of the model should be proven in an environment with full of moving wireless hosts.

- If it is running in an environment with full of LBU hosts, candidacy of LBU hosts should be controlled by the historical handoff actions. In other words, to prevent frequent handoff of hosts, either the number of handoff per host may be limited or timeout period may be extended.

- Functionality of the model should be monitored in an environment on which some hosts are equipped with 802.11b interface and others with 802.11g. According to the idea behind the model, it can also be a solution to wireless anomaly problems. Hosts with 802.11b equipped interfaces may be associated with a specific AP to keep others running at higher rate.

- Functionality of the model should also be checked in an environment with different technological wireless infrastructure. In other words, ability of the model should be checked in an environment where frequent vertical handoffs occur.

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APPENDIX A

PROGRAM CODES

wlan_usage_counter:

```
#!/usr/bin/python
import os
essid=""
result=""
quality=0
sec=0
os.system("date +%k:%M:%S--%d-%m-%Y > /tmp/time")
os.system("touch /MKG/TEZ/var/first")
time=str(os.popen("cat /tmp/time | awk '{print $1}'").readlines()[0].strip())
zero=int(os.popen("cat /MKG/TEZ/var/first | awk '{print $1}'").readlines()[0].strip())
recwlan=int(os.popen("cat /proc/net/dev | grep wlan0 | sed 's/:/ /' | awk '{print $2}'").readlines()[0].strip())
trawlan=int(os.popen("cat /proc/net/dev | grep wlan0 | sed 's/:/ /' | awk '{print $10}'").readlines()[0].strip())

assoc=str(os.popen("cat /MKG/TEZ/var/associatedap | awk '{print $1}'").readlines()[0].strip())
quality=str(os.popen("/sbin/iwconfig wlan0 | grep Quality | sed 's/=/ /' | awk '{print $3}'").readlines()[0].strip())

tmpnow=recwlan + trawlan
now=tmpnow /1000
diff=now - zero

os.system("echo "+time+" "+assoc+" "+quality+" "+str(diff)+" >> /MKG/TEZ/var/usage")
os.system("echo "+str(now)+ "> /MKG/TEZ/var/first")
```

HBDTM_MODEL:

```python
#!/usr/bin/python
import os
################################################################################################################
##### PHASE 0 #### Associate to the AP with higher RSSI if not already associated ####################
################################################################################################################
os.system("echo 'Phase-0:Associate to the AP with higher RSSI if not already associated:'")
test=os.popen("/sbin/iwconfig wlan0 | grep Access | awk '{print $6}'").readlines()[0].strip()
if test=='Not-Associated':
    os.system("echo \t->Not associated. Tries to do.'")
    os.system("/MKG/TEZ/bin/classical_connect")
else:
    associated=os.popen("/sbin/iwgetid | sed 's/:/ /' | awk '{print $3}'").readlines()[0].strip()
    os.system("echo \t->Already associated to AP '"+associated+".")
    os.system("echo "+associated+" > /MKG/TEZ/var/associatedap")
################################################################################################################
##### PHASE 1 #### Check number of AP available and link quality of each #############################
################################################################################################################
os.system("echo 'Phase-1:Check number of AP available and link quality of each:'")
os.system("/MKG/TEZ/bin/check_ap")
################################################################################################################
##### PHASE 2 #### Identify host's bandwidth usage ##################################################
################################################################################################################
number_of_ap=int(os.popen("cat /MKG/TEZ/var/ap_list | wc -l").readlines()[0].strip())
if number_of_ap > 1:
    os.system("echo 'Phase-2:Identify bandwidth usage of host:'")
    os.system("/MKG/TEZ/bin/host_chooser")
################################################################################################################
##### PHASE 3 #### Calculate access rate to gw through currently associated AP ######################
```

```
###############################################################################################################
        os.system("echo 'Phase-3:Calculate access rate to GW through currently associated AP'")
        chosen=int(os.popen("cat /MKG/TEZ/var/chosen_host").readlines()[0].strip())
        if chosen==1:
            os.system("/MKG/TEZ/bin/rate_calculator")
###############################################################################################################
##### PHASE 4 #### Execute temporary handoff to next AP and re-calculate access rate to GW ###########
###############################################################################################################
            os.system("echo 'Phase-4:Execute temporary handoff to next AP and re-calculate access rate to GW'")
            os.system("/MKG/TEZ/bin/temp_handoff_maker")
###############################################################################################################
##### PHASE 5 #### Best AP selection and last association ###########################################
###############################################################################################################
            os.system("echo 'Phase-5:Best AP selection and last association'")
            os.system("/MKG/TEZ/bin/decision_maker")
        else:
            os.system("echo '\t->Host is not a low bandwidth usage host.'")
            os.system("echo '\t->Skipping remaining procedures.'")
            os.system("echo '\t->!!!!!!!!!!END!!!!!!!!!!'")
else:
        os.system("echo '\t->There is only 1 AP to associate. Unable to balance load.'")
        os.system("echo '\t->Skipping remaining procedures.'")
        os.system("echo '\t->!!!!!!!!!!END!!!!!!!!!!'")
_____
```

classical_connect:

```python
#!/usr/bin/python
import os
q=0
q_new=0
ap=""
os.system("/sbin/iwlist wlan0 scanning | grep ESSID | sed 's/:/ /' | awk {'print $2'} | sed 's/\"//g' > /MKG/TEZ/var/ap_list")
number_of_ap=int(os.popen("cat /MKG/TEZ/var/ap_list | wc -l").readlines()[0].strip())
while number_of_ap>0:
    essid=os.popen("cat /MKG/TEZ/var/ap_list | tail -" + str(number_of_ap) +" | head -1").readlines()[0].strip()
    q_new=os.popen("/sbin/iwlist wlan0 scanning | grep -A 4 " + essid + " |grep \
Quality | sed 's/\=/ /' | awk '{print $2}'| sed 's/\// /' | awk '{print $1}'").readlines()[0].strip()
    if q_new>q:
        q=q_new
        ap=essid
    number_of_ap=number_of_ap-1
os.system("/MKG/TEZ/bin/iwconfignew " + ap)
os.system("echo "+ap+" > /MKG/TEZ/var/associatedap")
```

check_ap:

```python
#!/usr/bin/python
import os
essid=""
quality=0
os.system("/sbin/iwlist wlan0 scanning | grep ESSID | sed 's/:/ /' | awk {'print $2'} | sed 's/\"//g'  > /MKG/TEZ/var/ap_list")
number_of_ap=int(os.popen("cat /MKG/TEZ/var/ap_list | wc -l").readlines()[0].strip())
while number_of_ap>0:
    essid=os.popen("cat /MKG/TEZ/var/ap_list | tail -" + str(number_of_ap) +"  | head -1").readlines()[0].strip()
    quality=os.popen("/sbin/iwlist wlan0 scanning | grep -A 4 " + essid + " |grep Quality |\
sed 's/\=/ /' | awk '{print $2}'| sed 's/\// /' | awk '{print $1}'").readlines()[0].strip()
    os.system("cat /MKG/TEZ/var/ap | grep -v "+essid+" > /MKG/TEZ/tmp/ap; mv /MKG/TEZ/tmp/ap /MKG/TEZ/var/ap")
    os.system("echo "+essid+" "+str(quality)+" >> /MKG/TEZ/var/ap")
    print "\t->AP "+essid+" has link quality of "+str(quality)
    number_of_ap=number_of_ap-1
```

tcpnormal:

```
echo 131071 > /proc/sys/net/core/rmem_max
echo "window size is normal"
```

tcpzero:

```
echo 0 > /proc/sys/net/core/rmem_max
echo "window size is set to zero"
```

decision_maker:

```python
#!/usr/bin/python
import os
best_ap=os.popen("cat /MKG/TEZ/var/load |sort -k2 |head -1 | awk '{print $1}'").readlines()[0].strip()
current_ap=os.popen("cat /MKG/TEZ/var/associatedap | awk '{print $1}'").readlines()[0].strip()
if best_ap<>current_ap:
    os.system("echo '\t->Best AP is "+best_ap+". Now tries to re-associate it.'")
    os.system("/MKG/TEZ/bin/iwconfignew "+best_ap)
else:
    os.system("echo '\t->Currently associated to best AP. No more handoff required.'")
```

_____

temp_handoff_maker:

```python
#!/usr/bin/python
import os
associated_ap=os.popen("cat /MKG/TEZ/var/associatedap | awk '{print $1}'").readlines()[0].strip()
os.system("cat /MKG/TEZ/var/ap | grep -v "+associated_ap+" > /MKG/TEZ/var/next_aps")
number_of_next_ap=int(os.popen("cat /MKG/TEZ/var/next_aps | wc -l").readlines()[0].strip())
while number_of_next_ap>0:
    next_ap=os.popen("cat /MKG/TEZ/var/next_aps | tail -"+str(number_of_next_ap)+" | head -1").readlines()[0].strip()
    os.system("/MKG/TEZ/bin/iwconfignew "+next_ap)
    os.system("echo "+next_ap+" > /MKG/TEZ/var/associatedap")
    number_of_next_ap=number_of_next_ap-1
    os.system("/MKG/TEZ/bin/rate_calculator")
```

host_chooser:

```python
#!/usr/bin/python
import os
os.system("echo 0 > /MKG/TEZ/var/chosen_host")
t0=int(os.popen("tail -3  /MKG/TEZ/var/usage | head -1 | awk '{print $4}'").readlines()[0].strip())
t1=int(os.popen("tail -2  /MKG/TEZ/var/usage | head -1 | awk '{print $4}'").readlines()[0].strip())
t2=int(os.popen("tail -1  /MKG/TEZ/var/usage | head -1 | awk '{print $4}'").readlines()[0].strip())
last3minute=(t0+t1+t2)/3
os.system("echo "+str(last3minute)+" > /MKG/TEZ/var/movingaverage")
if last3minute<7500:
     os.system("echo 1 > /MKG/TEZ/var/chosen_host")
     print "\t->Host is selected to make temporary handoff."
     print "\t->It has "+str(last3minute)+" kBps bandwidth usage for last three minutes."
else:
     os.system("echo 0 > /MKG/TEZ/var/chosen_host")
     print "\t->Host is not low bandwidth usage host..."
```
_____

rate_calculator:

```python
#!/usr/bin/python
import os
time=0.0
times=0.0
gateway=os.popen("/bin/netstat -nr | grep 0.0.0.0 | grep G | awk '{print $2}'").readlines()[0].strip()
associated_ap=os.popen("cat /MKG/TEZ/var/associatedap | awk '{print $1}'").readlines()[0].strip()
os.system("/bin/ping -s 1024 "+gateway+" -c 10 | grep icmp | sed 's/=/ /g' | awk '{print $10}'| sort | tail -8 | head -5 > /MKG/TEZ/tmp/pingtime")
for i in range(1,6):
    time=float(os.popen("cat /MKG/TEZ/tmp/pingtime |head -"+str(i)+" |tail -1").readlines()[0].strip())
    times=times+time
average=times/5
os.system("cat /MKG/TEZ/var/load | grep -v "+associated_ap+" > /MKG/TEZ/var/load_tmp ;\
mv /MKG/TEZ/var/load_tmp /MKG/TEZ/var/load ")
os.system("echo "+associated_ap+" "+str(average)+" >> /MKG/TEZ/var/load")
print "\t->Access rate index when associated to AP "+associated_ap+ " is "+str(average)+"."
```

iwconfignew:

```python
#!/usr/bin/python
import sys, os
list=[]
for arg in sys.argv:
    list.append(arg)
ap=list[1]
if ap=="test1":
    ch=1
if ap=="test2":
    ch=6
control=0
exist=int(os.popen("/sbin/iwlist wlan0 scanning | grep ESSID | grep "+ ap+" | wc -l").readlines()[0].strip())
if exist==1:
    os.system("/MKG/TEZ/bin/tcpzero")
    while control==0:
        os.system("/sbin/iwconfig wlan0 channel "+str(ch)+" essid "+ap)
        os.system("sleep 1s")
        control=int(os.popen("/sbin/iwconfig wlan0 | grep Access\ Point | awk {'print $6'} | grep -v Not | wc -l ").readlines()[0].strip())
        os.system("sleep 1s")
    os.system("/MKG/TEZ/bin/tcpnormal")
    os.system("echo '\t->Associated to AP '"+ap
```

APPENDIX-B

SAMPLE SCREENSHOT

Screenshot captured from Host B (one of LBU host)