



## Review of Methods for Estimating the Decay Constant ( $k$ ) of Horton's Infiltration Model

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### ABSTRACT

Horton's equation is one of the earliest and most popular empirical models for simulating infiltration. The aim of this paper is to review and recommend the best method for determining Horton's decay constant from a number of methods in terms of its simplicity and accuracy. Six (6) infiltration tests was carried out and the average of the six tests was used for determining the steady state infiltration rate  $i_c = 4\text{cm/hr}$  and initial infiltration rate  $i_0 = 34\text{cm/hr}$ . Three methods were used to evaluate the decay constant  $k$ , Method I and III gave same result 0.8099 and the result of Method II is 0.8086. It is clear that there is no significant difference between the results, although they are supposed to be the same, the challenge with method II is the fact that it is very error prone. Method I is highly recommended above Method II and III because it is less disposed to error and simple to calculate.

**Key words:** Decay constant, linear regression, infiltration capacity, Horton's model

### INTRODUCTION

Infiltration is the process by which water seeps into the ground through the surface of the earth (Beven, 2004; Thornes, 2009). Horton's equation is the most popular empirical model for the simulation of infiltration. The equation named after Robert E. Horton (1940), is a semi-empirical formula that says that infiltration starts at a constant rate,  $i_0$ , and is decreasing exponentially with time,  $t$ . After some time when the soil saturation level reaches a certain value, the rate of infiltration will level off to the rate  $i_c$ . The infiltration rate is given by:

$$i = i_c + (i_0 - i_c)e^{-kt} \text{-----} \quad \text{Eq. [1]}$$

Then the cumulative Infiltration is the integral of equation 2.10

$$I = i_c t + \frac{i_0 - i_c}{k} [1 - e^{-kt}] \text{-----} \quad \text{Eq. [2]}$$

Where  $I$  is the cumulative infiltration,  $i$  is the infiltration rate at time  $t$ ;  $i_0$  is the initial infiltration rate or maximum infiltration rate;  $i_c$  is the constant or equilibrium infiltration rate after the soil has been saturated or minimum infiltration rate;  $k$  is the decay constant specific to the soil. Different methods have been used by different researchers for determining the equation's parameters, this paper is a review of the methods for determining Horton's decay constant with a specific aim to ascertain the most suitable, simple and accurate method.

### MATERIALS AND METHODS

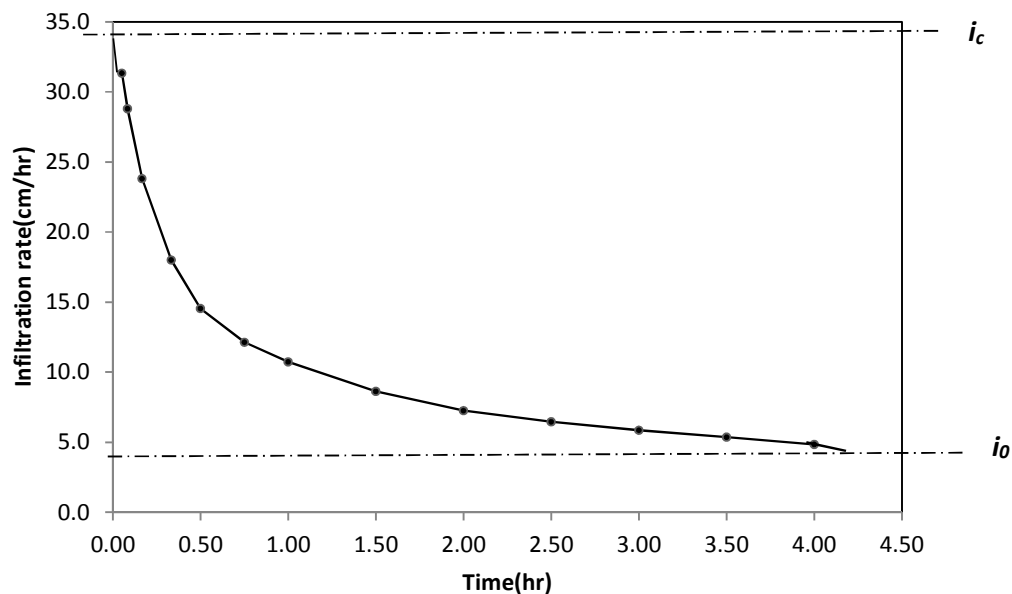
#### Data Collection and Analysis

Secondary cumulative infiltration data collected at six points at the experimental plot of the Department of Agricultural Engineering, Ahmadu Bello University was taken from Ajayi (2015) as shown in Table 1 below, and the average was used to estimate the parameters of the models.



Time (hr)	Cumulative Infiltration $I$ (cm)	Infiltration rate $i$ (cm/hr)
0.05	1.57	31.33
0.08	2.40	28.80
0.17	3.97	23.80
0.33	6.00	18.00
0.50	7.27	14.53
0.75	9.10	12.13
1.00	10.73	10.73
1.50	12.93	8.62
2.00	14.50	7.25
2.50	16.17	6.47
3.00	17.57	5.86
3.50	18.77	5.36
4.00	19.37	4.84

Table: Average values from the 6 infiltration run



### Methods of evaluating infiltration parameters

Three (3) methods for determining the equation parameters will be studied in this paper.

#### Method I

The most common method was used by Mudiare *et al.*, (2011). The linear least-squares regression procedure was employed for accurate estimation of the parameters of the model. In this first method, simple regression procedure was adapted to estimate the parameters of the Horton infiltration model from the field measured values, which involves the determination of  $k$  value as the slope of the line of best fit between  $I_n$  and elapsed time ( $t$ ).



From Eq. 1, Taking  $i_c$  to the left hand side gives:

$$i - i_c = (i_0 - i_c)e^{-kt} \text{-----Eq. [3]}$$

Dividing through by  $i_0 - i_c$  gives:

$$\left(\frac{i - i_c}{i_0 - i_c}\right) = e^{-kt} \text{-----Eq. [4]}$$

$$\left(\frac{i - i_c}{i_0 - i_c}\right) = e^{-kt} \text{-----Eq. [5]}$$

Taking the Logarithm of both sides gives:

$$\ln\left(\frac{i - i_c}{i_0 - i_c}\right) = -kt \text{-----Eq. [6]}$$

$$\text{Let } y = \left(\frac{i - i_c}{i_0 - i_c}\right)$$

$$\ln y = -kt \text{-----Eq. [7]}$$

To solve for the equation,  $i$  was taken as the measured infiltration rate at any given time  $t$ . Computing the values of the initial ( $i_0$ ) and final steady-state infiltration ( $i_c$ ) in the left hand-side. The plot of  $\ln y$  versus the elapsed time ( $t$ ) was obtained on a linear graph of which the slope gives the value of  $k$  which is the third parameter of the equation.

Time(hr)	$i$ (cm/hr)	$i - i_c$	$i_0 - i_c$	$y = \frac{i - i_c}{i_0 - i_c}$	$\ln(y)$
0.05	31.33	27.33	30	0.911	-0.093
0.08	28.80	24.80	30	0.827	-0.190
0.17	23.80	19.80	30	0.660	-0.416
0.33	18.00	14.00	30	0.467	-0.762
0.50	14.53	10.53	30	0.351	-1.047
0.75	12.13	8.13	30	0.271	-1.305
1.00	10.73	6.73	30	0.224	-1.494
1.50	8.62	4.62	30	0.154	-1.870
2.00	7.25	3.25	30	0.108	-2.223
2.50	6.47	2.47	30	0.082	-2.498
3.00	5.86	1.86	30	0.062	-2.783
3.50	5.36	1.36	30	0.045	-3.092
4.00	4.84	0.84	30	0.028	-3.574

Table2: Derivation of  $\ln y$

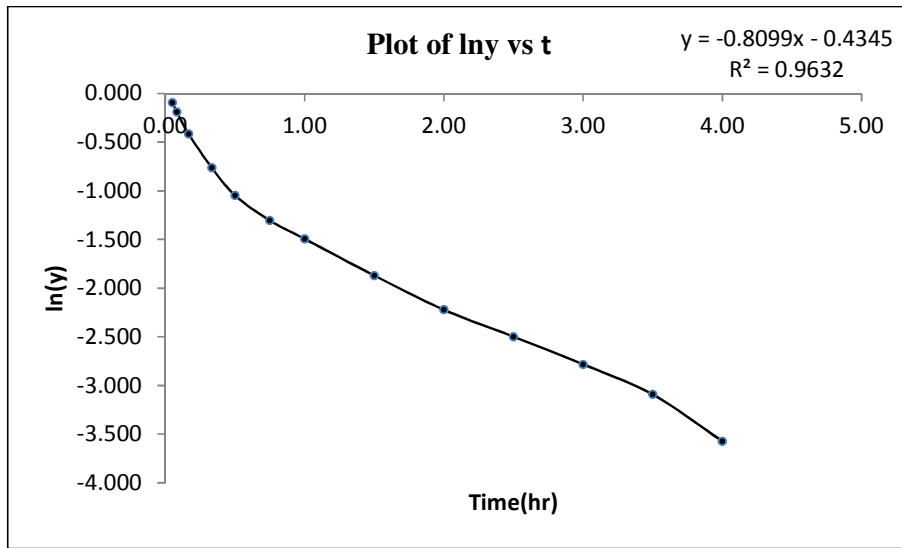


Fig2: The graph of  $\ln y$  and the elapsed time

From the graph above of the relation  $\ln y = -kt$ , the slope is the value of  $k$  which is equal to 0.4355. Substituting,  $i_o = 4$ ,  $i_c = 34$ ,  $k = -0.8099$  and the corresponding values of  $t$  into the equation, we'll have:

$$i = 4 + (34 - 4) * e^{-0.8099t} \text{----- Eq. [8]}$$

And the equation:

$$I = 4t + \frac{34-4}{0.8099} [1 - e^{-0.8099t}] \text{-----Eq. [9]}$$

### Method II

The second method studied was used by Reddy, (2004) and Raghunath, (2006), it involves analytical determination of the area under the infiltration curve. From Eq. 1

Tanking  $i_c$  to the left hand side we have:

$$i - i_c = (i_o - i_c)e^{-kt}$$

Integrating the right hand and the left hand side separately, gives:

$$\text{LHS -----} > \int_0^{\infty} (i - i_c). dt = I_c$$

Where  $I_c$  is the area of the shaded portion of the plot between  $i$ (cm/hr) and  $t$ (hr)

$$\text{RHS -----} > \int_0^{\infty} (i_o - i_c)e^{-kt}. dt = \frac{i_o - i_c}{k}$$

Equating both equations, gives:

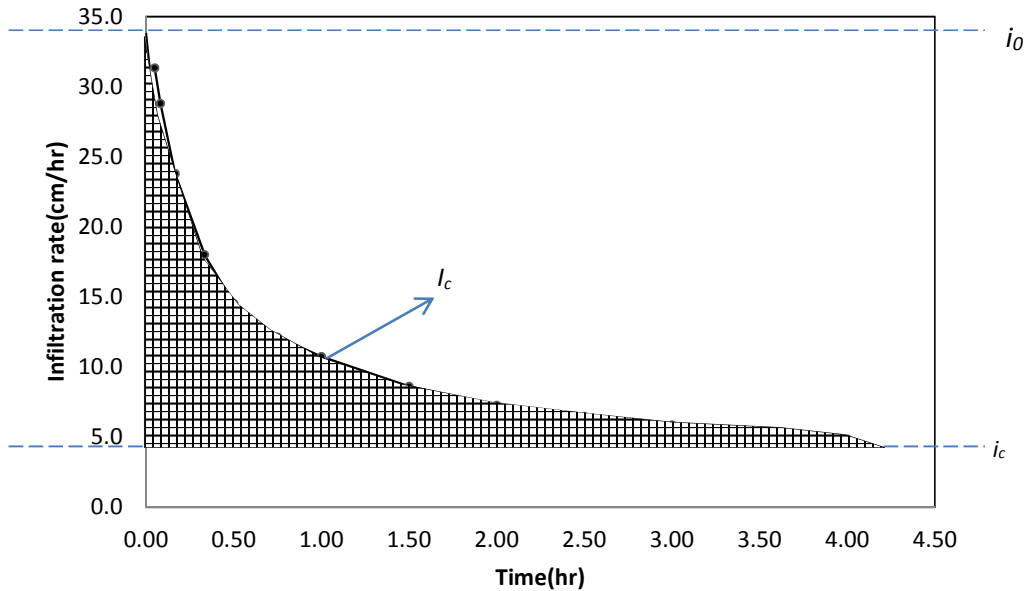
$$I_c = \frac{i_o - i_c}{k} \text{-----Eq. [10]}$$

Making  $k$ , the subject of the formula, we have:

$$k = \frac{i_o - i_c}{I_c} \text{-----Eq. [11]}$$



Fig3: The graph of infiltration rate and the elapsed time to get  $I_c$



From the graph above, on the x axis,  $0.5\text{hr} = 1\text{unit}$  and on the y axis  $5\text{cm/hr} = 1\text{unit}$ , the area of the big box will be  $(0.5\text{hr} * 5\text{cm/hr}) = 2.5\text{cm}$  square units or the small box will be  $0.1\text{hr} * 1\text{cm/hr}$  which gives  $0.1\text{cm}$  square units. The number of small boxes multiply by  $0.1\text{cm}$  square gives us the area of the shaded portion  $I_c$ . From the graph the area of the shaded portion from the number of small boxes are approximately 371. Multiplying by  $0.1\text{cm}$  gives  $37.1\text{cm}$ .

Therefore from Eq. [11]

$$k = \frac{34-4}{37.1} = \frac{30}{37.1} = 0.8086 \approx 0.8090$$

### Method III

The third method studied was also used by Reddy, (2004).

$$i = i_c + (i_0 - i_c)e^{-kt}$$

Tanking  $f_c$  to the left hand side we have:

$$i - i_c = (i_0 - i_c)e^{-kt}$$

Taking the natural logarithm of both sides we have:

$$\ln(i - i_c) = \ln(i_0 - i_c) - kt$$

Let  $y = \ln(i - i_c)$  and  $c = \ln(i_0 - i_c)$ , the equation becomes:

$$y = -kt + c \text{ Or } y = c - kt$$

Using analytical method to solve for the value of the slope; we use the table below:

$$r = \left[ \frac{(y - \hat{y}) * (t - \check{T})}{n} \right] / S_t * S_y$$

$$k = \frac{r * S_y}{S_t}$$



Where:  $r$  = correlation coefficient,  $S_t$  = the standard deviation of elapsed time,  $S_y$  = the standard deviation  $y$ ,  $\hat{y}$  = mean of  $y$ ,  $\bar{T}$  = mean of the time.

Time(hr)	$i/cm/hr$	$i - ic$	$y = \ln(i - ic)$	$(y - \hat{y})^2$	$(t - \bar{T})^2$	$(y - \bar{Y}) * (t - \bar{T})$
0.05	31.33	27.33	3.31	2.40	2.07	-2.23
0.08	28.80	24.80	3.21	2.10	1.98	-2.04
0.17	23.80	19.80	2.99	1.50	1.75	-1.62
0.33	18.00	14.00	2.64	0.77	1.34	-1.02
0.50	14.53	10.53	2.35	0.35	0.98	-0.59
0.75	12.13	8.13	2.10	0.11	0.55	-0.25
1.00	10.73	6.73	1.91	0.02	0.24	-0.07
1.50	8.62	4.62	1.53	0.05	0.00	0.00
2.00	7.25	3.25	1.18	0.34	0.26	-0.30
2.50	6.47	2.47	0.90	0.73	1.02	-0.87
3.00	5.86	1.86	0.62	1.30	2.28	-1.72
3.50	5.36	1.36	0.31	2.11	4.04	-2.92
4.00	4.84	0.84	-0.17	3.73	6.30	-4.85
$\bar{T} = 1.49$			$\hat{Y} = 1.76$			Mean = -1.42

Table3: Derivation of  $r$  and  $k$

The standard deviations are:  $S_t = 1.325$  and  $S_y = 1.093$

$$r = \frac{-1.42}{S_t * S_y} = \frac{-1.42}{1.325 * 1.093} = -0.9814$$

$$k = \frac{-0.9814 * 1.093}{1.325}$$

$$k = \frac{-1.0717}{1.325}$$

$$k = -0.8099$$

## RESULT, DISCUSSION AND CONCLUSION

The table below shows the result from the use of the three methods

Method	Method I	Method II	Method III
$k$ value	0.8099	0.8086	0.8099

From the result above, Method I and III gave same result, even though all the results are not the same, it is seen clearly that there is no significant difference between them, although they are supposed to be the same, the challenge with method II is the fact that it is very error prone, because of its complexity in analysis, care has to be taken when finding the area under the curve unless there is a way to get it done automatically by either using a model or a function, in this study, it was done by counting the boxes and that is where the deviation from 0.8099 came from. In conclusion Method I is highly recommended above Method III because it is less error prone and simple to calculate.



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## Design of WLAN Connectivity of Printers within an Office for an Office Environment with 30M Radius Coverage area using Linksys WRT 120N Wireless Gateway Router

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### ABSTRACT

This work focuses on the design of printer connectivity via wireless LAN for the various departments of an office. A wireless Access Point mounted 10.5 meters from the entrance of a central office was used to create a network that interconnected all the printers and computers within the coverage area of 30 meters as long as they are configured for the network. The network was furnished with security features such as disabled SSID broadcast, passphrase, MAC address filtering and WPA2 encryption to prevent unauthorized users from getting access to the network. The performance of the design was verified through an extensive range of tests (i.e. printing of documents from different locations within the network coverage area of 30 meters), and this yielded accurate and expected results. This design makes it possible to avoid the problems associated with the traditional wired method of networking computers and printing of documents between the units of an office.

**Key words:** WiFi, Local Area Network (LAN), integrated service router (ISR), Wireless Access Point (AP), Radio Frequency signal, Printers

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### INTRODUCTION

In the world today, the resources for living a successful and comfortable life are scarce and therefore, the world has resorted to sharing. Hence the popular sayings “sharing is caring” and “there is love in sharing” are not disputable. The major essence of sharing a resource is: to optimize its usage, to avoid the cost of providing it for each individual (either human being or computer) that needs it and to optimize the available space (Ergonomics). These benefits of sharing resources in the human world have been deployed in the world of computer network. Nowadays, printers, files, music, etc can be shared within a computer network to achieve the benefits listed above (Bergman, 1996). Interestingly, a tidy work environment and a technology that supports the mobile workforce, providing network connection for them anytime, anywhere can be achieved if the devices in the network are connected via wireless link. This method of connectivity is opposed to the traditional Local Area Network where computers and other network devices are physically wired to one another using Ethernet cables and network adapters via a central device like hub, switch or router (Agrawal D). The traditional method of networking makes the work environment untidy. Besides, in the aspect of achieving data connectivity with user mobility, it has proven to be inadequate in meeting the present day information technology challenges. Therefore, the need for a secured wireless local area network (WLAN) connectivity for sharing printers and other resources cannot be overemphasized (Comer, 2000).

According to Williams Schwebber (1996), a network is “a system that allows a group of users to communicate with each other”. Behind this simple statement is a complex system that must have proper interconnection paths, appropriate connection of each user to the overall system (either with physical cables or through electromagnetic waves), and rules for handling messages and various situations. He added that the network can be local (i.e.





within a section of a building) or spread over many miles and even throughout the world. Edeko (1997) observed that the development of computers and advances in the ability to link up several computer units via cable, optical fibre and microwave within the same vicinity (Local Area Network) and in remote location (Wide Area Network) have brought about the new and awesome phenomenon which has become known as INTERNET (i.e. International Network). The aim of this work is to achieve economy in system printing and submission of printed documents between units in an office. The purpose of this work is to design a system whereby printing of documents with a remote printer within a WLAN is possible. It is also to help eliminate the problems associated with traditional wired local networks. This work serves as a useful reference material to network engineers who will want to deploy the technology in other areas. It will also be useful to students and researchers alike (Bergman, 1996). There are low-cost multi-function devices available for home and small office networks that offer integrated routing, switching, wireless and security capabilities. An example of this type of integrated router is the Linksys wireless router (WRT 120N) shown below.



Fig.1 Linksys wireless router (WRT 120N)

## MATERIALS AND METHODS

### Design Overview

In this design, the infrastructure mode is adopted. An Integrated Service Router (ISR) which incorporates a switch, an access point, an internal omni-directional antenna and a router is used to create a local area network that connects all the clients within the coverage area as long as they are configured for the network. It is the Access Point (AP) in the ISR that actually performs this function.

### WLAN Devices Configuration

#### Linksys Wifi Access Point Configuration

Since the Integrated Service Router (ISR) was used, there was no need for a separate connection of the access point and a computer to a switch because the access point and the switch are already incorporated in the ISR. Instead, a computer was connected to the switch port of the ISR via a straight – through Cat 5e Ethernet RJ-45 cable. There are two

ways to configure the Access Point's wireless settings: the *Secure Easy Setup* device which involves automatic configuration or the manual configuration.

In this work the manual configuration setup is used. Using Windows 7 operating system, the following steps were taken:

**First**, click on the wireless network icon on the task bar to see all the available wireless networks within the coverage area, as shown in figure 2 below.

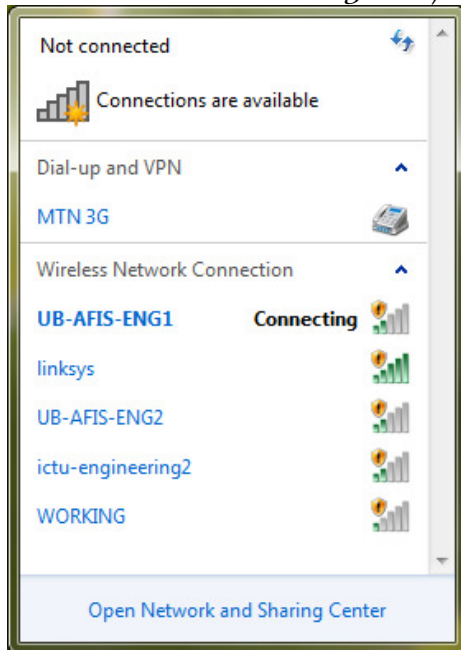


Fig 2 Available Wireless Networks

Then, select the Linksys wireless network which is the default network of the Access Point from the list. Click **Connect**. A dialog box comes up asking whether you want to set up your network, as shown in figure 3. Click OK.

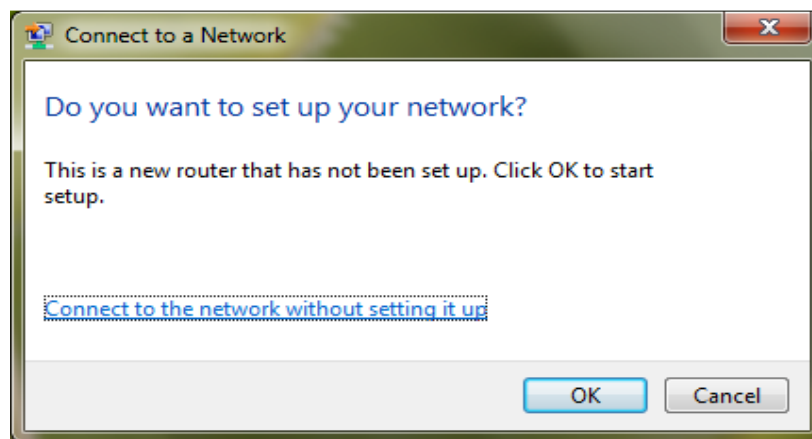


Fig 3. Network Set Up dialog box

The wireless network prompts for the *Router PIN*. Enter the router PIN, an 8-digit number that came with the device, as shown in figure 4. Then click **Next**.

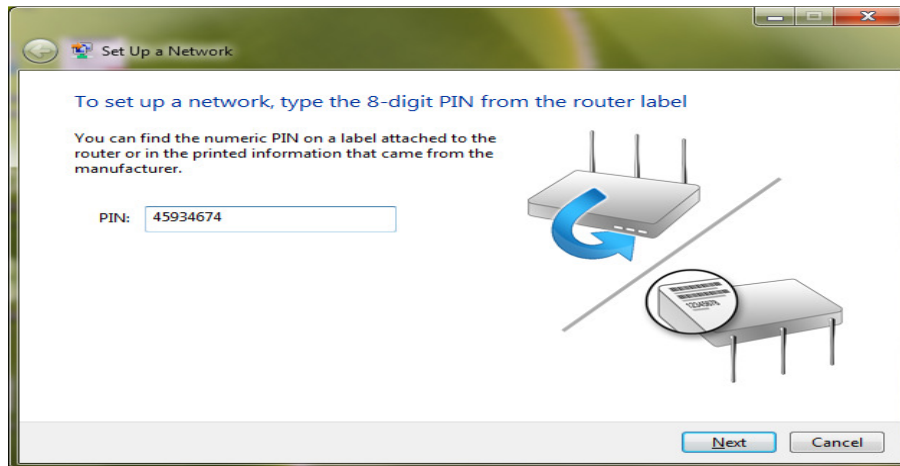


Fig 4 Enter Router Pin dialog box

The *Network Name* and *Security Options* were modified as follows:

NETWORK NAME: EEEMENG  
SECURITY TYPE: WPA2 – Personal  
ENCRYPTION TYPE: AES (Advanced Encryption Standard)  
SECURITY KEY/PASSPHRASE: AARONEST2345

This is shown in figure 5.

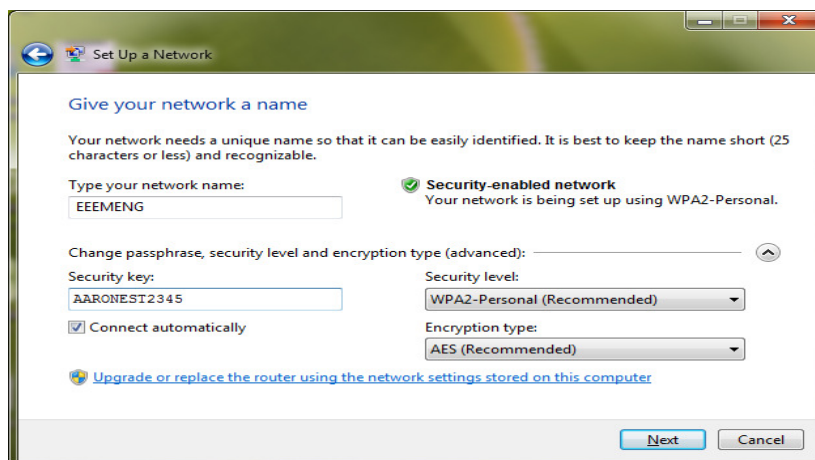


Fig 5 Network Name and Security Options dialog box

Click **Next**. The Network is successfully set up.

Next, open a web browser and access the router set up page by entering the **default IP address** 192.168.1.1 in the URL.

On the *Setup Screen*, the **DHCP** (Dynamic Host Configuration Protocol) is **disabled**. This is to allow static IP addressing. Then the **IP address** was changed from the default 192.168.1.1 to 192.168.5.1.

The **Subnet Mask** value was set to 255.255.255.0 since the IP address is a Class C private IP address. This is shown in figure 6.

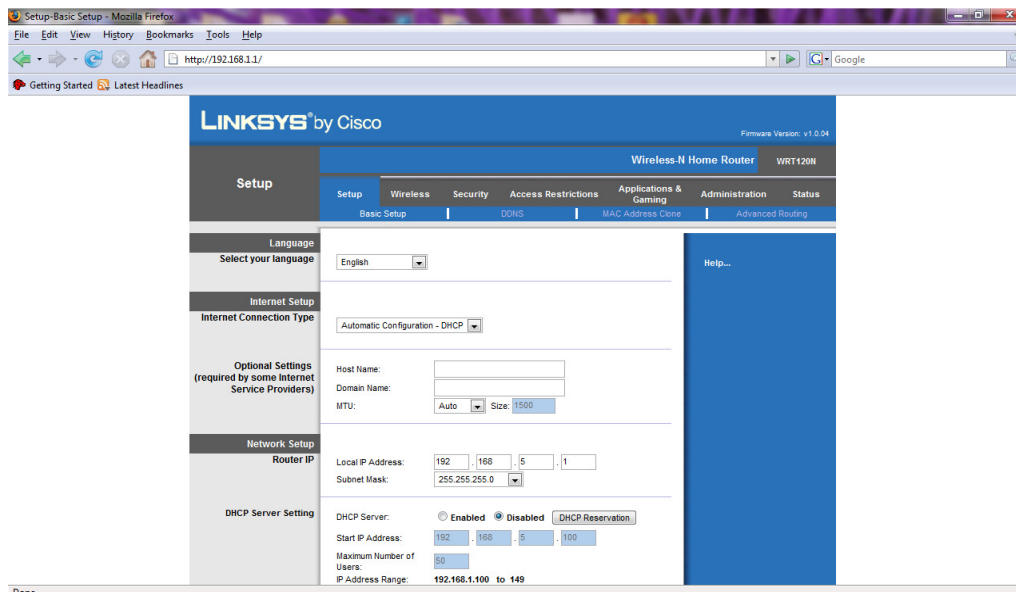


Fig 6 Router Basic Setup Settings

Then, the IP address of the Network Adapter of the computer used in configuring the Access Point was changed to 192.168.5.2, the Subnet Mask was set to 255.255.255.0 and the Default Gateway was changed to 192.168.5.1 so that the computer will be on the same network as the Access Point. This is done using the following steps:

- Go to NETWORK AND SHARING CENTER. On the left hand side of the window, click CHANGE ADAPTER SETTING.
- Double click on the wireless network EEMENG.
- On the Connection Status window click PROPERTIES
- On the PROPERTIES window click on **Networking** tab, and select **Internet Protocol version 4**. Then click **Properties** and change the settings as stated above.

Thereafter, click on **Save Settings** on the Wireless Router Setup Screen. The settings are saved and the setup page reappears.

Click on **Administration** tab, and set the following:

- Router Password: AARONEST
- Local Management Access via: HTTP
- Access via Wireless: ENABLED
- Remote Management: ENABLED
- Management Access via: HTTP
- Remote Upgrade: DISABLED
- Allowed Remote IP Address Range: 192.168.5.2 to 192.168.5.31
- Click on **Save Settings**.

This is shown in figure 7.

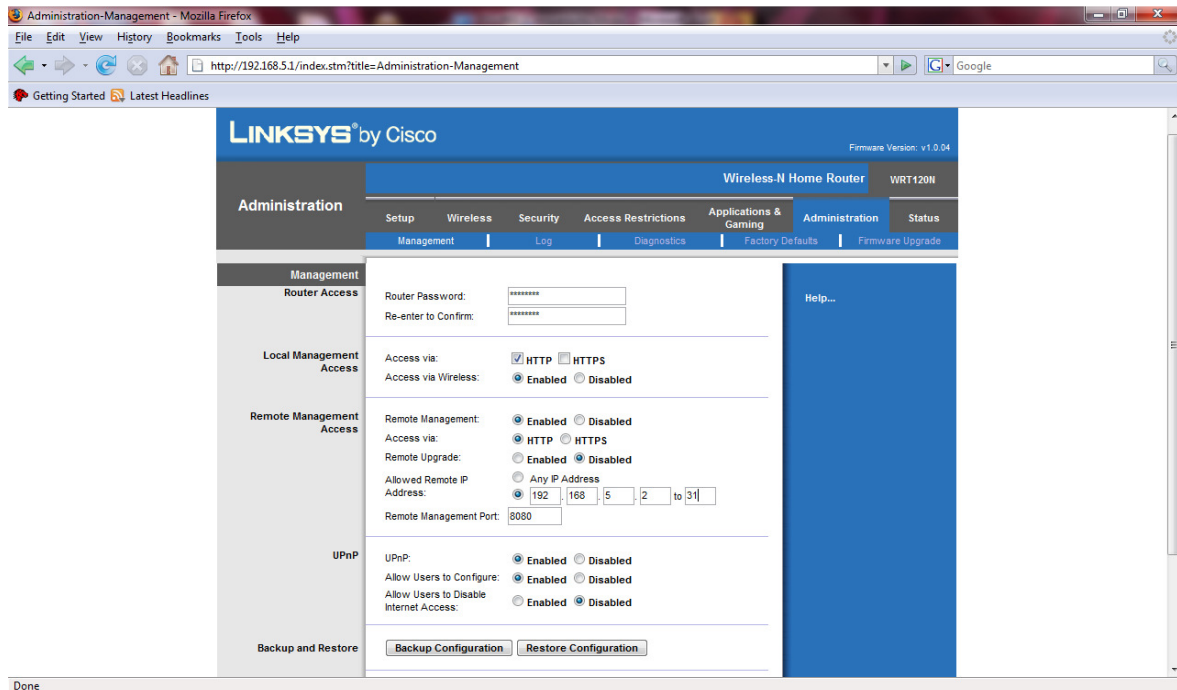


Fig 7 Router Administration Settings

Click on the *Wireless* tab on the Setup Screen. On the *Basic Wireless Settings* submenu, select **Manual Configuration View**. Then set the following:

- Network Mode: **Mixed**.  
This ensures the incorporation of 802.11n, 802.11g and 802.11b devices.
- Network Name (SSID): **EEEMENG**
- Channel Width: **Auto (20 MHz to 40 MHz)**
- SSID Broadcast: **Disabled**.  
This was to hide the SSID from intruders as a security measure.
- Click on **Save Settings**. This is shown in figure 8

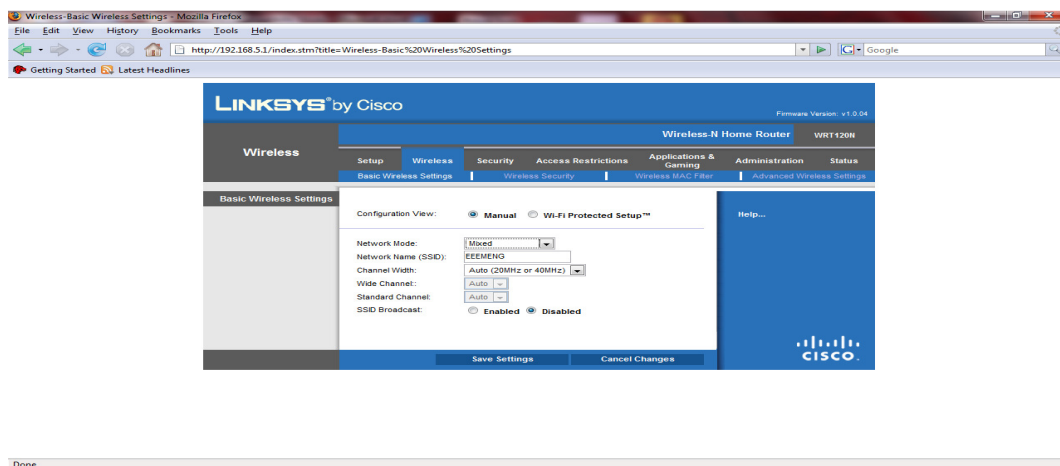


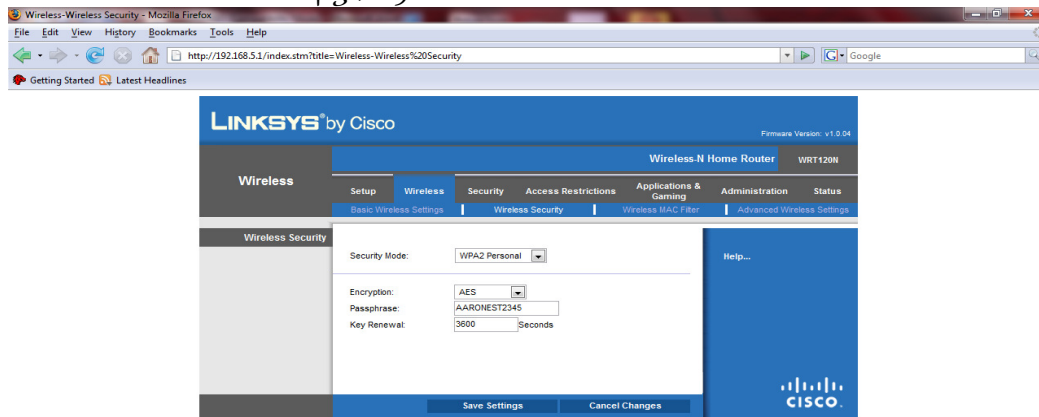
Fig 8 Router Basic Wireless Settings

Next, on the *Wireless Security* submenu, set the following:



- Security Mode: WPA2 Personal
- Encryption: AES (Advanced Encryption Standard)
- Passphrase: AARONEST2345
- Key Renewal: 3600 seconds
- Click on **Save Settings**.

This is shown in figure 9.



Done

Fig 9 Router Wireless Security Settings

Next, on the *Wireless MAC Filter* submenu:

- Set the Wireless MAC Filter to **Enable**.
  - Click on **Permit listed computers to access the wireless network** radio button.
  - Then enter the MAC addresses of the wireless clients that can access the network.
- Click on **Save Settings**.

This is shown in figure 10.

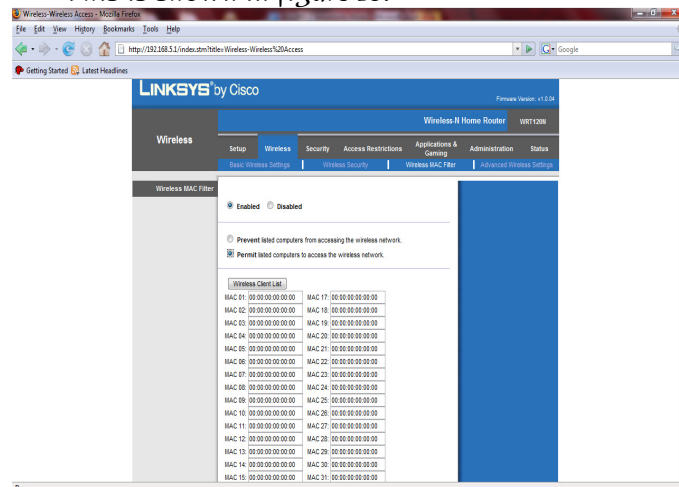


Fig 10 Wireless MAC Filter Settings



### Printer Installation

To install the DeskJet D1000 hp printer for instance, insert the CD ROM that contains the printer driver into the CD ROM drive of the server and click the **Run setup.exe** on the AutoPlay dialog box, as instructed by the manufacturer.

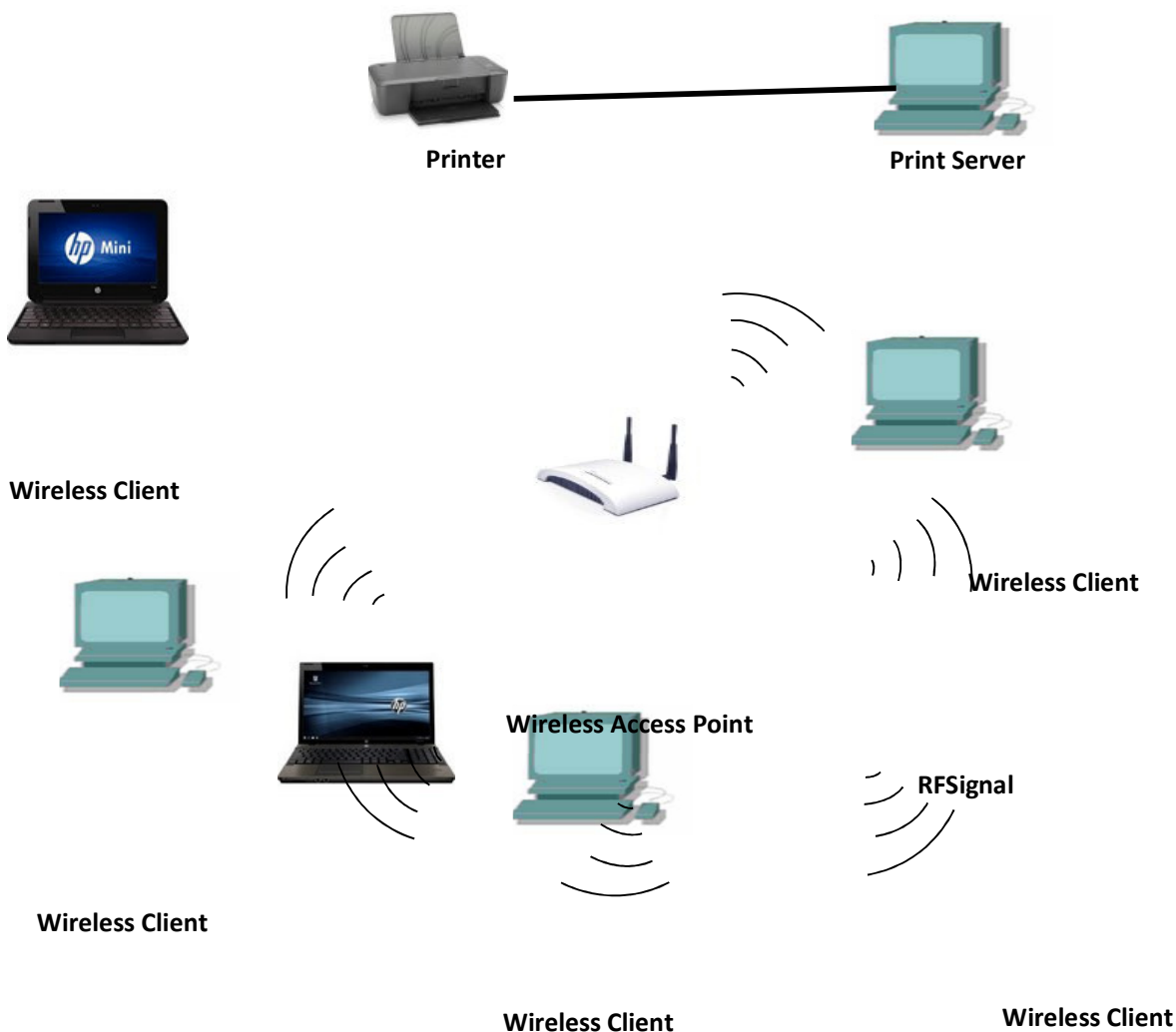
### Configuring a Wireless Client For The Network

For a wireless client that is offline to be connected, the following procedures must be taken:

1. From the client's system, *click* on the **wireless network connection** icon on the task bar to view available wireless networks.
2. Select the appropriate network and *click* **connect**.
3. *Enter* the SSID – **EEEMENG**.
4. *Enter* the PASSPHRASE – **AARONEST2345**.
5. *Enter* the client's MAC address on the MAC address filter list from the server.
6. *Configure* the client's **IP address** to match the network address. The IP addresses should be in the range **192.168.5.3** to **192.168.5.31**.
7. *Enter* the **Subnet Mask 255.255.255.0**.
8. *Set* the default gateway to **192.168.5.1**.

### Principle of Operation of a Wireless Lan Printer Connectivity

The figure 11 below describes the WLAN printer connectivity. It consists of a local printer attached to the print server via a USB cable, a wireless access point and other wireless client systems. The wireless print server and the wireless client systems connect to the access point through radio frequency generated by the access point.



**Fig II WLAN Architecture**

When a wireless client sends information such as a print job to the printer through the print server, the digital signal from the wireless client is used to modulate the radio signal (which serves as a carrier wave) generated by the access point. The print server then receives the modulated signal then demodulates and automatically adds the print job to its print queue. Then the document is sent from the print server to the printer for printing.

## RESULTS

The results of the test is presented in Table 1.



**Table 1: Project Test Results**

S/N	LOCATIONS	DISTANCE FROM AP	SIGNAL STRENGTH	PRINT STATUS
1	Office A	5 m	Excellent	Document printed
2	Office B	15 m	Good	Document printed
3	Office C	22 m	Good	Document printed
4	Office D	28 m	Poor	Document printed
5	Office E	30 m	Poor	Document printed
6	Office F	32 m	No signal	Document not printed

**Bill of Engineering Materials****Table 2: Bill of Engineering Materials**

S/N	MATERIALS	MODEL	QTY	COST (₹)
1	Wireless – N Integrated Service Router	WRT 120 N	1	9000
2	Printer	HP D1000 Series	1	6500
<b>TOTAL</b>				<b>15,500</b>

**CONCLUSION**

The WLAN standard, approved by IEEE 802.11 workgroup back in June 1997 was invented to enhance the use of current computer networking. It enables the local area networks (LANs) to be easily extended through wireless connections. It also helps to eliminate the problems associated with the traditional wired local networks. The objective of this project work which is to design a secured wireless local area network that will achieve wireless printer connectivity by all the connected computer systems in an office building was successfully achieved. The design was tested and produced good results. Printing of documents with a remote printer within a Wireless LAN is possible, as users connected to the WLAN could send documents for printing from any location within the wireless network coverage area. The wireless access point (WAP), which is integrated into the Integrated Service Router (ISR), creates the wireless network whose coverage range is about 30m (indoor). This design makes it possible to avoid the problems associated with the traditional wired method of printing of documents between the units of an office.

**RECOMMENDATIONS**

From this design and the results obtained, we are making the following recommendations:

1. In implementing the design, a Wireless – N Integrated Service Router with a Wi-Fi Radio Frequency of 5GHz should be used instead of the 2.4GHz Integrated Service Router. This is because the Wireless – N Access Point in the 5GHz Integrated Service Router has a higher data transmission rate and greater coverage range. Its typical data transmission rate is 74 Mbps and the maximum data transmission rate is 300 Mbps. The coverage area is about 300m.
2. To make the network completely wireless, there will be need to use wireless network printers in place of USB, serial or parallel printers.



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