

# An Investigation into Signal Strength of 802.11n WLAN

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## Abstract

With the continual improvement in IEEE 802.11 standards wireless networks are being deployed in ever increasing numbers. As technology advances the data rates and coverage of Wi-Fi increases and so the usage for different high bandwidth requirement applications increases. These enhancements to the technology do provide network design engineers with some significant problems when designing the network infrastructure. Prior to the installation of Access Points it is difficult to predict whether access can be guaranteed at specific locations. Additionally, to increase the level of security, it is often preferable, despite the use of security protocols, to ensure that the signal strength is not large enough to enable connection in areas other than those designated. Experience with existing equipment may not be sufficient to ensure a secure design. It is shown that it is likely that equipment built to the anticipated IEEE 802.11n specification that uses MIMO provide a far more complex situation than equipment designed to previous standards.

By combining the theory of antennae and the measurement of the performance of equipment built to the IEEE 802.11n draft, it is possible to create a mathematical model that can predict the network coverage which should be extendable to the new standard. Additionally it is argued that due to the backward compatibility of equipment then the increased data rates are not going to be realised until the all intended clients have been upgraded.

## Keywords

Wireless networks, Wi-Fi, Signal strength, Prediction of signals, IEEE802.11n.

## 1. Introduction

Over the past two decades, the demand for wireless service has grown at an extraordinary pace. The industry has grown from pagers, and cellular phones to Personal Communication Systems (PCS) and wireless local area networks (WLANs), providing services that deliver voice, data, and video in real time. For some time, wireless communications have been evolving from voice and low data rate services towards high bit rate services like video-telephony and multimedia (Fleury & Leuthold, 1996). In addition, wireless-in-house communications with a high degree of mobility are also emerging rapidly.

There is at present, a diverse range of client devices like laptops, PDAs and mobile phones that run applications such as multimedia imaging, video conferencing, online gaming, video streaming etc. which require very high bandwidth. There is therefore a requirement for a solution that will not only serve these devices, meeting the ever

increasing bandwidth and data rate requirements but also provide efficient wireless transmission between the communicating devices. This quest for more efficient communication has prompted the need for a deeper understanding of the wireless channels upon which these devices communicate (Liechty, 2007; Gast, 2002). It is anticipated that the use of Wi-Fi access will continue to increase for the foreseeable future due to the functionality being found as standard in mobile/cell phones.

Additionally, Wi-Fi Access Points are being installed in almost every conceivable location from public areas such as airports, coffee bars to private homes and even on the masts of boats. A major service provider (O2, 2009) boasts "*You can access our service at over 9,500 Wi-Fi hotspots across the UK*" as at 27th June 2008 which increased from over 7,000 locations 6 months earlier (Davies et al., 2008). A great deal of interest has been shown in the general provision of access points to enable town centres to be covered. For a network design engineer this is a relatively simple problem to solve since most design criteria provided by manufacturers is based on operation of a point source in the open air. However often the installation is required within a building and this is far more challenging since the signal strength is dependant on many factors including the physical attributes of the building, the contents (furniture) of the building and the restrictions on suitable installation sites.

To cope with this requirement the IEEE 802.11 Working Group (IEEE, 2009) regularly investigating new ways of improving existing standards in terms of distance covered and data rates. In 2003 this working group worked on an amendment to the IEEE 802.11 specification in attempt to increase the data rate of the existing IEEE 802.11b 2.4 GHz band standard from 11Mbit/s to 54 Mbit/s. This became the IEEE 802.11g specification as Clause 19 of the published IEEE 802.11-2007 standard. Most equipment installed today is designed to this standard. However the working group are now investigating the possibility of improving this standard to provide data rates of up to 600Mbit/s and it is anticipated that this standard will be ratified in December 2009 as IEEE 802.11n.

With great insight manufacturers have, when designing equipment to operate with the new standards, made them backwards compatible so that existing equipment does not become redundant. Even though the IEEE 802.11n standard has not been ratified work is going on to design chips and equipment for early release. At present it is possible to purchase equipment that has been designed to what is known as IEEE 802.11n draft. This equipment is based on the same technology but operates at the reduced speed of 450 Mbits which is still a great improvement on the 54 Mbps possible by IEEE 802.11g. The Wi-Fi Alliance started certifying products based on IEEE 802.11n Draft 2.0 mid-2007.

Due to the backward compatibility of the standards many systems that were designed to measure the signal strength of access points can still be used e.g. Network Stumbler, (Netstumbler, 2009) or AirMagnet (Airmagnet, 2009). One of the major drawbacks of WLANs, unlike cabled networks, is that the strength of the signal can not be relied upon to provide adequate reliable access to the network. There are many factors that effect the signal strength ranging from the quality and positioning of the antenna at either end of the link to the terrain between and surrounding the ends. Unfortunately the affect of these are very difficult to predict accurately and so

simplified models are constructed. In previous work such a model was put forward for the IEEE 802.11a,b & g standards which provided reasonable results. This paper investigates how typical equipment designed to the IEEE 802.11n (draft) performs from the area coverage point of view compared to existing standards to see if a similar model could be applied.

## 2. Technology

### 2.1. Wireless LAN Network Elements

WLANs consist of four major network elements. They are the station, access point, wireless medium and distribution system. Stations are the devices with wireless network interfaces. An access point (AP) is a wireless router or bridge that interfaces the wireless network with the wired network. The wireless medium is the physical layer standard used to move frames from station to station and the distribution system is the logical component used to forward frames from one access point to another in a large coverage area. The distribution system is often called the backbone network (Lammle, 2007; IEEE, 2007; Gast, 2002).

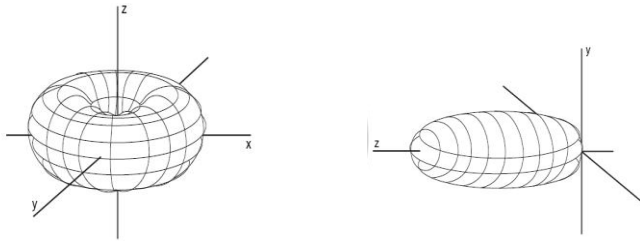
#### 2.1.1. RF Component

Radio communication involves two or more devices tuned to the same frequency. One device acts as the transmitter while the other the receiver. Basically, the transmitting station has a transmitter that generates the radio frequency, an antenna and a transmission line that connects the two. The receiving station at the other end has a receiver, an antenna and a transmission cable. RF communication begins with an oscillating signal of a constant frequency transmitted from the transmitter to the receiver. Both the transmitter and the receiver have to be at the same frequency for communication to take place. The antenna converts the electrical signals from the transmitter through wires to radio waves for transmission.

#### 2.1.2. Antennas

Antennas are the most important component for wireless communication. An antenna is defined by Stallings (2004) as “*an electrical conductor or system of conductors used for either radiating electromagnetic energy or for collecting it.*” For signal transmission, radio-frequency electrical energy from the transmitter is converted into electromagnetic energy by an antenna and radiated into the surrounding environment. The reverse happens for reception.

Antennas are characterised by their radiation pattern as Omni-directional antennas and directional antennas. Omni-directional antennas attempt to propagate signals in all directions e.g. a dipole antenna. Omni-directional antennas are suitable for coverage in a broad room or a whole floor where the Access point is located in the centre of the room. Directional antennas are usually used for point-to-point communication. They propagate radio frequency for a longer distance using a narrow beam e.g. a dish or parabolic reflective antenna. Often the shape of the field is plotted out showing points of equi-potential versus the distance away from the antenna. Figure 1 shows such plots for an omni directional and directional antenna.



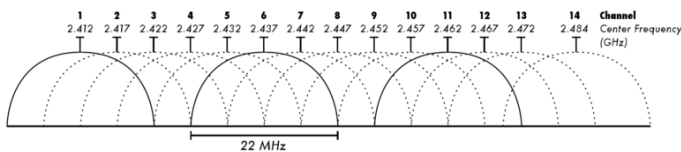
**Figure 1: Antenna fields** (N Makarov Sergey., (2002))

## 2.2. Wireless LAN Network Topology

The two basic wireless network topologies are: the Independent Basic Service Set (IBSS) or Ad-hoc Network and the Infrastructure Basic Service Set. Independent Basic Service Set topologies are easy to set up but difficult to maintain. Devices communicate directly with each other and there is no link to a wired infrastructure so is of little interest for this application. However the *“Infrastructure BSS contains a gateway to the wired domain and enables communication between a station of one service area and a station of other service area”* (Prasad et al., 2005). This gateway is the access point which is needed for all communication as they provide the link to the wired network.

## 2.3. Channels

802.11 divides the frequency bands (2.4GHz and 5GHz) into channels. The 2.4-GHz range is subdivided into 13 channels of width 22MHz, spaced 5MHz apart. These channels usually overlap one another resulting in signal degradation. There are only 3 non-overlapping channels available in the IEEE 802.11 standard. They are channels 1 with centre frequency 2.412GHz, channel 6 with centre frequency 2.437GHz and channel 11 with frequency 2.482GHz as shown in figure 2. Clearly access points that are located near each other need to avoid overlapping frequencies.



**Figure 2: Wifi Channel Allocation** (Lammle, T., (2007))

Even though the frequency of the channels is well defined there is no international standard for the usage. Most countries use the first 13 channels leaving channel 14 unused however in North America only the first 11 channels are used. Japan uses channel 13 for IEEE 802.11b networks.

IEEE 802.11n will be the first wireless standard to ratify the use of multiple antenna design. It will make use of the Multiple Input Multiple Output (MIMO) antenna design in its construction. According to DeBeasi (2007), this design will make

transmission and reception of signals better and more reliable. Because of the MIMO implementation IEEE 802.11n will also have an increased channel width from 20MHz to 40MHz which will double the information carrying capacity.

### **3. Wireless Range and Coverage**

The range of a wireless signal can be defined as the maximum distance at which two radios can operate and maintain a connection. The range of an access point is affected by various factors such as the transmitting power of the access point, the number of antennas being used and the gain and directivity of the antennas. The coverage area is the total area at which all radios can maintain a connection to one another sometimes called a cell. Clients within a cell can associate with the AP and use the wireless LAN.

#### **3.1. Importance of Signal Propagation Prediction**

The performance of wireless communication systems depends on the radio wave transmission path between the transmitter and the receiver. Unlike their wired counterparts whose distance limitations and data rates are fully understood due to the use of specific standards and controlled media, distance limitation (i.e. the range) and data rates of Wi-Fi networks are more difficult to determine. They interact with the environment through which they propagate by means of reflection, refraction and scattering, hence their (almost) random nature.

It is essential to understand the propagation characteristics for a proposed WLAN before deployment. One of the most important reasons of this is security. Predicting how far a signal can go before installation will ensure that a connection cannot be made in areas where it is not desired. Iskander & Yun (2002) considered in their paper that the strength, range and coverage area of an access point is strongly affected by its positioning in reference to its environment. To avoid undesired connection in places where it should not be made, it is necessary to carefully predict the signal strength, range, coverage and the correct placement of base stations. For a small network in a limited area, manufacturer's information on the coverage range might be enough to deploy access points. For a larger network however, a more accurate procedure is required to ensure sufficient coverage and network functionalities.

#### **3.2. RF Signal Propagation Prediction**

Most manufacturers' information is provided for outdoor use since there is little interaction with the environment which is not the case for most indoor installations. There are two basic approaches to designing an access point's location in an indoor scenario - manual deployment using site survey or by planning using signal propagation models (Mikas et al., 2003).

It is believed that the best approach to optimise an AP's location is to perform a site survey. The procedure involves the deployment of temporary APs in preliminary locations and taking live measurements of the signal strength and quality. An

advantage of a site survey is that it simulates the actual environment the network will be deployed and so base station placement can be optimised.

The free space model is only an idealised model. However radio signals propagation within buildings can be really complex. The simplest wave propagation case is that of a direct propagation in free space which the Friis Transmission Equation addresses (Friis, 1946).

$$P_{rx} = P_{tx} G_{rx} G_{tx} \left( \frac{\lambda}{4\pi d} \right)^2 \text{ so } P_{rx} \propto P_{tx} \left( \frac{1}{d} \right)^2$$

Where  $\lambda$  = signal wavelength,  $d$  = distance from the transmitter,  $G_{tx}$  = Transmitter antenna gain,  $G_{rx}$  = Receiver antenna gain,  $P_{tx}$  = Transmitter Power and  $P_{rx}$  = Received Power.

For a given access point transmitting at a fixed frequency,  $G_r$ ,  $G_t$ ,  $P_t$ ,  $f$  and  $c$  are constant. Hence, the received power varies inversely as the square of the distance the signal has to travel to reach the receiver. This equation however only holds true for free space models (Rappaport & Sandhu, 1994; Durgin et al, 1998). Previously Davies et al (2008) showed that even though this is a very simplified model it could be used as a reasonable approximation for IEEE 802.11g networks.

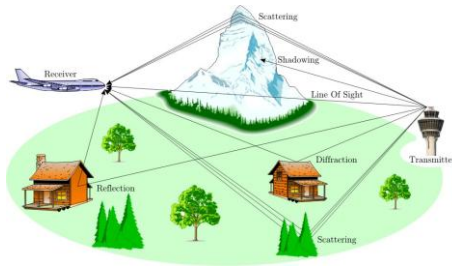
### 3.3. RF Signal Propagation Prediction for IEEE 802.11n

Since IEEE 802.11n wireless networks use MIMO then the above equation falls down since the fixed conditions are no longer true. Clearly the wavelength is not constant since different channels are utilised and therefore  $G_{tx}$  and  $G_{rx}$  are no longer constant since they are frequency dependant.

### 3.4. Effect of using radio signals indoors

Various mechanisms affect the propagation of radio signals. These mechanisms can however be attributed to five main physical phenomena - reflection, diffraction, refraction, scattering and absorption (Hucaby, 2007; Durgin, et al, 1998; Sarkar, et al., 2003). These basic mechanisms distort the propagating signal, making the signal either become stronger or lead to losses. These phenomena can also create additional propagation paths beyond the direct line of sight path between the radio transmitter and receiver, resulting in multiple signals getting to the receiver with different delays. This leads to shadowing and multi-path fading, affecting the performance of wireless communication systems as it depends on the transmission path between the transmitter and the receiver.

Generally these phenomena are dependant on the surrounding environment and the frequency of the signal used. To determine the effect of each of these phenomena for a given environment for a given frequency is not an easy task and gives rise to very complex models. Since IEEE 802.n uses MIMO then this gives rise to even more complexity since there are multiple frequencies involved.



**Figure 3: Multi-path Propagation**

### 3.5. Signal Propagation Losses

The propagation of Wi-Fi signals, as for any electromagnetic wave, is governed by the properties of materials in the propagation medium. Although the high frequency used by Wi-Fi is able to penetrate obstacles such as walls and ceilings, these obstacles affect the signal propagation. Many studies have shown that penetration loss depends on the properties of the materials in the propagation medium (Muqaibel, et al., 2005; Sarkar et al., 2003).

For a wireless network in a home or office, obstructions such as walls, furniture, people etc. impede the propagation of signals. Losses of varying dBs are introduced depending on the material of construction for the various items in the room. In a multi-storey building, losses between floors are also introduced, depending on the building materials used. A loss of approximately 6dB is usually experienced between adjacent floors. The table below gives the approximate losses for different building materials (Rackley, 2007).

Range	Materials	Loss (dB)
Low	Non tinted glass, Wooden doors, Cinder block walls, Plaster	2-4
Medium	Brick wall, Marble, Wire mesh, Metal tinted glass	5-8
High	Concrete wall, Paper, Ceramic bullet-proof glass	10-15
Very high	Metals, Silvering (Mirrors)	>15

**Table 1 Typical attenuation for building materials at 2.4GHz**

### 3.6. Prediction Models

A lot of work has been done on the prediction of radio signal propagation. Although the concept is the same, many different techniques have been proposed by

researchers. Many mathematical radio propagation models have been developed over the years which accurately predict the potential propagation of signals within an environment (Durgin, et al, 1998; Iskander & Yun, 2002; Mikas, et al., 2003; Garg, 2007). Basically two approaches to modelling radio networks exist, the Empirical or Statistical method and the Deterministic method.

The empirical method is based on site survey and it depends on measured data gathered from the actual environment that is to be modelled. The deterministic model (also known as Ray-Optical or Ray-Tracing models) uses software based on the theory of electromagnetic wave propagation. It is more convenient and cost-effective when compared with the site survey model. By simulating different configurations of the environment where the network will be deployed, an optimal configuration can be reached. This method however depends on the availability of data such as the composition of the obstacles along the signal path and their corresponding effect on electromagnetic signals (Sarkar et al., 2003; Iskander & Yun, 2002; Mikas, et al., 2003) to get an accurate prediction. Site surveying is usually the quickest and the most accurate.

#### 4. Investigations

For this study, off the shelf commercially available equipment was used which was stamped and approved by the Wi-Fi alliance. Two access points were used: Linksys Compact Wireless-G Broadband Router WRT54GC and Linksys Wireless-N Broadband Router. A laptop with Dell's 1370 WLAN mini PCI card and Belkin Wireless N1 USB adapter were used to perform the measurements.



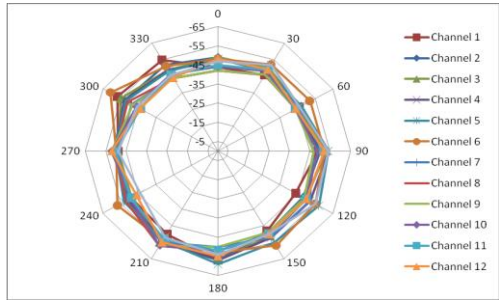
**Figure 4: Equipment Used for Measurements (Linksys(2009))**

##### 4.1. Data Collection

NetStumbler was used to provide the values of received signal strength. However during this study the values of signal strength and SNR reported by NetStumbler fluctuated greatly and frequently in some cases the variation was up to 10dBm and even 15dBm in a few cases. So the default scripting option was used to export readings in specific locations for a few minutes. These readings were later processed, getting the average value of the signal strength for that point.

##### 4.2. Data Analysis

By taking readings at various distances and angles it is possible deduce some conclusions about the performance of the access point and the associated antenna.

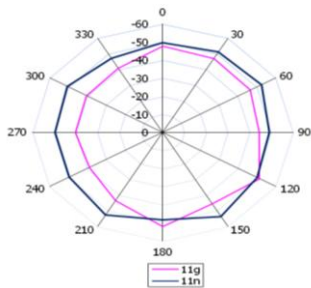


**Figure 5: Received Signal Strength for different Channels**

Since IEEE 802.11n uses MIMO technology it was decided to produce a graph showing how the signal strength varied with the channel used as the access point was rotated around the axis at a fixed distance of 6 metres. It can be seen from Figure 5 that the received signals whilst on channel 1 and 6 were found to be different from the average received by as much as 7dBm with deviation of about 5.1% and 5.6% respectively from the average value.

#### 4.3. Comparison of signal coverage of IEEE 802.11g with IEEE 802.11n

A similar set of measurements were made of the signal strength at 6 metres whilst the base station was rotated. This was carried out firstly for an IEEE 802.11g then for an IEEE 802.11n access point.



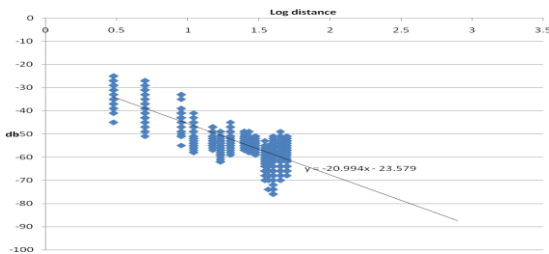
**Figure 6: Received Signal Strength for 802.11g & 802.11n access points**

It can be seen from Figure 6 that there is quite a considerable variation in the values obtained. For all but one direction the strength of the 802.11n is greater than that of the 802.11n access point. The difference is as high as 27% in certain directions and the average improvement is 13%.

#### 4.4. Outdoor Propagation

To investigate the path loss model of propagation prediction, measurements were taken in the middle of an open field without any interference from other transmitting signals or obstruction from any source using the free space principle. The access point was stationary while the laptop distance was varied from 3m to 50m. Since the signal strength is measured in dBs which is a log scale the graph shown in the Figure 7 has been plotted against the log of the distance. For this to fall in line with the Friis transmission equation then this should be a straight line with a negative gradient. A straight line has been fitted to these results and the equation has been displayed showing  $y \propto 21x - 24$ . So the gradient of the line is 21/10 since the db scale contains

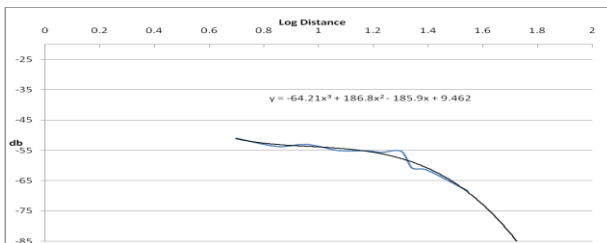
a factor 10. Showing  $P_{rx} \propto P_{tx} \left( \frac{1}{(d)} \right)^{2.1}$  which is very close to  $P_{rx} \propto P_{tx} \left( \frac{1}{(d)} \right)^2$



**Figure 7: Scatter-plot of Received Signal Strength in Air v Distance**

The straight line fit to the points has been extrapolated to estimate where it would cut -84db since this is the sensitivity level of the receiver. It shows the approximate max distance that could be obtained is (antilog of 2.87801) = 130 metres for 802.11n compatible access point. Previous measurements show that for 802.11g this distance is approximately 80 metres.

#### 4.5. Indoor Propagation



**Figure 8 Indoor Received Signal Strength – Large hall**

The same measurements were taken in a large hall (the William Aston Hall in Wrexham) since it was a conveniently placed large room used for public lectures and performances. This should be very close to the free air except that it is enclosed. As

in the previous section the received signal strength was plotted against the log of the distance and are shown in Figure 8 with a line of best fit through the points.

It is interesting to note that the best fit for the points this time is a polynomial of order 3. Evidently this does not fit with the Friis transmission equation. When a similar large room was tested it was also found that this approximated to a polynomial of order 3.

#### 4.6. Effect of Materials

Measurements were taken through different types of materials to estimate the absorption coefficient so that further models could be made. A summary of the partition attenuation factor is shown in Table 2.

Partition type	Material Thickness	Measured Attenuation	Standard Deviation
Concrete Wall	25cm	16.61	1.63
Partition wall Library	25cm	4.18	
Partition – class rooms	25cm	5.25	1.51
Glass tinted		21.13	3.79
Open library	60cm	13.62	2.13
Concrete Pillar	70cm	25	1.71

**Table 2 Absorption values for different materials**

## 5. Conclusion

The improvement in performance in terms of data rates and coverage area will enhance the usage of Wifi. If the IEEE 802.11n standard can be made to operate at speeds up to 600Mbps then it will certainly improve the quality of service provided for users who wish to use the more data intensive applications like streamed music, video and VoIP. Based on the investigations carried out this paper on IEEE 802.11n draft then it is likely that there are clear benefits to this type of technology.

However the benefits do come at a price, the extra complexity introduced to the network design engineers who need to be able to make sound judgements about data rates and coverage area. If installations are carried out on the basis of the previous generation of access points IEEE 802.11g then it is possible that the network could be exposing itself to security problems. Since the signal from access points supporting 802.11n is capable of extending far further than previous access points this could provide acceptable signal outside of buildings.

This work shows that the signal will travel further in a free air situation; however when measured indoors, due to the multi-frequencies used by the MIMO technology then strength is unpredictable. Experienced gained from using the previous technologies can not be relied upon. Since it is possible to make measurements that will provide reasonably reliable values for the attenuation experienced by different materials then these can be built into the models. However the effect of reflection, refraction, diffraction and scattering are much more difficult to predict. These could be troublesome due to the different frequencies that are used by the technology since the effects are likely to be frequency specific.

From the point of view of data rates then since most of the equipment in existence at present only supports the IEEE 802.11 a, b and g standards which run at much lower data then it is likely that the deployment of IEEE 802.11n equipment will not show an increase until all the client machines can support this technology. The backwards compatibility is a two edged sword, it is useful since it can support existing devices but this leads into running the network at a reduced data rate.

Much of this work is preliminary in preparation for the equipment which will be built to the ratified IEEE 802.11n standard later this year. However design models need to be worked on at present in preparation. Having these preliminary results has lead to the proposing of a mathematical model for both outdoors in free air and indoors. The models are quite different and at present analysis has only taken place in large indoor rooms. Clearly this work needs to be extended to take into account smaller areas of differing characteristics.

## 6. References

Airmagnet (2009) <http://www.airmagnet.com/assets/whitepaper/WP-802.11nPrimer.pdf>

Davies J. N., Grout V., Picking R. (2008), Prediction of Wireless Network Signal Strength within a Building, INC 2008, University of Plymouth.

DeBeasi, P., (2007). Burton Group 802.11n: Beyond the Hype. Available at: <http://www.burtongroup.com/Research/PublicDocument.aspx?cid=1142> [Accessed March 4, 2009].

Durgin, G., Rappaport, T. & Hao Xu, (1998). Measurements and models for radio path loss and penetration loss in and around homes and trees at 5.85 GHz. Communications, IEEE Transactions on, vol. 46 No. 11, pp. 1484-1496.

Friis H.T.,(1946) Proc. IRE, vol. 34, p.254. 1946

Fleury, B. & Leuthold, P., 1996. Radiowave propagation in mobile communications: an overview of European research. Communications Magazine, IEEE, vol. 34 No. 2, pp. 70-81.

Garg, V.K., (2007). Wireless Communications and Networking, Morgan Kaufmann Publishers

Gast M., (2002), 802.11 Wireless Networks: The Definitive Guide, O'Reilly Media Incorporated

Hucaby, D., (2007). CCNP BCMSN Official Exam Certification Guide 4th edition, Cisco Press.

IEEE (2007), IEEE Standard for Information technology-Telecommunications and information exchange between systems-Local and metropolitan area networks-Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. IEEE Std 802.11-2007 (Revision of IEEE Std 802.11-1999).

IEEE (2009) <http://www.ieee802.org/11/> IEEE 802.11 Wireless Local Area Networks - The Working Group for WLAN Standards

Iskander, M. & Zhengqing Yun, (2002). Propagation prediction models for wireless communication systems . Microwave Theory and Techniques, IEEE Transactions on, 50(3), 662-673.

Lammle, T., (2007) CCNA: Cisco Certified Network Associate, Study Guide, Exam 640-802, 6th Ed, Sybex

Liechty, L., (2007). Path Loss Measurements and Model Analysis of a 2.4GHz Wireless Network in an Outdoor Environment. Georgia Institute of Technology. Available at: [http://smartech.gatech.edu/bitstream/1853/16308/1/liechty\\_lorne\\_c\\_200708\\_mast.pdf](http://smartech.gatech.edu/bitstream/1853/16308/1/liechty_lorne_c_200708_mast.pdf) [Accessed April 22, 2009].

Liechty, L., Reifsnider, E. & Durgin, G., (2007). Developing the Best 2.4 GHz Propagation Model from Active Network Measurements. In Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th. pp. 894-896.

Mikas, F., Zvanovec, S. & Pechac, P., (2003) Measurement and Prediction of Signal Propagation for WLAN Systems. Available at: <http://www.urel.fec.vutbr.cz/ra2008/archive/ra2003/papers/205.pdf>

Muqaibel, A., Safaai-Jazi, A., Woerner, B., Riad, S. & Attiya, A. (2005) Ultrawideband through-the-wall propagation. Microwaves, Antennas and Propagation, IEE Proceedings, pp. 581-588.

Netstumbler (2009) <http://www.netstumbler.com/> - Wireless networking tool

O2 (2009) <http://consumero2.directoryconnection.com/>

Prasad, A. & Prasad, N. (2005), 802.11 WLANs and IP Networking: Security, QoS, and Mobility, Artech House.

Rackley, S., (2007). Wireless Networking Technology, Newnes Publishing

Rappaport, T. & Sandhu, S., (1994). Radio-wave propagation for emerging wireless personal-communication systems. Antennas and Propagation Magazine, IEEE, Vol. 36 No. 5, pp. 14-24.

Sarkar, T.K., Zhong, J., Kyungjung, K., Medouri, A. & Salazar-Palma, M., (2003). A survey of various propagation models for mobile communication. Antennas and Propagation Magazine, IEEE Vol. 45 No. 3, pp. 51-82.

Stallings, W. (2004). Wireless Communications & Networks, Prentice Hall

N Makarov Sergey., (2002) Antenna and EM modelling with matlab, John Wiley & Sons

Linksys(2009), <http://www.linksysbycisco.com/US/en/products/WRT610N>