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Wireless local area network in a residential building

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The thesis can be divided in primary and secondary parts. The primary part concentrates on a wireless local area network (WLAN) in a residential building and the secondary part concentrates on an advertisement portal.

The idea of the primary part, WLAN in a residential building, was to find out whether a common WLAN among residents could be built in a residential building in a way that it would make sense both from technical and business points of view. To find this out calculations and measurements of signal propagation in an indoor environment were done. The access points locations were searched in a way that throughput, coverage and the physical location of the access points would fill the requirements. In the end the network was tested in practice in a residential building at Tuusula, Finland for a period of two months.

The used WLAN technology was IEEE 802.11n draft. IEEE 802.11n is the most advanced version of IEEE 802.11 family currently. It provides better coverage and throughput than earlier versions. This is mostly achieved with MIMO technology. The technology behind IEEE 802.11n draft 2.0 is explained in this thesis.

The idea of the secondary part, advertisement portal, was to plan a new kind of advertising medium. The idea was that users need to watch an advertisement before gaining access to internet. The advertisement portal was designed, implemented and integrated to the WLAN in co-operation with University of Turku. The advertisement portal was tested in practice with the WLAN. The link between the WLAN in the residential building and the advertisement portal is to test an alternative way to gain income, instead of just charging a fee from the users.

The main results are the following. One access point per floor is needed. In the coverage planning it was found out that multi wall model did not provide accurate results. To obtain accurate models, professional software is needed. The most suitable market for the advertisement portal would be a local market, but there are other potential markets as well. The core competences of the advertisement portal are that it is dynamic, interactive, nature conservative and that it provides cost savings from distribution and materials.

Keywords: Advertising, IEEE802.11n, indoor propagation, picocell, WLAN

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Diplomityö voidaan jakaa kahteen osakokonaisuuteen. Ensimmäinen osa keskittyy langattomaan verkkoon asuinkiinteistössä ja toinen osa mainosportaaliin.

Ensimmäisen osan ideana on selvittää, voidaanko yhteinen langaton lähiverkko rakentaa asukkaille siten, että se on järkevää teknillisesti ja kaupallisesti. Tämän selvittämiseksi radioaaltojen etenemistä laskettiin ja mitattiin sisätiloissa. Tukiasemien paikat valittiin siten, että radiopeitto, yhteyden nopeus ja tukiaseman fyysinen paikka täyttävät vaatimukset. Suunniteltua WLAN:ia testattiin kahden kuukauden ajan Tuusulassa sijaitsevassa asuintalossa. Kokeiluun osallistui kuusi perhettä.

Käytetty WLAN-tekniikka oli IEEE802.11n draft. IEEE802.11n on tällä hetkellä IEEE802.11–perheen edistynein tekniikka. Kyseinen tekniikka tarjoaa nopeamman yhteyden ja paremman radiopeiton kuin edeltäjänsä. Nämä saavutetaan suurimmaksi osaksi MIMO–teknologialla. IEEE802.11n-teknologia käydään läpi tässä diplomityössä.

Toisessa osassa on suunniteltu uudenlainen mainontamedia. Ideana on, että käyttäjien on katsottava mainos ennen kuin he pääsevät käyttämään internetiä. Mainosportaaali suunniteltiin, toteutettiin ja integroitiin WLAN:iin yhteistyössä Turun Yliopiston kanssa. Mainosportaali testattiin käytännössä WLAN:in käyttäjätestauksen yhteydessä. Käyttäjien lisäksi mainosportaalin testausjaksossa oli mukana yhdeksän mainostajaa. Yhteys WLAN:in ja mainosportaalin välillä on etsiä uusia tapoja ansaita palveluntuottajalle tuloja sen sijaan, että käyttäjiltä vain veloitettaisiin verkon käytöstä.

Keskeisemmät tulokset ovat seuraavat. Asuintalossa kerrosta kohti tarvitaan yksi tukiasema. Kun tukiaseman peittoa suunnitellaan, ns. multi wall –malli ei tuota tarkkoja tuloksia. Tukiaseman peiton suunnittelussa tarvitaan ammattilaisohjelma. Mainoportaali sopii parhaiten paikalliselle markkinalle. Sen dynaamisuutta, interaktiivisuutta, luontoystävällisyyttä ja säästöjä verrattuna kilpailijoihin voidaan pitää dominoivina kilpailuetuina.

Avainsanat: IEEE802.11n, langaton lähiverkko, mainonta, pikosolu, radioaaltojen eteneminen sisätiloissa

Preface

Writing this thesis for the degree of Master of Science in Communications Engineering in Digita has been an interesting and educational experience.

I would like to thank a number of people who have contributed to this thesis. Especially, I would like to express my gratitude to my instructor Vesa Erkkilä who made my work possible and whose advices have been indispensable.

I would also like to express my gratitude to my supervisor professor Pertti Vainikainen for all the advice, comments and inspiring guidance.

Finally, I would like to express my gratitude to my family for their encouragement and support throughout my studies.

Espoo, April 1, 2009

Sampsa Lindroos

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List of symbols

λ	wavelength
ε_r	complex permittivity
θ_i	angle of incidence
σ_N	noise variance
c	speed of light
d	distance
d	thickness of the layer
F_{FFT}	frequency spacing between adjacent subcarriers
f	frequency
f_c	centre frequency
G_R	antenna gain of receiver
G_T	antenna gain of transmitter
H_B	height of the obstacle from the reference level
h_k	channel coefficient
i	index of subcarrier
k	index of transmitted symbol
L	propagation loss
L_p	path loss
L_f	penetration loss for a floor
L_w	penetration loss for a wall
M_R	number of receiver antennas
M_T	number of transmitter antennas
N	number of FFT points
$n_{i,k}$	independent adaptive noise
n_i	additive noise at receive
P_T	transmitted power
R	Fresnel plane wave reflection coefficient
R'	complex reflection coefficient
$R_{//}$	parallel polarization reflection coefficient
$R_{\perp}$	perpendicular polarization reflection coefficient
r	distance
S_R	receiver sensitivity

s_{RF}	continuous sequence of transmitted OFDM signal
T	symbol length
T'	complex transmission coefficient
$T_{//}$	parallel polarization transmission coefficient
$T_{\perp}$	perpendicular polarization transmission coefficient
T_{FFT}	FFT time
T_{guard}	guard interval
T_{win}	window interval
$w(t)$	pulse shape
$x_{i,k}$	signal constellation point
$y_{i,k}$	received signal constellation

List of abbreviations

ACK	Acknowledgement
ADSL	Asymmetric Digital Subscriber Line
AP	Access Point
BSS	Basic Service Set
CPT	Cost Per Thousand
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CTS	Clear To Send
DAC	Digital to Analog Converter
DCF	Distribution Coordination Function
DFS	Dynamic Frequency Selection
DIFS	DCF Inter Frame Space
DS	Distribution System
DSS	Distribution System Services
DSSS	Direct Sequence Spread Spectrum
ESS	Extended Service Set
FCS	Frame Check Sequence
FDM	Frequency Division Multiplexing
FEC	Forward Error Coding
FHSS	Frequency Hopping Spread Spectrum
GI	Guard Interval
HR/DSSS	High-Rate Direct Sequence Spread Spectrum
IBBS	Independent Basic Service Set
ICI	Inter Carrier Interference
IDFT	Inverse Discrete Fourier Transformation
IEEE	Institute of Electrical and Electronics Engineering
IFFT	Inverse Fast Fourier Transformation
IR	Infrared Light
ISI	Inter Symbol Interference
LLC	Logical Link Control
MAC	Medium Access Control
MCS	Modulation Coding Scheme
MIMO	Multiple Input Multiple Output
MPDU	MAC Protocol Data Unit

MSDU	MAC Service Data Unit
NLOS	None Line Of Sight
OFDM	Orthogonal Frequency Division Multiplexing
PHY	Physical
PLCP	Physical Layer Convergence Procedure
PMD	Physical Medium Dependent
PoE	Power over Ethernet
PPDU	PLCP Protocol Data Unit
RTS	Request To Send
SIFS	Short Inter Frame Space
SISO	Single Input Single Output
SM	Spatial Multiplexing
SS	Station Services
STA	Station
TPC	Transmit Power Control
UMTS	Universal Mobile Telecommunications Systems
WGAN	Wireless Global Area Network
WIMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WWAN	Wireless Wide Area Network

1 INTRODUCTION

The wireless local area network (WLAN), a concept that used to be known only to specialists, has in a couple of years become an ordinary man's term. WLAN offers wireless data transmission between computing devices.

WLAN has found its market among consumers. Today, more and more people have WLAN in their homes. The reasons behind this are:

- Wireless connection is much more convenient than wired connection, cables are not needed.
- Laptops have become popular among consumers. As laptops are mobile, the wireless connection is naturally more desired than wired.
- Competition is strong between manufactures of WLAN. Due to this the prices have gone down and WLAN has become affordable for the majority of consumers.

Currently, WLAN in consumer market works in a way that each consumer buys his or her own WLAN hardware and builds his or her own WLAN. In a residential building with for example 20 apartments there can be as many as 20 WLANs as well. In this case the frequency band is getting crowded. The idea of this thesis is to find out whether a common WLAN could be built among residents in a way that it would make sense in technical and in business points of view. The biggest benefits would be that customers would not need to invest in their own WLAN and they would not need to worry whether the WLAN works or not.

To find out if the WLAN can be built among residents several calculations and measurements of signal propagation in indoor environment will be done. The access points locations will be searched in a way that throughput, coverage and the physical locations of access points will fill the requirements. In the end, the network will be tested in practice.

The used WLAN technology is IEEE 802.11n draft. It is the most developed version of IEEE 802.11 family at the moment. It provides better coverage and throughput than earlier versions. This is mostly achieved with MIMO technology. The technology behind IEEE 802.11n draft 2.0 is explained in this thesis.

A business model, which would consist of the common WLAN among residents, would not certainly provide core competence in today’s business world. The business model could be copied in no time. Therefore an advertisement portal was brought in the game.

The idea of the advertisement portal is to test a new kind of advertising medium. The idea is that the users need to watch an advertisement before gaining an access to use internet. For one advertisement the user will get one hour of access time.

The advertisement portal was designed from the beginning. It was implemented and integrated to the WLAN in co-operation with University of Turku. The advertisement portal was tested in practice to find out answers to the following questions:

- Does the advertisement portal have a need or want in a market?
- What would be the best market for the advertisement portal?
- How could the advertisement portal be improved?

The tests were conducted at the same location for the same period with the same user group as WLAN at Tuusula. In addition to the users the advertisement portal was tested among advertisers. Nine advertisers took part in the research.

2 WIRELESS LOCAL AREA NETWORK

WLAN is a data transmission system providing a wireless connection to infrastructure network or wireless connection between two devices. The connection between devices is created with electromagnetic waves propagating in air instead of using fixed cables. Frequencies vary depending on the used WLAN technology. Mainly radio frequencies are used.

2.1 Motivation for using WLAN in residential buildings

The essential question is why WLAN was chosen to be used in the residential buildings instead of other wireless communication network techniques. First let's go through what the other wireless communication network techniques are. Then why WLAN and its technology IEEE 802.11 were chosen is explained. In the end, the ultimate question is discussed, namely why wireless instead of wired?

The wireless networks that already exist in the market can be classified in four different categories: wireless global area networks (WGAN), wireless wide area networks (WWAN), wireless local area networks (WLAN) and wireless personal area networks (WPAN) [1]. WGANs use satellites and have coverage measured in hundreds of kilometres even in thousands of kilometres. WWANs use cellular network technologies such as UMTS and WIMAX and have coverage that is measured in kilometres. WLANs have coverage of tens of metres and are used in offices and homes. WPANs have coverage of less than ten metres. Bluetooth is the most well known example of WPAN technologies.

The properties required for the wireless network technique in the residential building environment are the following.

- The coverage has to include the whole building but outside the building the signal should be as weak as possible for security reasons.
- Throughput has to be high enough; throughput tells how much data moves between devices.

- Low mobility, desired technique needs to handle walking speed.
- Medium security level, it does not need to be the best possible one but good enough that it takes an advanced hacker to break it.

Different wireless communication network techniques are compared in Table 1. From Table 1 can be seen that WLAN is the best option. It provides high throughput, necessary mobility, and desired coverage, of course the low cost is not forgotten. WWAN is not suitable because of high cost and large coverage. WPAN is not suitable because of low coverage and low throughput. Actually WPAN is meant for devices that require low power consumption. [1]

Table 1. Current status of wireless communication network techniques

	WWAN	**WLAN**	**WPAN**
Throughput	max. 2Mbps	54-300 Mbps	max. 10 Mbps
Coverage	15m-10km	20-100m	max. 10m
Mobility	high	low	very low
Cost	high	very low	very low

IEEE 802.11 standard has become a synonym to WLAN in laypersons' term. There are similar technologies to IEEE802.11. The other known WLAN technologies are Home RF and HIPERLAN TYPE 2, but none of these has grown as big as IEEE802.11-standard. [1]

From Table 1 one can observe that WWANs and WPANs actually are not competitors of WLAN. On the contrary, they complement WLAN and target to different markets. The real challenger of WLAN is wired LAN and more precisely wired LAN technology IEEE 802.3 (Ethernet). IEEE 802.3 is a mature technology and it has been used for several years. The enormous benefit that WLAN provides compared to LAN is mobility. The user is not fixed to a certain place. Instead of that the user has freedom to move in a certain area. On the other hand, wireless equipment are much more sensitive to interference and the available radio spectrum is limited. The interference and the radio spectrum are discussed later in this thesis.

At this point, it is good to remember that the interference and the limitation of radio spectrum are drawbacks in the wireless domain.

2.2 IEEE 802.11n standard (Draft 2.0)

In this section the IEEE 802.11 standard family and especially the IEEE 802.11n standard are discussed. The reason why IEEE 802.11n was chosen is that the n-technology can provide clearly higher throughput, a larger coverage area, and better interference tolerance than its descendant’s (IEEE 802.11b, IEEE 802.11g). [2]

The n-technology has not been standardized (estimated to be standardized in 2009) yet, but in the market there are several devices that are built based on the drafts of the n-technology. Draft 2.0 is discussed instead of newer drafts. All the equipment used were implemented according to the Draft 2.0. In this section architecture, physical layer and medium access layer are described. Multiple input multiple output (MIMO) technique is a part of the physical layer but it is discussed in its own section.

The n-technology has several features and the standard manual is 500 pages long. Because most of the features are never implemented, only the features that are used in test equipment are discussed in this thesis. All the unnecessary technology is ignored and due to this the thesis stays more comprehensible as well. The test equipment is described in Chapter 4. [2]

2.2.1 Architecture

IEEE 802.11 networks consist of four main components. These components are described in Figure 1.

Stations (STA) are used to transfer data to other stations in network. Any computing device, with a wireless network interface, can be defined as a STA. The STAs do not need to be mobile. [3]

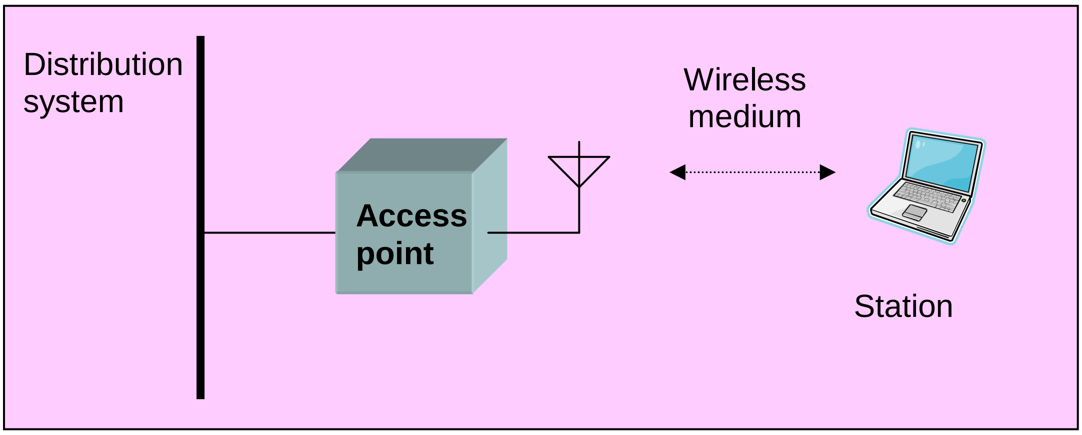

Figure 1. The main components of a IEEE 802.11 network

An access point (AP) is a device between wireless and wired medium. Frames are received from the wireless medium and forwarded to the wired medium or vice versa. Before the frames can be forwarded, they are converted to support the particular medium. The frames and the framing are discussed later in this chapter. [3]

Distribution system (DS) is a logical component, whose task is to forward frames between the APs and outside the IEEE 802.11 network. Communication between the APs is needed, when several APs are connected in the same network, to track the movement of the STAs inside the network. If the APs were independent from each others and the STA would move to other area of AP, then the new AP would not recognize the STA and the connection would be lost. There are several ways to implement the distribution systems. The chosen implementation depends on how reliable the network needs to be, and reliability is proportional to cost. [3]

The IEEE 802.11 standard supports two topologies, Basic service set networks (BSS) and Extended service set networks (ESS). These two topologies are explained separately below, starting from the simple one. [4]

Basic service set (BSS)

The basic building block of the IEEE 802.11 network is BSS and the simplest form of BSS is independent BSS (IBSS), which is shown in Figure 2. In IBBS computers are communicating between each other directly and to be able to do this they need to be in a direct communication range. The smallest IBBS consists of two computers. The IBBS is usually set up for a short period of time, e.g. for a meeting.

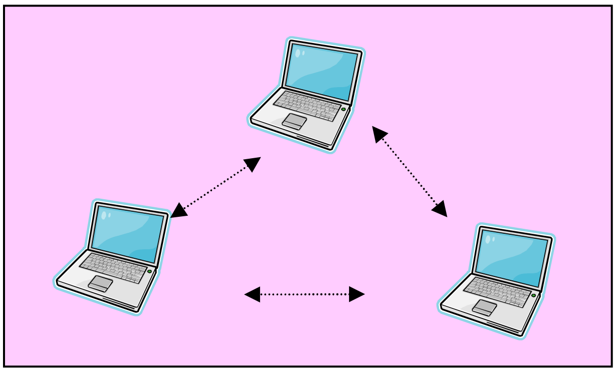

Figure 2. Topology of Independent Basic Service Set (IBBS)

A little bit more complex network is Infrastructure BBS, which is shown in Figure 3. The AP plays a key role in this particular network, as all the traffic goes through the AP. Stations never communicate directly between each other. If the STA wants to send data to an other STA in the same network then two hops are needed, which is more costly than in IBBS, where one hop is enough. On the other hand, it has two advantages. Firstly, distance between stations can be larger. The maximum distance is achieved, when STAs are in opposite directions from the AP and as far as the connection between the AP and the STA can be accomplished. Secondly, the AP can buffer data. The receiver STA does not need to keep its wireless receiver on all of the time, which saves a lot of power. [3]

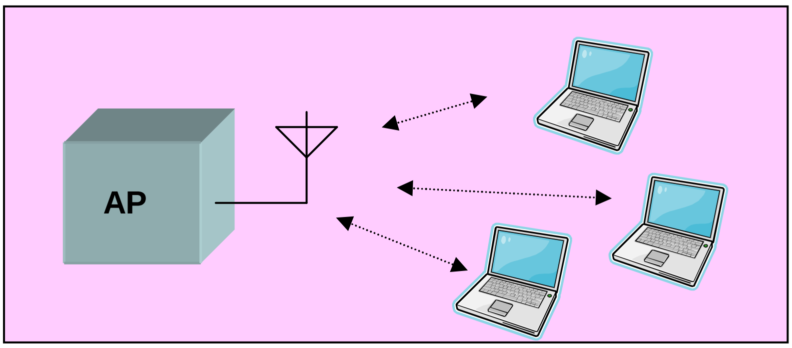

Figure 3. Topology of Infrastructure Basic Service Set

Extended service set (ESS)

The idea of an ESS is to put several basic service sets together to form a larger network. This is done by linking BSSs to a distribution system as shown in Figure 4. The specific DS technology does not exist (as mentioned earlier), but the DS device needs to provide a set of services. A good example of the DS device is a combination of a router and an AP.

The STAs can communicate with the other STAs inside the ESS. It does not matter if the other STA is in a different BBS. The STAs can also move freely inside the ESS without loosing connection.

Consider a case where frames are wanted to be delivered to the station inside the ESS from outside world. Addressing is done with a MAC address. The router asks the APs who has the STA with the certain MAC address in its basic service area. The AP who has it answers to the router. The router sends the frames to the AP. The AP converts the frames and then forwards them to the station. [3]

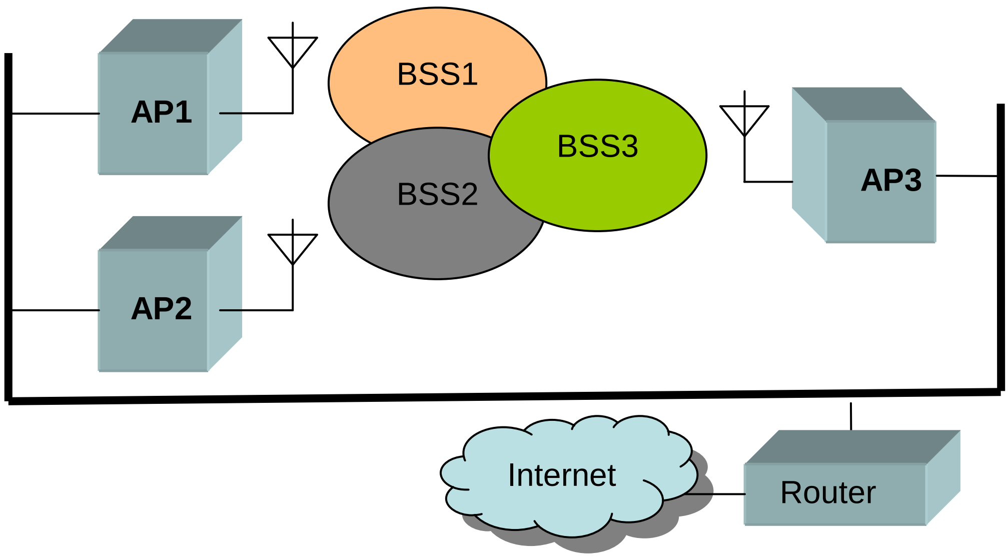

Figure 4. Topology of an Extended Service Set (ESS)

2.2.2 Services

The standard services of the IEEE 802.11 are divided into station services (SS) and distribution system services (DSS). The services can be considered as a meter measuring how functional the network is. Equipment vendors can also implement services in a way they see fit.

The SS include stations and APs and there are five following services;

- Authentication
- Deauthentication
- Data confidentiality
- MSDU delivery.

In addition, there are transmit power control (TCP) and dynamic frequency selection (DFS). These services are ignored because they are used in the 5 GHz frequency band and this thesis concentrates only on the 2.4 GHz frequency band.

The authentication service controls network access, STAs need to go through an authentication procedure before accessing the network. Two authentication methods are used, open system authentication and shared key authentication. The deauthentication service is opposite to authentication. Its task is to terminate the authenticated connection, when it is asked to do so by the STA. The idea of the data confidentiality service is to prevent attacks to the network and to protect the content of messages. The protection is done by encrypting the messages. The idea of the MSDU delivery service is to take care that the data is transferred to the desired endpoint.

The distribution system services (DSS) include distribution system and it functions via an access point. Five services that comprise the DSS are association, reassociation. disassociation, distribution, and integration

The association service works as a map, it registers an information, that which AP to use for any mobile station, to the DS. This makes it possible that frames can be correctly delivered from the DS to STAs. The reassociation service is used when a STA changes basic service area inside an extended service area. The change is registered to a DS register. The reassociation is initiated by the STA and it is done when the STA notices that an other AP can provide better connection. The reassociation is the same thing as handover in mobile phone world. The disassociation service is provided when the STA wants to terminate an existing association. When the STA has been disassociated from the network, it does not belong to the network anymore and it cannot send or receive data from the STAs inside the network. The distribution service is used every time when a STA sends data. The STA sends data to an AP, and after the AP has accepted the data, it forwards data to a DS, and the DS delivers it to its desired destination. The distribution service is used even in the case where a STA sends data to other STA inside the same basic service area. The distribution service is not used in the IBBS. The integration service is used in the distribution system and it allows the DS to connect to a non-IEEE 802.11 network. [4]

Mobility

Mobility is undoubtedly the greatest benefit of WLAN compared to the wired LAN. STAs can move, be connected and send frames at the same time. The mobility can cause three different transitions depending on the network and movements of the STAs.

The simplest one is that no transition occurs at all. This happens when the STA moves inside its basic service area. The STA is connected to the same access point all of the time, or the STA is not moving at all.

In the BSS transition, the STA moves from a basic service area to other basic service area in the same ESS. The connection is not lost as long as the coverage area of the

APs overlap. The BSS transition is the same thing as the reauthentication, which is explained in the previous section.

The third one is the ESS transition. In the ESS transition the STA moves from one basic service area to other basic service area, but the basic service areas are in different ESSs. This kind of connection is not supported in the IEEE 802.11 and the connection is lost in the transition. [5]

2.2.3 Medium access control layer (MAC layer)

The main task of the MAC layer is to provide reliable data transfer over the dynamic medium, control access to the shared medium, protect information that it transmits, and to be compatible with existing higher level standards. Above the MAC layer is the Logical Link Control (LLC) layer. They both belong to a layer called data-link layer. The LCC layer is used in several communication networks, not only in IEEE 802.11 networks. [3]

The basic access mechanism

Distributed coordination function (DCF) is a basic access mechanism in the MAC layer. It is based on carrier sense multiple access with collision avoidance (CSMA/CA,) which is also used in IEEE 802.3 (Ethernet). The MAC structure of the DCF is described in Figure 5. Consider a case that a STA wants to send a frame to an access point. The STA listens the medium and if it is idle the STA waits a DCF inter frame space (DIFS) time interval. If the channel stays idle during the DIFS period, the STA starts the frame transition to the AP. When the AP has received the frame it waits a short inter frame space (SIFS) time interval before sending an acknowledgement (ACK) frame back to the STA and when the STA has received the ACK frame the transmission is completed. In a case the medium is not idle at the beginning of transmission process the STA waits a certain period of time, which is defined by exponential backoff algorithm. In the case the STA does not receive ACK frame from the AP the STA expects that the frame is lost and the AP is required to resend the frame. To make sure that other STAs or APs do not transmit data at the same time carrier sensing functions are used. In this case, a virtual carrier sensing is used by a Network Allocation Vector (NAV). At the same time, when the STA starts to transmit the frame, it tells to other STAs the time that it expects to use the medium. The other STAs then set the NAV to that given time and start to count down from NAV to zero. When the NAV is nonzero the virtual carrier sensing function indicates that the medium is busy and when the NAV reaches zero the virtual carrier sensing function indicates that the medium is idle. [6]

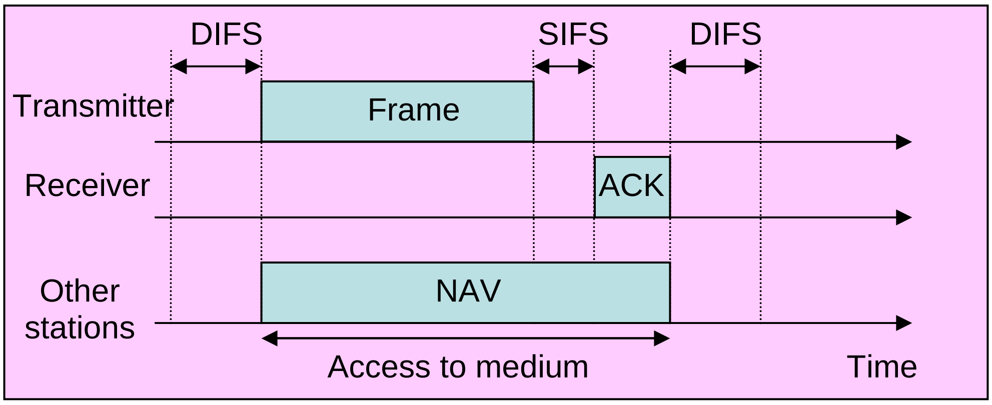

Figure 5. The Mac structure of distributed coordination function

In the DCF lies one big problem called the hidden node problem. It is described in Figure 6. Consider a case that three stations are physically located as shown in Figure 6, the STA2 can hear the STA1 and the STA3, but the STA1 and the STA3 cannot hear each other. In the previously explained DCF case this would mean that if the DCF access mechanism was performed between the STA1 (transmitter) and the STA2 (receiver) the STA3 would not have any idea of the on going transmission. As far as the STA3 knows the medium is idle and nothing would stop it from starting to transmit to the STA2. [5]

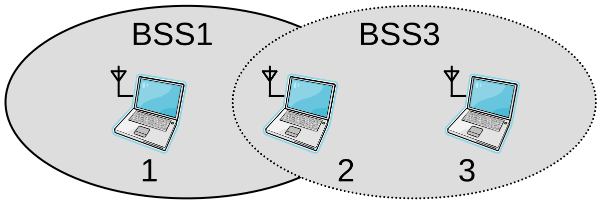

Figure 6. The hidden node problem, STA2 can hear STA1 and STA3, but STA1 and STA3 cannot hear each other

A RTS/CTS phase can be inserted before the data transmission to overcome the hidden node problem. This method is described in Figure 7. The access mechanism is the same as in the DCF except at the beginning after the DIFS time interval transmitter sends a request to send (RTS) signal and the NAV for an expected transmission time. The receiver waits for the SIFS time interval and then sends a clear to send (CTS) signal and the NAV for the expected transmission time. This method makes sure that all STAs that can affect transmission will hear that the medium is busy for the indicated time. The RTS/CTS method consumes a fair bit of capacity, and due to this it is only used in high capacity environments and in environments with large contention on transmission. [5]

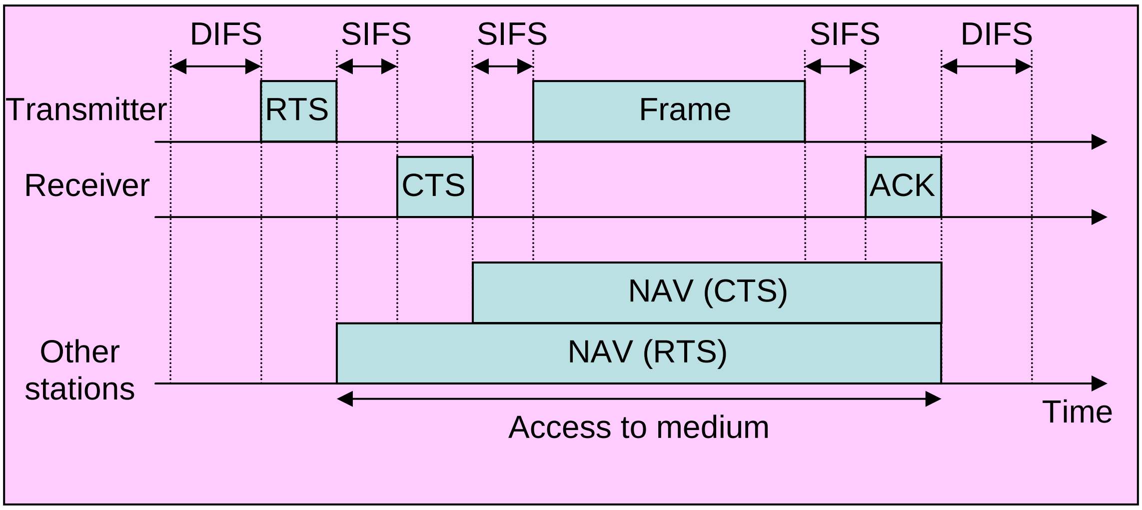

Figure 7. The MAC structure of distributed coordination function with an additional RTS/CTS phase

Frame format

In the IEEE 802.11 standard the MAC layer receives data from the LLC layer, which is above the MAC layer, in a form of MAC service data unit (MSDU). The MSDU is not a suitable frame format for the lower level Physical (PHY) layer. Before forwarding the frame to the PHY layer the frame format needs to be changed to a MAC protocol data unit (MPDU). In addition to the MPDU data frame the MAC layer generates management and control frames. [5]

The frames have three different parts, a MAC header, a frame body and a frame check sequence (FCS). The format is described in Figure 8. The MAC header is divided in several parts: frame control, duration, address, sequence control, QoS control, and HT control. The MAC structure is the same in all IEEE 802.11X standards except that the HT control is only used in n-technology. The frame body is the payload of the higher level, it is not present in all frame types and subtypes. The field size of the frame body can vary; the maximum size is the maximum size of the MSDU. The FCS is a kind of error control mechanism; the FCS is calculated by the transmitter before the transmission. The receiver can conduct the same calculation and compare it to FCS field and if they match the frame is most likely undamaged. All the features listed above do not necessarily exist in the MPDU frame. The features depend on which frame type is used, but the frame control, duration, address and the FCS exist always. [2] [5]

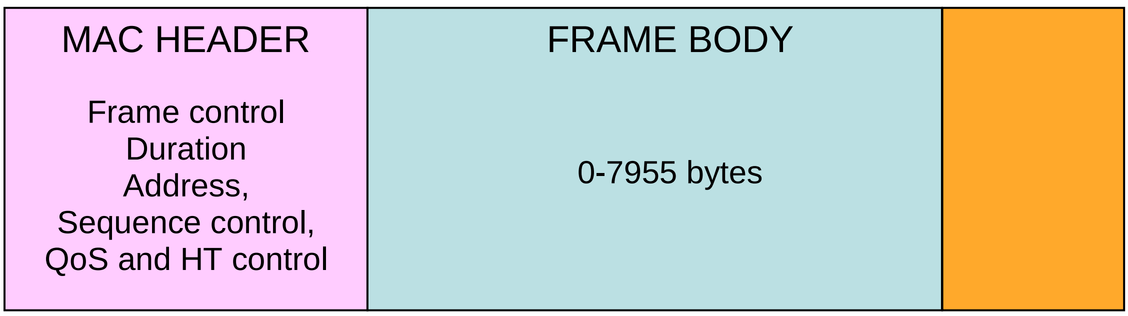

Figure 8. The MPDU frame format

Fragmentation

The fragmentation is a method where a frame is divided into small parts. It is optional in IEEE 802.11 but reassembly is compulsory. The reassembly is opposite to fragmentation. The fragmentation brings more reliability in a noisy environment, but in a good radio channel it creates overhead. The fragmentation is used when the MSDU frames are transformed to the MPDU frames. A need for the fragmentation is decided with a help of Fragmentation_treshold, if the MPDU is larger than the Fragmentation_treshold the fragmentation is implemented. When the fragmented frames are transmitted the medium is reserved as long as the whole original MPDU is transmitted. [3]

2.2.4 Physical layer (PHY layer)

The physical layer lies between the MAC layer and the wireless medium. The physical layer has three main services: carrier sensing, transmitting and receiving data frames to and from the MAC layer or to and from the wireless medium. Currently five physical layers have been standardized. The first three standards were standardized in 1997 and two more joined this group further in 1999. The physical layers are listed below:

- Frequency-hopping spread-spectrum (FHSS) PHY
- Direct-sequence spread spectrum (DSSS) spectrum PHY
- Infrared light (IR) PHY
- High-Rate Direct Sequence (HR/DSSS) PHY
- Orthogonal Frequency Division Multiplexing (OFDM) PHY

The IR PHY uses infrared light instead of radio waves and the standard is not used in the WLAN. The FHSS, DSSS and HR/DSSS represent old school techniques. Though the n-technology supports them they do not provide the best possible service. The OFDM PHY provides the best service currently and it is replacing the older PHY techniques. It seems like a waste of time to discuss of FSSS, DSSS and HR/DSSS PHY techniques because they are starting to be in the end of their life circle in the IEEE 802.11 standard. In this thesis only the OFDM PHY technique is discussed. [2]

Orthogonal frequency division multiplexing (OFDM) physical layer

The OFDM PHY layer is based on OFDM. The basic principle of OFDM is to split a high rate data stream into several lower rate data streams. The data is sent simultaneously over a number of subcarriers. The data is separately modulated on each subcarrier. The lower data rate subcarries have a larger symbol duration, which decreases multipath delay spread. [1]

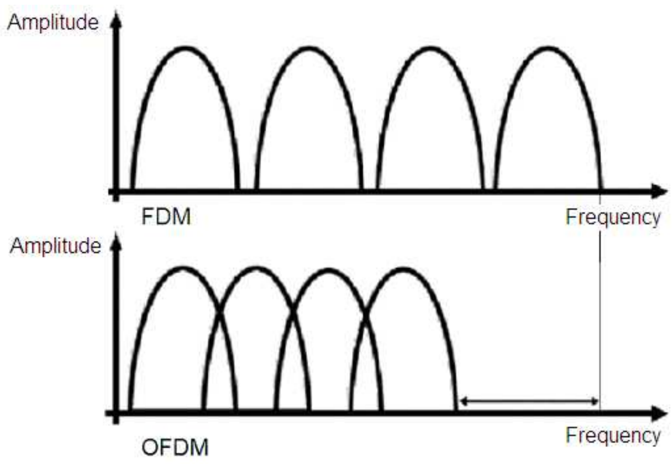

Figure 9. FDM signal compared to OFDM signal in frequency domain

To understand the OFDM better let’s first concentrate on the Frequency Division Multiplexing (FDM). The idea of FDM is that the signal is divided into many parts and transformed in several different frequencies. The difference between FDM and OFDM is shown in Figure 9. From Figure 9 it can be observed that the OFDM signals are overlapping and due to this the OFDM has a better spectral efficiency than the FDM. Figure 10 illustrates how the overlapping does not create inter carrier interference (ICI). From Figure 10 it can be observed that when any of the signals reach the peak value amplitudes of the adjacent signals are zero and this means that the signals are orthogonal. It is important to notice, that the peak value is the most important part of the signal, because it encodes data. [5]

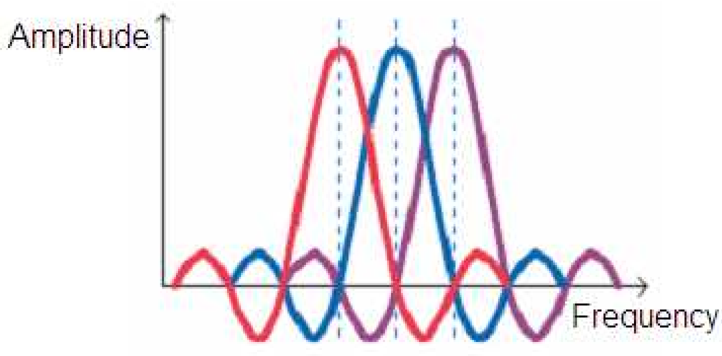

Figure 10.Three orthogonal signals in frequency domain

Now that the idea of OFDM is known, let’s discuss the OFDM transmission system. A point to point OFDM transmission system is shown in Figure 11 as a block diagram. The system is broken down in the following paragraphs starting from the data source and ending to the data sink.

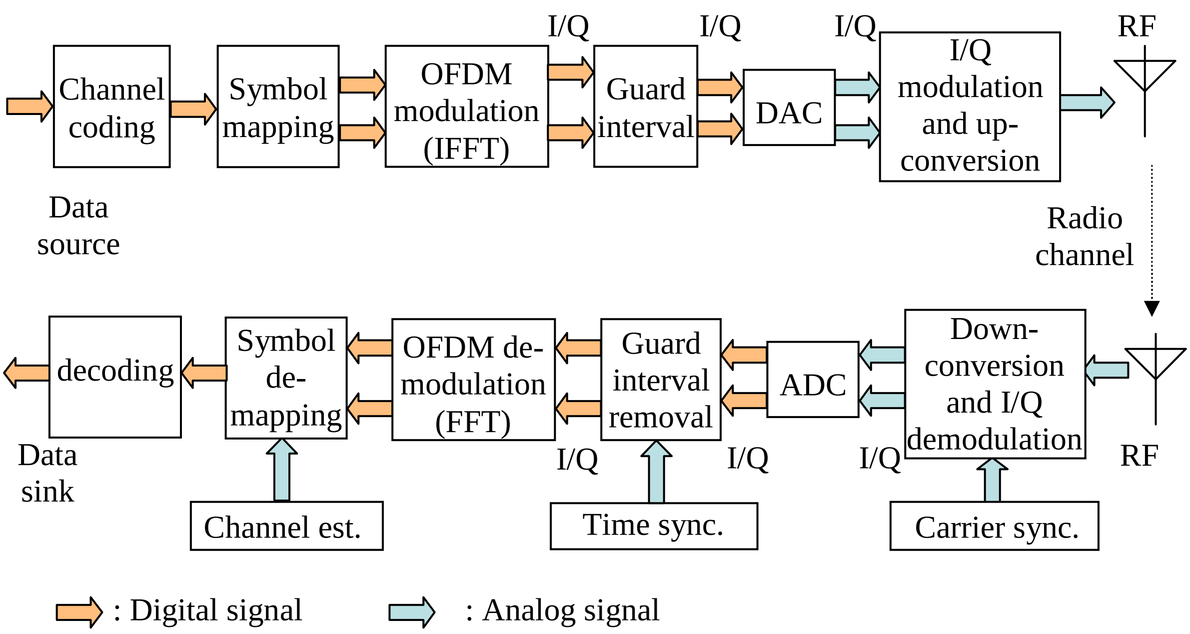

Figure 11. Point-to-point OFDM transmission

In the channel coding -block the data is encoded into suitable and more reliable form to be ready to be sent over wireless medium. Usually forward error coding (FEC) is used. In the symbol mapping –block the data is mapped into constellation points, depending on which modulation scheme is used. In the OFDM modulation –block required amplitudes and phases of subcarriers are calculated according to the constellation diagram. Then the subcarriers are converted into time domain signals using inverse fast Fourier transformation (IFFT) and summed. In the guard interval –block a guard interval (GI) is defined. The GI is needed to reduce inter symbol interference (ISI) and ICI. The ISI is not as big a problem in the OFDM systems as it is in many other systems, because of the Fourier transform but the ICI can be a major problem. The ICI can occur because of the Doppler effect or if the clocks of receiver and transmitter are not perfectly synchronized. In the n-technology the GI is 400ns or 800ns. Windowing is also implemented in the Guard Interval block. The windowing is a technique where a new symbol is gradually build up and the old symbol is faded in the same pace. If the new symbol were brought up suddenly it would cause high frequency components, which would be considered as noise. In the DAC –block a digital to analog conversion (DAC) is implemented. Converted analog signals are then sent to the I/Q –modulation and up conversion block, where the I/Q –signals are combined and converted to desired radio frequencies. The signal is transmitted to air via an antenna. [1] [5]

In a receiver, an antenna receives the signal and forwards it to the down conversion and I/Q-demodulation –block. The signal is down converted to a lower frequency and divided to the I/Q–signals. To be able to obtain correct I/Q –signals carrier synchronization needs to be implemented. The I/Q-signals are forwarded to the ADC –block, where the analog I/Q –signals are converted to the digital I/Q –signals. The digital I/Q –signals are forwarded to the Guard Interval block, where the GI is removed. The time synchronization plays an essential role. If the synchronization is incorrect a wrong part of the signal will be removed. In the OFDM demodulation –block the signals are separated and converted from the time domain to the frequency domain, and after this the constellation diagram can be created. In the symbol demapping block the constellation diagram is demapped to a single line of data. Channel estimation is required because the receiver needs to have phase and amplitude reference to be able to detect symbols correctly. The data is forwarded to the decoding –block, where the data is decoded and if everything has worked as they should have the data should be as same as in the data source. [1]

The above point to point OFDM transmission description is superficial and hardly scratches the surface. On the other hand, it gives comprehensible description of the system. Let's view the above system from a mathematical point of view to obtain a better understanding.

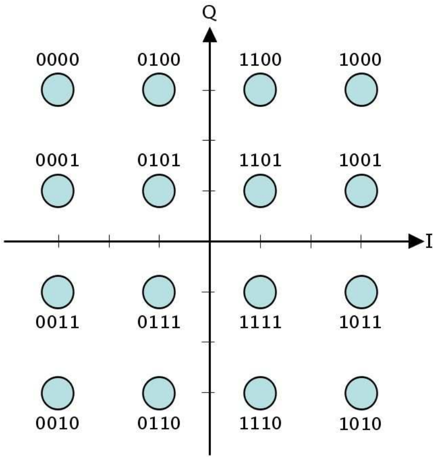

Figure 12. Constellation diagram for rectangular 16-QAM

At the output of symbol mapping block the data is in the constellation diagram. An example of the constellation diagram is in Figure 12. A constellation point is a complex number and it is represented as a symbol $x_{i,k}$, where *i* and *k* stand for *i*th subcarrier of the *kth* OFDM symbol. At the output of the I/Q –modulation and upconversion –block a mathematical expression for a continuous sequence of transmitted OFDM signal is shown in Equation (1)

$$s_{RF}(t) = \sum_{k=-\infty}^{\aleph} S_{RF,k}(t-kT) \tag{1}$$

In Equation (1) $S_{RF}(t-kT)$ is obtained from Equations (2) or (3) depending on *t*s value

$$S_{RF}(t-kT) = \mathrm{Re}\left\{ w(t-kT) \sum_{i=-N/2}^{N/2-1} x_{i,k} e^{j2\pi (f_c + \frac{i}{T_{FFT}})(t-kT)} \right\} \tag{2}$$

when $kT - T_{win} - T_{guard} \le t \le kT + T_{FFT} + T_{win}$, otherwise

$$S_{RF}(t-kT) = 0 \tag{3}$$

The $w(t-kT)$ is a delayed version of the transmitter pulse shape $w(t)$ and $w(t)$ is obtained from Equation (4).

$$w(t) = \begin{cases} \frac{1}{2}[1 - \cos \pi (t + T_{win} + T_{guard}) / T_{win}] & -T_{win} - T_{guard} \le t \le -T_{guard} \\ 1 & -T_{guard} \le t \le T_{FFT} \\ \frac{1}{2}[1 - \cos \pi (t + T_{FFT}) / T_{win}] & T_{FFT} < t \le T_{FFT} + T_{win} \end{cases} \tag{4}$$

The symbols and their meanings that were used in Equations (1)-(4) are listed below in Table 2. In Equations (1)-(4) the OFDM signal is a sum of prototype pulses shifted in the time and frequency directions, and multiplied by data symbols. The modulated wave form is generated by IFFT, which can be seen from Equation (2). Instead of IFFT an Inverse Discrete Fourier Transformation (IDFT) could be used, but it is not as efficient in a digital system. [1]

The radio channel has an effect on the transmitted signal. The received signal is not totally same as the transmitted signal and therefore the received signal is noted $r_{RF}(t)$ instead of the transmitted signal $s_{RF}(t)$.

Table 2. The explanation of symbols that were used in Equations (1) - (4)

Symbol	Explenation of symbol
T	Symbol length
T_{FFT}	FFT time
T_{guard}	Guard interval
T_{win}	Window interval
f_c	Centre frequency
$F = 1/T_{FFT}$	Frequency spacing between adjacent subcarriers
N	Number of FFT points
k	Index of transmitted symbol
i	index of subcarrier
$x_{i,k}$	Signal constellation point (complex number)

From the received signal, after the ADC is implemented, the received signal constellation $y_{i,k}$ can be extracted according to Equation (5), where $y_{i,k}$ equals to $x_{i,k}$ in the receiver side. In the particular equation it is assumed that an exact time instant kT, which is a start point of the OFDM symbols, is known.

$$y_{i,k} = \sum_{i'=N/2}^{N/2-1} x_{i',k} h_{i',k} \frac{1}{T_{FFT}} \int_{u=0}^{T_{FFT}} e^{-j2\pi(i-i')u/T_{FFT}} du + n_{i,k} \tag{5}$$

All the symbol meanings are the same as in the transmitter side (Table 2) and in addition $n_{i,k}$ is independent additive noise, $u = t - kT$ and $h_{i,k}$ can be obtained from Equation (6).

$$h_{i,k} = \int_{\tau=0}^{\tau_{\max}} h_k(\tau) e^{-j2\pi i'/T_{FFT}} d\tau \tag{6}$$

In Equation (6) h_k is a channel coefficient. [1]

The subcarriers travel in different radio paths as mentioned earlier. Due to this they have different attenuations. The attenuation for a single subcarrier after the FFT is defined in Equation (7).

$$(E_c / N_0)_{i,k} = \frac{E\left\{\left|x_{i,k}\right|^2\right\}\left|h_{i,k}\right|^2}{\sigma_N^2} \tag{7}$$

In Equation (7) σ_N^2 is noise variance, $E\left\{\left|x_{i,k}\right|^2\right\}$ is signal energy and $h_{i,k}$ is a channel coefficient. [1]

It is important to notice that all the mathematical expressions above are for the ideal point to point transmission. Every now and then something might go wrong, for example synchronization error or timing offset may occur.In this case the expressions above are not valid any more. The ways to overcome these problems are not handled in this thesis, but there are several books about this like for example reference [1].

Frame format

The PHY layer is further divided into Physical Layer Convergence Procedure (PLCP) and the Physical Medium Dependent (PMD) sublayers. The PHY layer logical architecture is described in Figure 13. From Figure 13 it can be seen that the PLCP locates below MAC layer. The task of PLCP is to convert the PSDU frame to the PLCP protocol data unit (PPDU) and vice versa. The PPDU frame is shown in Figure 14. PLCP does the conversion by adding its own header and preamble to PSDU frame. The task of PMD is to transmit bits that it receives from the PLCP into air via the antenna. [5]

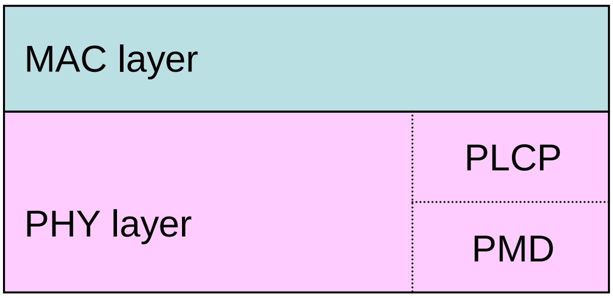

Figure 13.The PHY layer logical architecture

The meaning of the preamble, shown in Figure 14, is to help to synchronize incoming traffic. It has 12 OFDM symbols, whose task is to synchronize several timers between the transmitter and the receiver. The first ten symbols are called short training sequence, which are used for AGC convergence, selecting the right antenna, and large-scale synchronization. The last two symbols are called long training sequence and they are used for channel estimation and fine tuning of the synchronization. The short training sequence symbols are not protected with the GI but the long training sequence symbols are protected. The PLCP header is transmitted in the signal field and in a part of the data field as well, as shown in Figure 14. Its main task is to tell the PMD layer which modulation and coding schemes (MCS) is used. [2] [5] [7]

Preamble	Signal	Data
12 symbols	1 symbol	Variable number of symbols

Figure 14. Physical protocol unit of PPDU

The OFDM PHY uses different MCS, and the data rate varies from 6.5 MHz up to 300 MHz. The reason why data rates vary is that the radio medium is dynamic and not static like in the wired world. Thus the data rate is directly proportional to received signal level, the better the signal level, the higher the data rate. The task of OFDM PDM is to implement the modulation, but which implementation to use is defined by upper levels.

The modulation and coding schemes that were used in the test equipment are listed in Table 3. APs always try to use the best MCS as possible. From Table 1 it can be seen that the MCS 13 is the best because it provides the best throughput. The values are exactly the same as in the standard. In addition to Table 3:

- In the 20 MHz band the number of subcarriers is 52
- In the 40 MHz band the number of subcarriers is 108
- One FEC encoder is used for all of the schemes

Table 3. The modulation and coding schemes [2].

MCS	Number of spatial streams	Modulation	Coding rate	GI=800ns		GI=400ns		Sensitivity level [dBm]
				Rate in 20MHz [Mbit/s]	Rate in 40MHz [Mbit/s]	Rate in 20MHz [Mbit/s]	Rate in 40MHz [Mbit/s]	
0	1	BPSK	½	6,5	13,5	7 2/9	15	-88
1	1	QPSK	½	13	27	14 4/9	30	-84
2	1	QPSK	¾	19,5	40,5	21 2/3	45	-81
3	1	16-QAM	½	26	54	28 8/9	60	-78
4	1	16-QAM	¾	39	81	43 1/3	90	-75
5	1	64-QAM	2/3	52	108	57 7/9	120	-70
6	1	64-QAM	¾	58,5	121,5	65	135	-69
7	1	64-QAM	5/6	65	135	72 2/9	150	-68
8	2	BPSK	½	13	27	14 4/9	30	-88
9	2	QPSK	½	26	54	28 8/9	60	-84
10	2	QPSK	¾	39	81	43 1/3	90	-81
11	2	16-QAM	½	52	108	57 7/9	120	-78
12	2	16-QAM	¾	78	162	86 2/3	180	-75
13	2	64-QAM	2/3	104	216	115 5/9	240	-70
14	2	64-QAM	¾	117	243	130	270	-69
15	2	64-QAM	5/6	130	270	144 4/9	300	-68

The meanings of the columns in Table 3 are explained below:

- The first column indicates which MCS index is used.
- The second column indicates the number of spatial streams. The spatial streams can vary from one to two and the idea of spatial streams is explained in the following MIMO section.
- The third column indicates which modulation is used.

- The fourth column indicates the used coding rate, e.g. if coding rate is ¾, then three data bits and one error correction bit are sent. The higher the coding rate value is the less error correction is used.
- The fifth and sixth columns indicate the data rate per bandwidth. The column is further divided for 20 MHz and 40 MHz bandwidths. The reason that makes the values different in columns is GI. The value of GI is shown on top of the two columns.
- The seventh column indicates the minimum signal level at the receiver. [2]

Multiple input multiple output (MIMO) technique

Multiple Input Multiple Output (MIMO) technique is the main aspect that separates n-technology from its predecessors. The idea in the MIMO technique is to use more than one antenna in the transmitter and the receiver. Antennas are spatially distributed which provides an additional dimension complementing the time dimension [8]. The MIMO systems provide much higher spectral efficiency than single input single output (SISO) systems in none-line-of-sight (NLOS) environments. In SISO systems the current spectral efficiency value is 2-3 b/s/Hz in NLOS. MIMO systems have achieved as high as 42b/s/Hz in NLOS [7].

A mathematical expression for MIMO channel is discussed below. Transmitter and receiver have M_T and M_R antennas, respectively. Consider a case where a signal $s_j(t)$ is transmitted from *j*th antenna of the transmitter. Then the received signal at the *i*th antenna of the receiver is shown in Equation (8).

$$y_i(t) = \sum_{j=1}^{M_T} h_{i,j}(\tau,t) \otimes s_j(t) + n_i(t), i = 1,2,3,...,M_R \tag{8}$$

In Equation 8 $n_i(t)$ is additive noise at receiver and $h_{i,j}(\tau,t)$ is time-varying channel impulse response between the *j*th antenna of the transmitter and the *i*th antenna of the receiver. $h_{i,j}(\tau,t)$ is obtained from channel response $H(\tau,t)$ which is $M_R \times M_T$ matrix shown in Equation (9).

$$H(\tau,t)=\begin{bmatrix} h_{1,1}(\tau,t) & h_{1,2}(\tau,t) & \cdots & h_{1,M_T}(\tau,t) \\ h_{2,1}(\tau,t) & h_{2,2}(\tau,t) & \cdots & h_{2,M_T}(\tau,t) \\ \vdots & \vdots & & \vdots \\ h_{M_R,1}(\tau,t) & h_{M_R,2}(\tau,t) & \cdots & h_{M_R,M_T}(\tau,t) \end{bmatrix} \tag{9}$$

In the MIMO technique there are several ways to achieve high spectral efficiency. In this thesis only the techniques that are used in the test equipment are discussed. In the test equipment only one MIMO technique is used, namely spatial multiplexing. [9].

Spatial multiplexing (SM) offers increase over SISO systems in transmission rate, with the same bandwidth and without any power increase. For example in the case where the receiver and the transmitter have two antennas, the signal is split in two halves and transmitted simultaneously and put together again in the receiver end. The signal travels at the same frequency but in different spatial radio paths. Receiver diversity is needed to make this possible, which means that the receiver has a full knowledge of the channel. Transmission rate increases in proportion to the number of antennas. The SM needs an environment with rich scattering, moderate to high SNR, and data rate much higher than maximum Doppler spread [8].

3 INDOOR PROPAGATION

This chapter concentrates on how the radio waves propagate in an indoor environment. When the radio wave propagates in a certain environment, whose characteristics are known, coverage and throughput can be determined. Before discussing on indoor propagation, let's discuss what kind of propagation exists and how it can be measured.

3.1 Multipath propagation

In the indoor environment the radio propagation is multipath propagation in most of the cases. Multipath propagation results from the fact that the signal travels different ways from the transmitter to the receiver as shown in Figure 15. From Figure 15 it can be seen that different obstacles reflect the signal and due to reflection the distance that the signals travel from the transmitter to the receiver varies. In addition, signal can also diffract from the obstacles. Differences of the transmitted signal at the receiver due to multipath propagation are:

- Arriving time, which is described as delay spread
- Different phase, that is due to different distances
- Attenuation, that the signal has suffered.
- Direction, where the signal has been transmitted and received
- Polarisation, changes when the signal e.g. reflects from a obstacle [10]

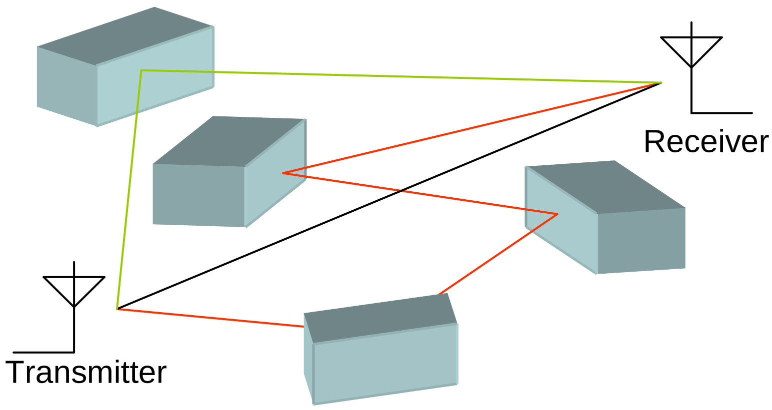

Figure 15. Multipath propagation phenomena

A good way to calculate the received signal level at the receiver is to build a link budget. The link budget is presented in Equation (10)

$$P_R\,[\text{dBm}] = P_T\,[\text{dBm}] + G_T\,[\text{dB}] + G_R\,[\text{dB}] - L_p\,[\text{dB}] \tag{10}$$

In Equation (10) $P_T\,[\text{dBm}]$ is the transmitted power in dBm, $G_T\,[\text{dB}]$ and $G_R\,[\text{dB}]$ are the antenna gains in decibels of the transmitter and the receiver, respectively, L_p [dB] is the path loss in dBm and $P_R\,[\text{dBm}]$ is the received signal level at the receiver in decibels. Shadowing and small scale fading are not included into the link budget because they are neglected in the calculations (see Chapter 4). [16]

3.2 Path loss

Path loss describes how much the signal attenuates while travelling between the transmitter and the receiver. It is an overall decrease in the field strength. The distance and obstacles between the transmitter and the receiver have an effect on the path loss. The bigger is the distance, the higher the path loss is. Thickness, amount and location of obstacles increase the path loss. A typical model for the path loss in indoor environment is shown in Equation (11).

$$L_p = 20 \cdot \lg\left(\frac{4\pi \cdot r_{ref} \cdot f}{c}\right) - 10n \cdot \lg(r) \tag{11}$$

In Equation (11) r is the distance between the receiver and the transmitter, $r_{ref} = 1\,m$ is the reference distance, f is the used frequency, n is the path loss exponent and c is the speed of light. The value of n depends on the environment where the signal travels, for example in the free air the value of n is around 2, in the indoor environment the value of n is usually around three and four and, in the hallway the value of n can be less than two because the corridor resembles a waveguide. [10]

3.3 Shadowing

Shadowing is also known as slow fading. Shadowing is a phenomenon where local characteristics cause variation to the median value given by the path loss. Shadowing occurs e.g. due to local obstacles like furniture, partitions, etc. In the indoor environment the shadowing has a remarkable impact since the obstacles like furniture and people are large in wavelengths. Shadowing is usually log-normally distributed. [5] [10]

3.4 Small scale fading

Small scale fading is also known as fast fading. In small scale fading signal strength varies frequently and it can vary up to 40 dB. Variation occurs on a scale of about a half wavelength. At 2.4 GHz half wavelength is 62.5 mm. Small scale fading results from interference between multiple waves reaching the receiver simultaneously. Small scale fading is typically Rayleigh distributed [10]

3.5 Criteria of indoor propagation

The two best criteria for the radio propagation in any given environment are coverage and throughput. The coverage is the area that the transmitted signal covers. The throughput is the speed, in a certain location, of how much information travels simultaneously. Throughput is expressed as a bit/s. Criteria for coverage and for throughput is that all of the apartments will be covered and maximum throughput will be achieved in 90% of the area inside the apartments (see Section 4.3).

3.6 Indoor propagation models

For the WLAN in almost 100% of the cases the radio wave propagation happens in indoor environments. In the indoor environments one cell (a certain area) is called a picocell because access points are located inside the building. The cell means an area that one access point covers. The indoor radio wave propagation depends on the following factors:

- Geometry of the building

- Construction materials of the building
- Frequency
- Furniture
- People

The first three factors are static factors in other words they are not moving. The last two factors are dynamic; at different times the number and the position of them may change.

The propagation of radio waves can be computed from Maxwell's equations. The amount how much of the signal penetrates through and reflects from the obstacle and to which direction depends on the angle of arrival, complex permittivities of the obstacle (walls, partitions, ceilings and floors), and thickness of material as visually described in Figure 16 and 17.

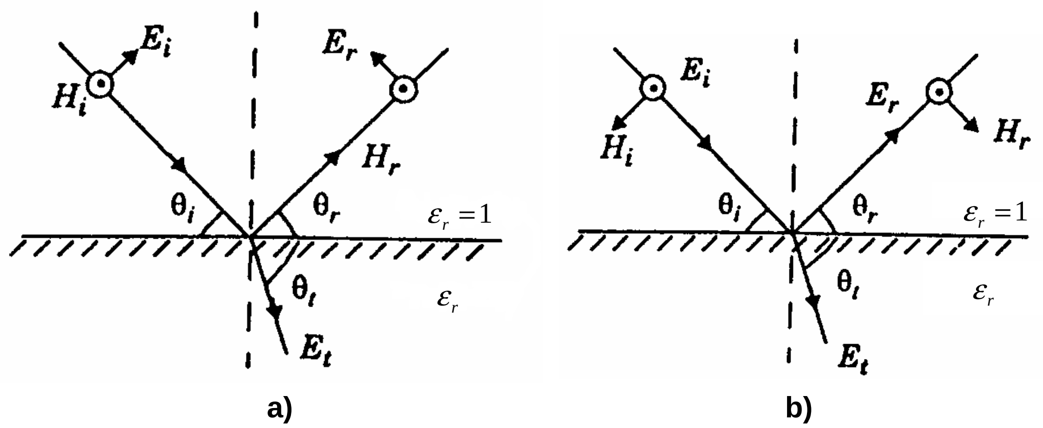

Figure 16. Signal wave incident a) parallel polarization b) perpendicular polarization [17]

Mathematically the situation in Figure 16 a) and Figure 16 b) can be expressed as transmission coefficients in Equations (12) and (13) respectively and reflection coefficients in Equations (14) and (15) respectively. [17]

$$T_{//} = \frac{2\sqrt{\varepsilon_r}\,\sin(\theta_i)}{\varepsilon_r \sin(\theta_i) + \sqrt{\varepsilon_r - \cos^2(\theta_i)}} \tag{12}$$

$$T_{\perp} = \frac{2\sin(\theta_i)}{\sin(\theta_i) + \sqrt{\varepsilon_r - \cos^2(\theta_i)}} \tag{13}$$

$$R_{//} = \frac{-\varepsilon_r \sin(\theta_i) + \sqrt{\varepsilon_r - \cos^2(\theta_i)}}{\varepsilon_r \sin(\theta_i) + \sqrt{\varepsilon_r - \cos^2(\theta_i)}} \tag{14}$$

$$R_{\perp} = \frac{\sin(\theta_i) - \sqrt{\varepsilon_r - \cos^2(\theta_i)}}{\sin(\theta_i) + \sqrt{\varepsilon_r - \cos^2(\theta_i)}} \tag{15}$$

When a signal faces an obstacle with a certain thickness and complex permittivity reflection or transmission may occur as shown in Figure 17. [17]

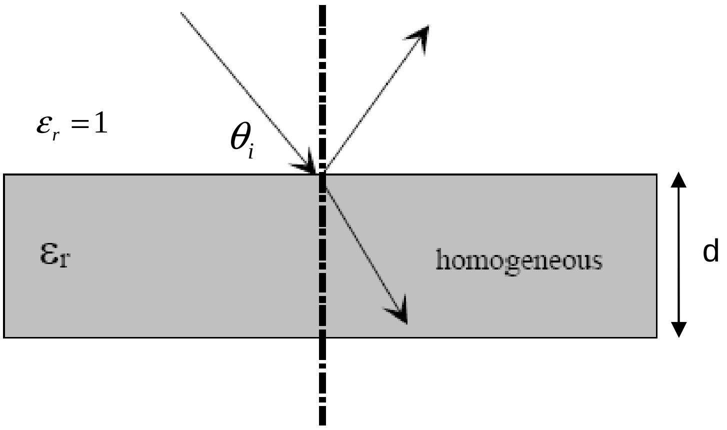

Figure 17. Reflection and transmission over a layer with a finite width [17]

The complex reflection coefficient is shown in Equation (16) and complex transmission coefficient is shown in Equation (17). In Equations (16) and (17) *R* is the Fresnel plane wave reflection coefficient. [17]

$$R' = \frac{1 - \exp(-j\frac{4\pi d}{\lambda}\sqrt{\varepsilon_r - \cos^2\theta_i})}{1 - R^2\exp(-j\frac{4\pi d}{\lambda}\sqrt{\varepsilon_r - \cos^2\theta_i})}R \tag{16}$$

$$T' = \frac{(1 - R^2)\exp(-j\frac{2\pi d}{\lambda}\sqrt{\varepsilon_r - \cos^2\theta_i})}{1 - R^2\exp(-j\frac{4\pi d}{\lambda}\sqrt{\varepsilon_r - \cos^2\theta_i})} \tag{17}$$

In addition to transmission and reflection, diffraction needs to be considered as well. Diffraction is very complex to analyse. Diffraction may occur when the signal hits the obstacle. The shape and structure of material have a huge effect on diffraction.

Equations (12) – (17) are the basic equations in the ray tracing method. The symbols used in Equation (12) – (17) are listed in Table 4.

Table 4. The symbols in Equation (12) –(17)

Symbol	**Explanation of symbol**
ε_r	complex permittivity
λ	wavelength
θ_i	angle of incidence
d	thickness of the layer

Because the Maxwell equations can be complex to calculate radio wave propagation models have been developed. The radio wave propagation in the static environment can be modelled quite accurately but in the dynamic environment the radio wave propagation is harder to model and accurate modelling is almost impossible. The radio wave propagation models in the picocell can be divided into empirical and physical models. [10]

3.6.1 Empirical models

The empirical models are simple and they are primarily based on experimental data. The idea of the empirical models is that each wall attenuates a certain amount and only the direct path is considered. Because the direct path is very rarely the dominant path and other aspects such as wave guiding in a corridor, diffraction, scattering and reflection occur in practice, the empirical models are more likely approximate than accurate. In addition, the incoming direction when the signal faces the wall or floor is ignored. Figure 18 describes the principle of empirical models visually. [10]

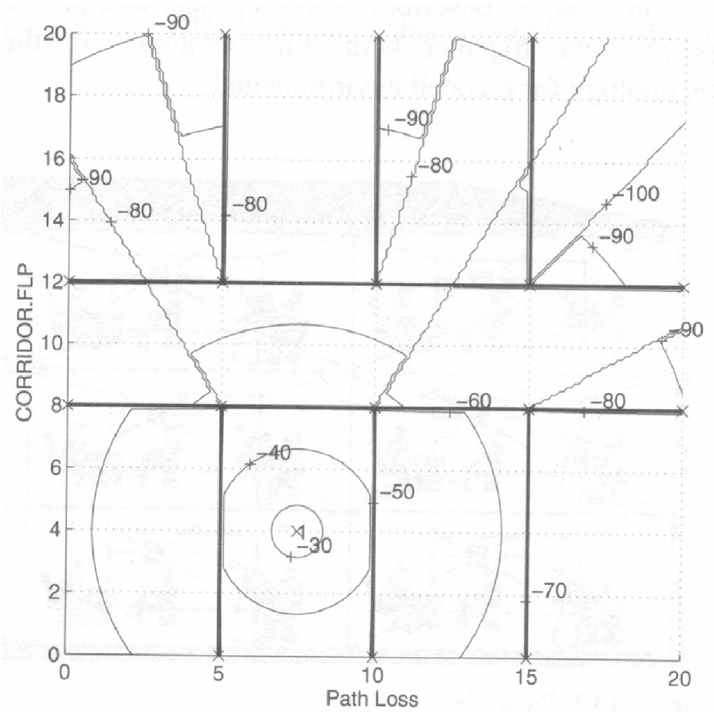

Figure 18.Empirical model in picocell propagation[10]

<u>*Motley Keenan model*</u>

The Motley Keenan model is a very easy and simple model for path loss prediction. Due to this it is a very rough estimation of the real path loss. The model is shown mathematically in Equation (18).

$$L = 20 \cdot \lg\left(\frac{4\pi \cdot r \ \cdot f}{c}\right) + n_f L_f + n_w L_w \qquad (18)$$

In Equation (18) L_f and L_w are the penetration losses in dB of the floors and walls, respectively. n_f and n_w are the numbers of floors and walls, respectively. The first part of Equation (18) represents a free space path loss. A good point to notice is that the attenuation is the same for all walls and floors. [10]

Multi wall model

The multi wall model is more accurate than the previous Motley Keenan model but as a drawback this model is more complex as it requires more detailed information on the building structures. The difference compared to Motley Keenan model is that each wall and floor have their own attenuation factors depending on the material used. However in the end this model is still far a way from modelling the reality. The model is shown mathematically in Equation (19)

$$L = L_p + \sum_{i=1}^{N} n_{wi} L_{wi} + n_f L_f \qquad (19)$$

In Equation (19) N is the number of wall types, n_{w1} is the amount of type i walls crossed by the direct path and L_{wi} is the penetration loss for a wall of type i in dBm. [11]

3.6.2 Deterministic models

Deterministic models are based on the electromagnetic wave propagation theory. On the contrary the empirical models the deterministic models are not based on extensive measurements. However, they need a precise layout of the building to be able to model the indoor propagation precisely. In deterministic models the calculations are much more complex but the modelling is more accurate than in the empirical models and also delay spread and angle of arrival spread can in principle be determined. In Figure 19 an example of the deterministic model coverage estimation is shown and it can be seen that diffraction and wave guiding effect of the corridor are considered. In Figure 18 these were not considered.

Figure 19.Deterministic model in picocell propagation[11]

The propagation of radio waves could be computed from Maxwell's equations. Because of the equations are complex, ray tracing methods have been developed to make the calculations simpler. [12]

Ray tracing model

The idea behind ray tracing is that high frequency radio waves act similarly to rays. Due to this radio wave propagation can be modelled as ray propagation. The method approximates the scattering of radio waves by reflection, refraction and diffraction.

The ray tracing method can be divided to image method and ray launching method. In the image method all the plane faces are assumed to be mirrors in the indoor environment. For line-of-sight the signal can be traced back from the receiver to the transmitter. The signal can travel several ways from the transmitter to the receiver. In the ray launching method all possible propagation paths are calculated. The receiver is modelled as a receive circle or sphere in the two or three dimensional case, respectively. All the possible paths that may leave the transmitter and arrive to the receiver are calculated. [12]

The deterministic models provide more accurate models than the empirical models, but the deterministic models are by far more complex. In the end both of these models provide only static information, as the dynamic factors such as furniture and people are ignored.

4 PLANNING OF WLAN IN A RESIDENTIAL BUILDING

Now, as the basics of WLAN and radio wave propagation are known, it is time to concentrate on what was actually done in this thesis. The idea of the primary part of this thesis was to build a WLAN in a residential building and search answers for the following aspects:

- Could a WLAN be built in a way that it would make sense in the technical and in the business points of view?
- Would the coverage be good enough?
- Would the throughput be high enough?

The chosen residential building is located in Tuusula. It has three similar floors and the layout of the floors is shown in Figure 20. The WLAN network that was built to Tuusula is called WLAN Tuusula for the reason that a reader will not get confused between this particular WLAN system and WLAN in general.

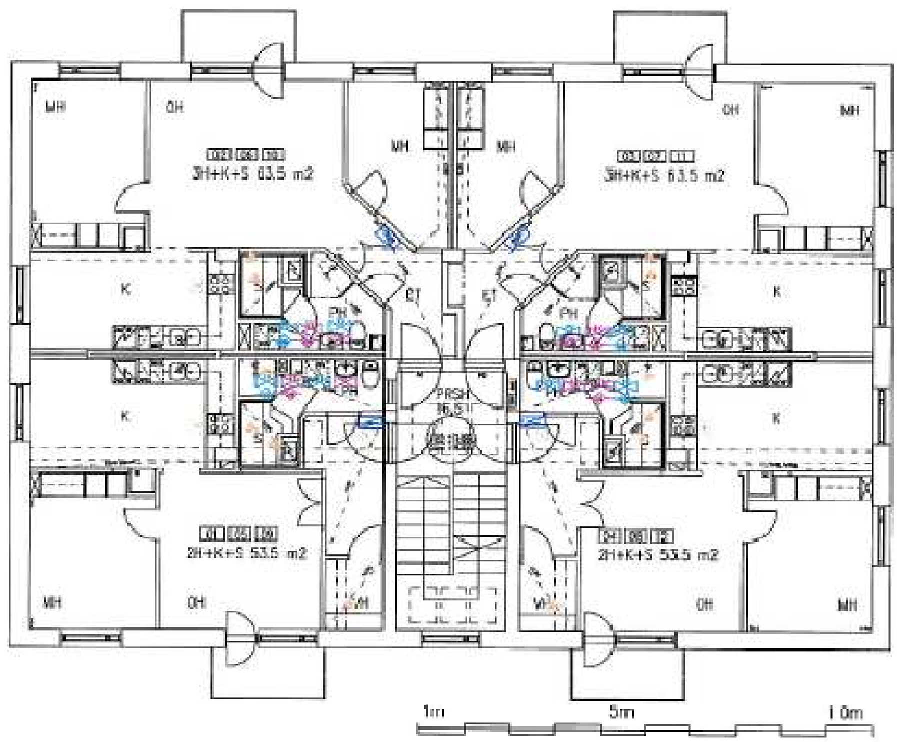

Figure 20.The layout of the floors

4.1 Architecture of WLAN Tuusula

WLAN Tuusula was implemented in co-operation with University of Turku. The topology of the system is shown Figure 21. The asymmetric digital subscriber line (ADSL) modem is a standard modem and its task is to connect the controller to the internet. The switch is a standard device and its task is to forward traffic between the APs and the controller. The APs and the controller are discussed in the following sections.

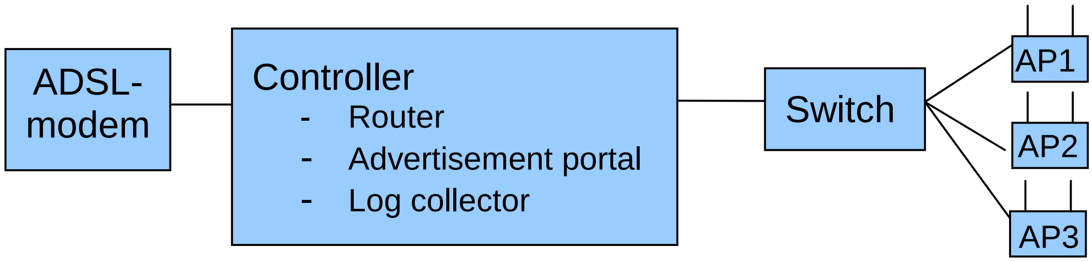

Figure 21. The architecture of WLAN Tuusula

The used APs were produced by D-link and the model is DAP-1353. The APs support the IEEE802.11n (D2.0) standard. The features of APs are shown in Table 5. The tasks of APs were discussed in Chapter 2. Three important things to point out are the following:

- 20MHz frequency band was used.
- GI = 800ns
- The APs worked as IBSS at different frequencies.

Table 5. The main features of DAP-1353

Standard	Frequency range [MHz]	Emission scheme	transmit power [dBm]	Antenna gain [dBi]	Operation temperature
IEEE 802.11n IEEE802.11n IEEE802.11b	2412-2472	DSSS, OFDM	15	3	0 C°to 40 C°

The controller can be divided into three following parts:

- Router
- Advertisement portal
- Log collector

The advertisement portal and the log collector are discussed later in Chapters 5 and 6. The task of the router is to route traffic inside WLAN Tuusula, into WLAN Tuusula from internet, and vice versa. When a STA registers to WLAN Tuusula an IP-address, DNS address, default gateway, and subnet mask are given by the router and the traffic is routed according to the addresses above. An important aspect to notice is that the APs don't route traffic but they follow the commands of the router. The APs only transform the traffic into proper form as discussed in Chapter 2.

4.2 Location of access points

The Location of the APs is actually the most crucial aspect when planning the WLAN in the residential building, not only in the technical but also in the business point of view. If the installation and maintenance of the WLAN is not cost efficient enough, it will not be profitable business. After several discussions it was decided that the best location for the APs would be in the staircase with one AP per floor. The reasons for the staircase and one AP per floor are the following:

- At the beginning of planning process, it was decided that the APs need to be inside the building, because hardware for indoor environment is three times cheaper than hardware for outdoor environment.
- Inside the building, the staircase was the only suitable place for the APs. For the maintenance and convenience reasons it was out of question to install APs inside the apartments.

In the planning process, to make sure that the WLAN will provide good enough coverage and throughput, path loss calculations and measurements were performed. An important aspect to point out is that perfect coverage and perfect throughput were not the goal of the design process. The goal was to provide good enough coverage and throughput for the users.

4.3 Path loss calculations

The following path loss calculations are performed with the Multi Wall model, introduced in Section 3.6.1. Deterministic models would have provided more accurate results but because of their complexity the empirical model was chosen instead.

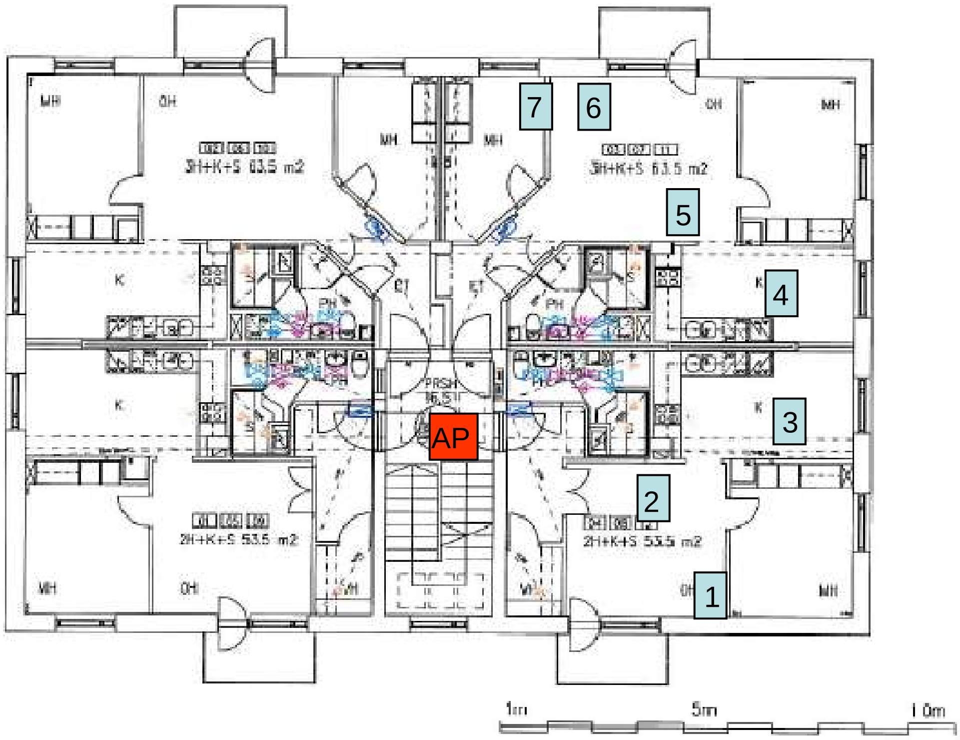

Figure 22. The location of the calculation points and the AP

In the calculations, the AP was located in the staircase. Seven calculation points were chosen. The calculation points and the location of the AP are shown in Figure 22. The three floors of the building are similar and from Figure 22 it can be seen that the both sides of the building are each other’s mirror images. Due to this an estimation of the coverage of a half of the one floor provides the coverage in the whole building.

Table 6. The value of symbols used in Equation (20)

Calculation point	Distance [m]	Number of penetrated cinder block walls	Number of penetrated plasterboard walls	Number of penetrated doors
1	7,0	1	1	0
2	4,6	0	1	1
3	8,1	0	2	1
4	8,6	2	1	0
5	7,7	2	1	0
6	9,7	0	1	1
7	9,2	0	1	1

From the Multi Wall model in Equation (19) and from the path loss equation, which is shown in Equation (11) Equation (20) is obtained

$$L = 20 \cdot \lg\left(\frac{4\pi \cdot r_{ref} \cdot f}{c}\right) + 10n \cdot \lg(r) + \sum_{i=1}^{N} k_{wi} L_{wi} + k_f L_f \tag{20}$$

In Equation (20) f = 2.4 GHz, n = 3 [10] and the rest of the values are shown in Table 6. In the building two different types of walls and one type of door exist and the penetration losses at 2.4 GHz are estimated to be the following [12]:

- Cinder block wall, loss 4 dB
- Plasterboard wall, loss 3 dB
- Wooden door, loss 4 dB

The wall between the staircase and the apartment and the wall between the apartments are cinder block walls. The walls inside the building are plasterboard walls. The wooden doors are front doors and doors inside are assumed to be open. The building has been renovated several times and the attenuations of the walls are rough estimations.

The signal level at the calculation point is desired. Therefore the results from Equation (20) need to be inserted into the link budget equation Equation (10). The transmit power and the antenna gain of the transmitter can be obtained from Table 5 and the antenna gain [dBi] of the receiver is assumed to be zero.

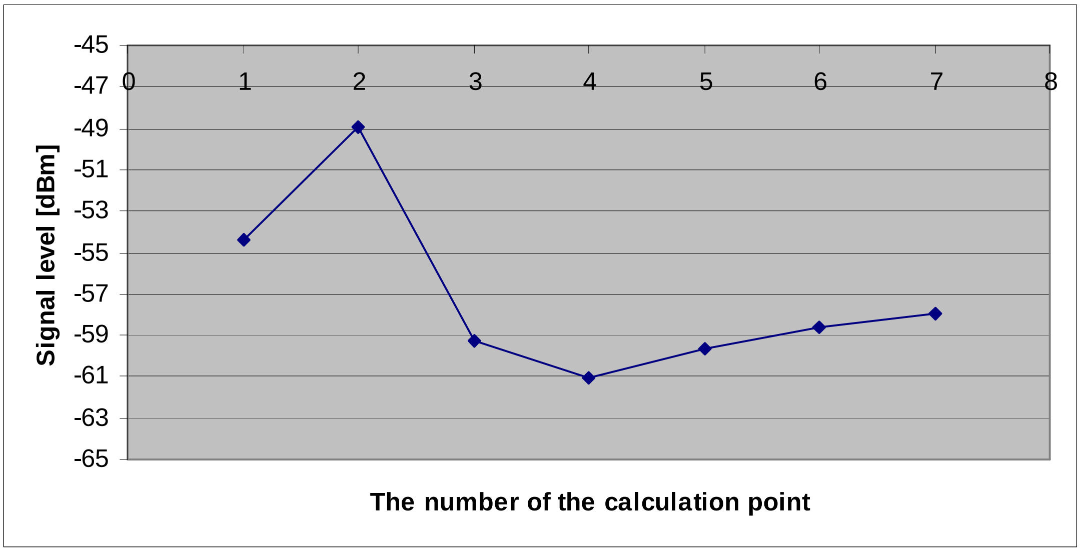

Figure 23.The calculated signal level at the calculation points

The calculated results are shown in Figure 23. From Figure 23 it can be seen that the lowest value is obtained at point 4, where P_R [dBm] = -61 dBm. The value can be compared with sensitivity values and further with the corresponding throughput values in Table 3. From Figure 23 and Table 3 it can be concluded that even in the measurement point where the signal level is the lowest the maximum throughput should be achieved.

4.4 Path loss measurements

From Chapter 3 it was learnt that the empirical and the deterministic methods provide only static models and the dynamic factors such as furniture and people are ignored. Multipath propagation is ignored as well. The attenuation factors of the walls and doors were estimations. Due to these reasons calculations cannot be trusted and measurements were conducted to make sure that the designed WLAN will cover the whole building and the throughput would be high enough. This section concentrates on measurements, how the measurements were made, what equipment were used and the obtained results are discussed.

Measurements were conducted at the pilot location. The AP was set up in the staircase. The measurements were made in two apartments, in seven different points. The points and the location of AP were the same as in the calculations and they are shown in Figure 22. Three floors of the building are similar and, from Figure 18 can be seen that both sides of the building are each other's mirror images, so measuring a half of one floor provides the coverage of the whole building.

In the measurements the received signal level at the measuring points was measured. From the signal level at different points the coverage and the throughput can be derived with the help of Table 3.

The used measurement equipment is listed in Table 7. The wireless card in the measurement device (STA) does not support n-technology. The card supports only the predecessors of the n-technology. In the measurements, the used IEEE802.11 technology does not necessarily need to be n-technology. It can be g-technology as well because the g-technology supports diversity and the modulation is the same as in the n-technology (OFDM). Simulation tool Network Stumbler was used in the measurements to measure the signal level. The software is an open software.

Table 7. The measurement equipment

Device	Description of device
AP (transmitter)	D-Link, DAP-1353 (The same as in WLAN Tuusula network)
STA (receiver, measurement device)	HP laptop with integrated Intel® Wireless LAN 802.11a/b/g, Mini-PCI-card

The results from the measurements are shown in Figure 19. The blue spots are the average signal level value at the measurement points. The red line shows the fluctuation of the signal level at the measurement points. The fluctuation consists of the values between the minimum and maximum signal levels. At one measurement point the measurement was done for 30 seconds.

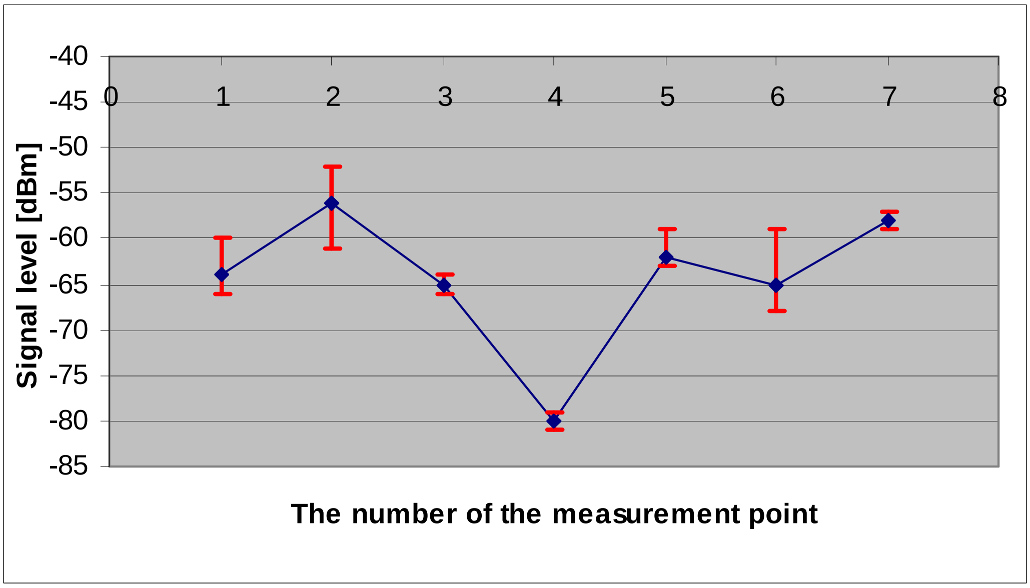

Figure 24. The received signal level at the measurement points

The measured signal levels are compared to corresponding sensitivity levels in Table 3 and further to corresponding throughput values in Table 3 as well. GI = 800 ns is assumed. The obtained throughput is shown in Figure 25.

From Figure 25 it can be seen that even though the signal level at the measurement points varies, the throughput stays the same. This of course is logical because the signal level does not go below the sensitivity level of that particular MCS value. The exception is measurement point 4. What makes this interesting is that the signal level at measurement point 5 is over 15 dB higher than the signal level in measurement point 4 even though the number of penetrated walls is the same and the distance between the transmitter and receiver is almost the same. The reason is that the route to measurement point 4 is just much more complex than into measurement point 5.

The route does not look that much more complex, but perhaps people or furniture can be blocking the way to measurement point 4.

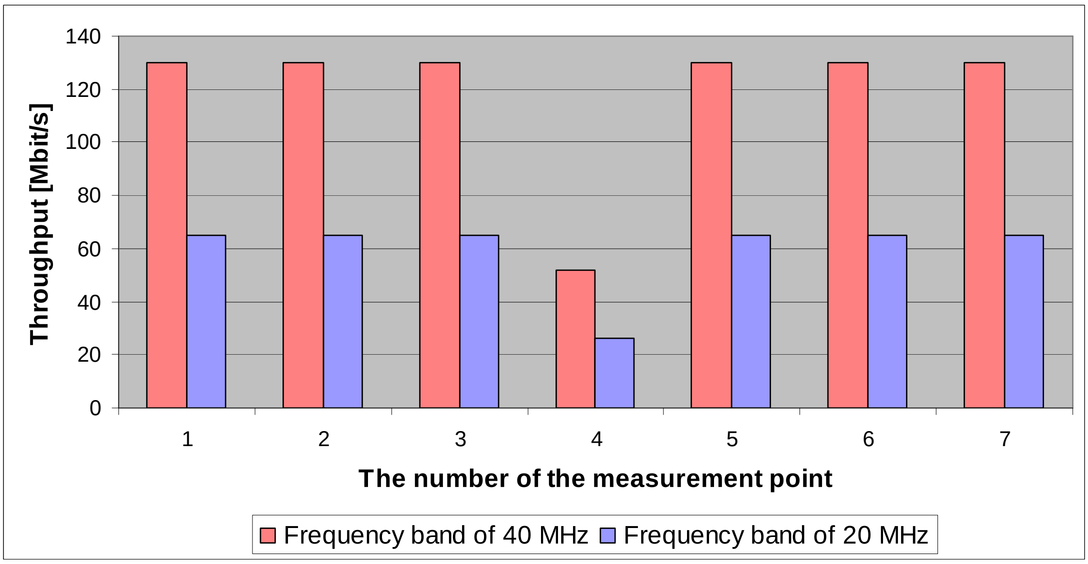

Figure 25.The throughput at the measurement spots, GI = 800 ns

From Figure 24 it can be noticed that at the some measurement points the signal fluctuation is much higher than in the other points. The fluctuation is the highest in the points that are located in the living room area. The fluctuation was caused by moving obstacles while the measurements were measured. In this case, the moving obstacles were people.

4.5 Measurement values compared to calculated values

The measurements and calculated signal levels are drawn in the same graph in Figure 26. The calculated signal level values are optimistic compared to the measured values except in measurement point 7. Due to this it can be concluded that the walls attenuate signal more than it is assumed in the calculations.

From Figure 26 can be seen that the calculations do not consider multipath propagation. This can be understood from the discussion in Section 4.4. Also the fluctuation is ignored in calculations.

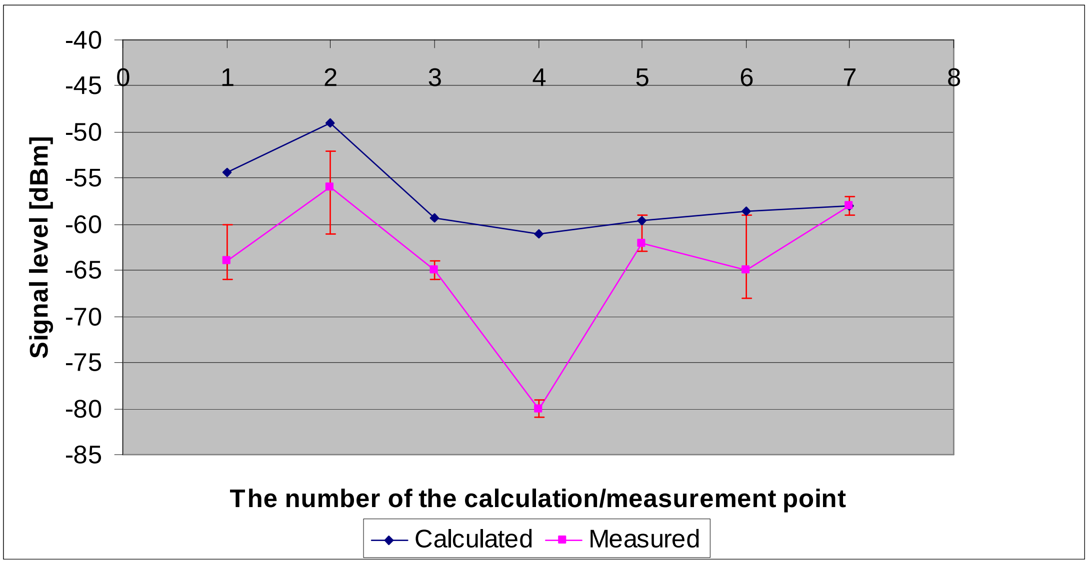

Figure 26. The receiver level of the measured and calculated signals

5 ADVERTISEMENT PORTAL

The secondary part of the thesis work consists of an advertisement portal. The link between the WLAN in a residential building and the advertisement portal is to test an alternative way for the internet service provider to gain cash flow than just charging a monthly internet connection fee from the users.

The advertisement portal was implemented in co-operation with University of Turku. In the architecture of WLAN Tuusula the advertisement portal is a part of the controller, as shown in Figure 20. The idea of the tested advertisement portal is that when a user connects to the internet he or she needs to watch an advertisement. From one advertisement, the user gets one hour access time to use the internet. When the time is up the user needs to watch another advertisement or alternatively the user can watch N advertisements in advance and get N hours of access time.

5.1 Architecture of the advertisement portal

Advertisements consist of three pages. The first page is the main page, shown in Figure 26. The user can choose which advertisement to watch from twelve different advertisements. The idea of giving a freedom to choose which advertisement to watch is from the user’s point of view that the user would not feel forced to watch advertisements and from the advertiser’s point of view is that the advertiser would see that their advertisement is working. The advertiser can see this by comparing the number of times their advertisements has been watched to the media value of watched advertisements. In general, if the value is higher than the media value the advertisement is working for the users and if the value is lower than the media value the advertisement is not working for the users.

Figure 27.The main page of the advertisement portal

After the user has chosen which advertisement to watch (see figure 27), the advertisement shows up. The advertisement consists of two parts. In the first part, the actual advertisement or the offer depending on company is shown, described in Figure 28. In the second part, the information of the advertiser such as webpage address, contact number or where the advertiser can be found is shown, described in Figure 29. In addition, an informative question appears in the second part. The idea of putting the information in the form of an informative question is to try to make the user to think. In general, when people need to think something they register information better, therefore they remember the information longer. Before the user gains the access to internet she or he needs to answer to the question by choosing yes or no. Also other alternative answers could be used such as a), b) or c).

Figure 28.The first part of the advertisement

After the access control has been accomplished the user is directed to the home page. A timer for the access time and a link to watch more advertisements is available on the home page.

While the user is going through the access control logs are being collected. In the logs the time, when the advertisement is watched, which advertisement is watched, which computer is used (MAC adreess), and what has been answered to the question are collected. The logs are kind of feedback from the users or more likely feedback from what the users have done. The relevance of the logs appears better when the results are discussed in Chapter 6.

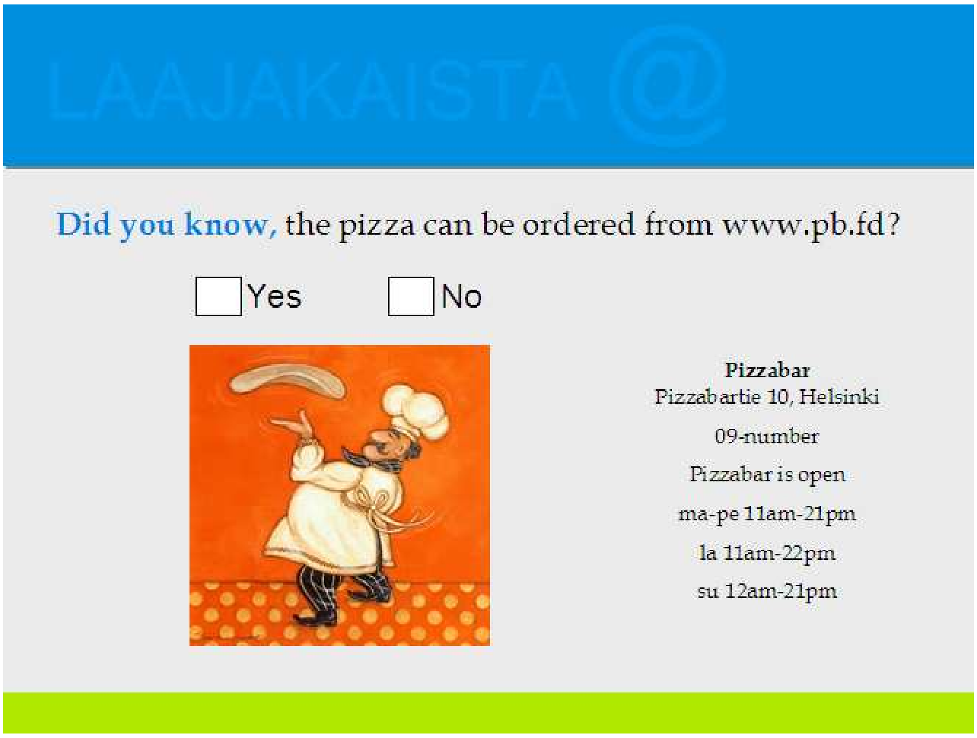

Figure 29.The second part of the advertisement

5.2 Technology of the advertisement portal

The access control was mostly implemented with a firewall. The architecture of the access control is described in Figure 30. The part: “http://192.168.43.254” is the address from where the user’s computer finds the access control, the number 8000 is the port where the user is initially directed and, M.ppt is the main page file that opens (Figure 30). The user is always directed to this page when the access time is zero. By choosing the desired advertisement the user is directed to the page http:/192.168.43.254:8001/N.ppt. The number 8001 is the port number and the N is the number of the chosen advertisement. The number N can vary between 1 and 12 as it can be seen from Figure 27. When the user moves on to the second part of the advertisement the user is directed to the page http://192.168.43.254:8002/kN.ppt. The number 8002 is the port number and k denotes for the second part of the advertisement. After answering to the informative question the user is directed to the page http:/192.168.43.254:8003/?ad=N&v=K or http:/192.168.43.254:8003/?ad=N&v=E depending on the user's answer. The number 8003 is the port number and the last letter K or E stands for answer: "yes" or "No" respectively. From this page the user is automatically forwarded to the page http:/192.168.43.254:8004 which is the home page and where number 8004 is the port number.

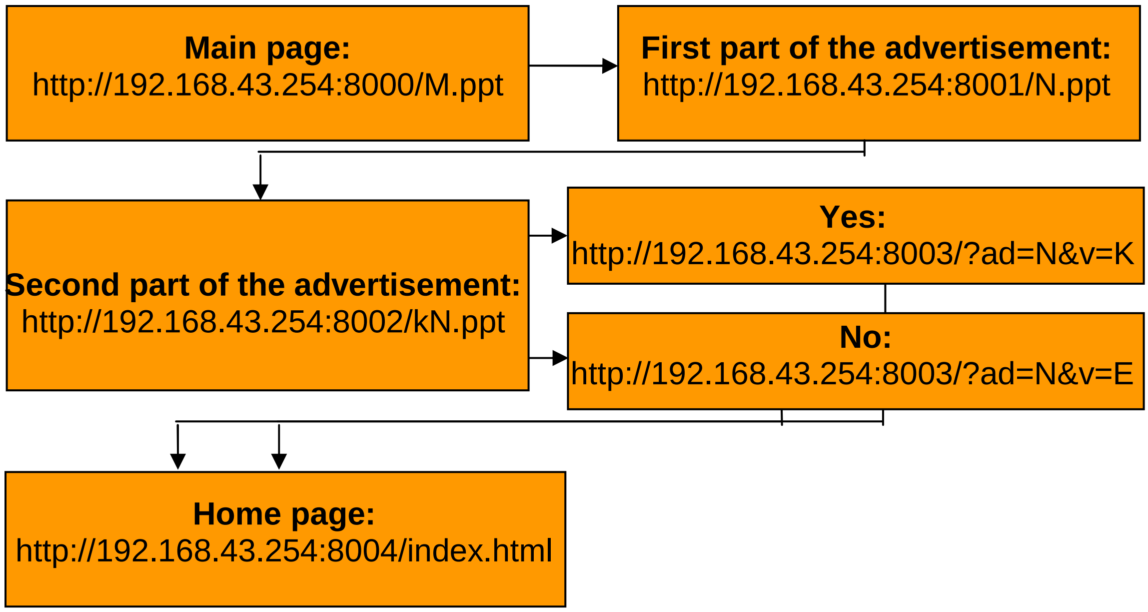

Figure 30. The architecture of the access control

The user needs to go through step by step all of the steps or otherwise the access will not be opened. For example if the user jumps from port 8000 to port 8002 the connection will be lost. On the other hand, it would not be too hard for the user to bypass the advertisement portal. At this stage, when the idea is being tested there is no point to make the advertisement portal perfect. It would consume too much more money.

5.3 Supportive information for a market analysis of the advertisement portal

The market analysis of the advertisement portal was not planned beforehand. The idea was that the market analysis would be formed during the pilot period (see

Chapter 6). The formation of the market analysis is done based on the learning school [13]; let's test what works and what does not work in real life. At this point the benefits, weaknesses and, potential competitors are discussed. The idea of this information is to provide supportive information for the conclusions of the market analysis (see Chapter 7).

5.3.1 Strengths and weakness of the advertisement portal

The strengths of the advertisement portal are the following:

- Focused
- Customized
- Interactive
- Dynamic
- Nature friendly

One of the strongest strengths of the advertisement portal is that the advertisements can be focused and customized. Consider a case, that a restaurant chain has several restaurants located all over Finland. The second page of the advertisement could be the same all over Finland but the information on the third page (see Section 5.1) could change according to the location of customers. In this way, the customers would see where the closest restaurant is. Of course the second page could also change. It depends on the wants and needs of the company.

The informative question is just a one form of interactivity. The interactivity can be easily developed further, for example in the restaurant case, at the end of the advertisement the customer could have an option to buy food and the food would be delivered home.

The dynamic feature is an important benefit when a company needs to change its advertisement at a short notice. The big problem of advertisements, which are not in an electronic form, is that the delay between the time when the advertisement is prepared and the time when the advertisement is seen by the potential customer is long. This is not an issue when brand advertising is conducted. In other cases it might be a problem. Consider a case that a shop has products that are getting out of date in a few days. The shop cannot advertise the products in traditional ways, such as printing flyers and getting them delivered to people's homes or putting an offer in a local newspaper, the process would take too much time. In the advertisement portal this can be conducted in no time. The other benefit of the dynamic feature is that the advertisements can vary. The customer does not need to see the same advertisement of the company twice.

Currently, customized and focused advertisements are mostly printed on paper and mailed or distributed to people's homes. The process is costly and harms the nature. YTV, the waste management company operating in Helsinki area, recommends people to put a notice to their post boxes which says: No free distribution, thank you. The post offices hand out cards that forbid free distribution even if the letter would have your name and address on it. The used material is not the only thing that harms the nature but also energy that is used for distribution does it. In the end the advertisement portal is much more nature friendly than the traditional ways of advertising. [14]

All the options above are benefits that the advertisement portal provides. The greatest weakness is that the advertisement portal needs a lot of users. The main concern of advertisers is that how many people from their target group can see their advertisement. Due to this a lot of users are needed to be gained before the advertisers can be convinced that the advertisement portal is a good medium to reach target customers.

5.3.2 Competitors of advertisement portal

The competitors of the advertisement portal are the other media such as television, radio, newspapers, magazines, billboards and flyers. In Figure 31, the advertising media are shown as a position diagram. In the vertical axis is the advertisement accuracy geographically; how well the area where the advertisements are wanted to be seen can be focused. In the horizontal axis is the number of potential users; how many users could potentially be obtained. The location of advertisements, in the Figure 31 are defined based on how many potential viewers advertisement could reach and how well the advertisement can be focused in a certain geographical area. For example local newspaper can reach a certain amount of people, not as many as national TV, but the area can be focused better. [15]

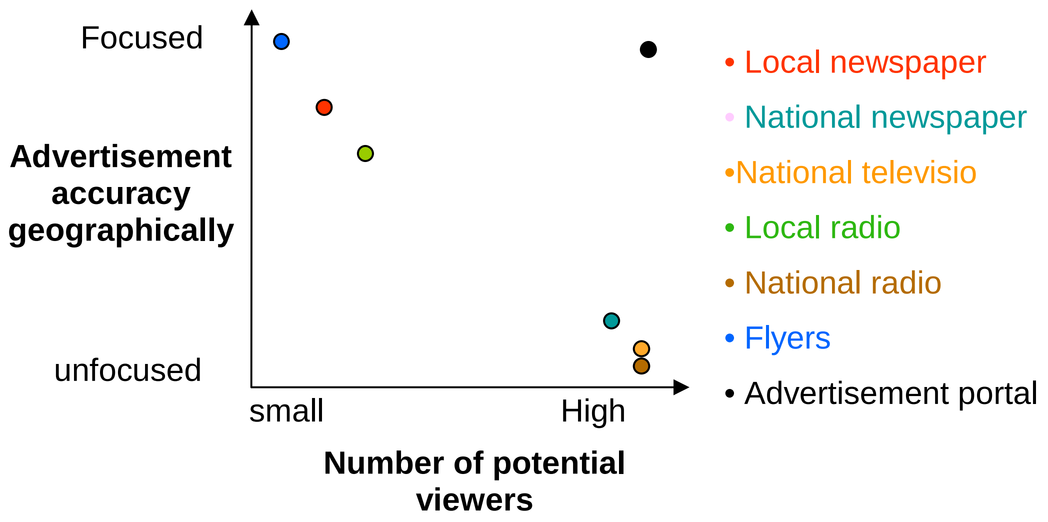

Figure 31. The position diagram of different advertisement media in the market

To define which media is competing in the same market the desired advertisement area needs to be taken account. For example a supermarket may advertise in a local newspaper because the customers are coming from a large area. Opposite to that a small grocery store does not want to advertise in the local newspaper because the advertisement space is too expensive and the distribution area is larger than needed. Therefore they rather distribute flyers to the geographical area of their target market. The advertisement portal can compete in both of these areas if it has enough users. Due to this it is important to define the desired advertising area before the competing media of the advertisement portal can be defined. The important aspect to notice is that if the advertisement portal has a lot of users it can compete against all the other advertisement media.

6 WLAN Tuusula in practice

The designed WLAN Tuusula was installed in the residential building for a period of two months. One AP per floor was needed. Six different families, which formed a user group of eleven people altogether, participated in the research. The research was called a pilot and it is also referred to by that name in the text.

A laptop was given to each family. During the pilot logs of the use of the laptops and the advertisement portal were collected. The users were obligated to a fill user diary and take part in personal interviews. Details of the laptops are listed in Table 8. In this chapter the testing period in practice is discussed, mostly concentrating on what was learnt during the period.

Table 8. The description of laptop

Device	Description of device
Laptop	Fujitsu Siemens Amilo Notebook PA 3515
Integrated WLAN card	Intel® Wireless LAN 802.11a/b/g/n-draft, Mini-PCI-card

6.1 Wireless connection

During the pilot, the time when the users' laptops were connected to WLAN Tuusula was collected in the log. The results are shown in Figure 32. From Figure 32 it can be seen that some users were more active than others. The activity was not affected by a bad connection according to the users another fact to support this claim is that the laptops that were at least connected located on different floors. This was the only technical criterion to measure how the wireless connections worked. The rest of the criteria are based on the users' opinions.

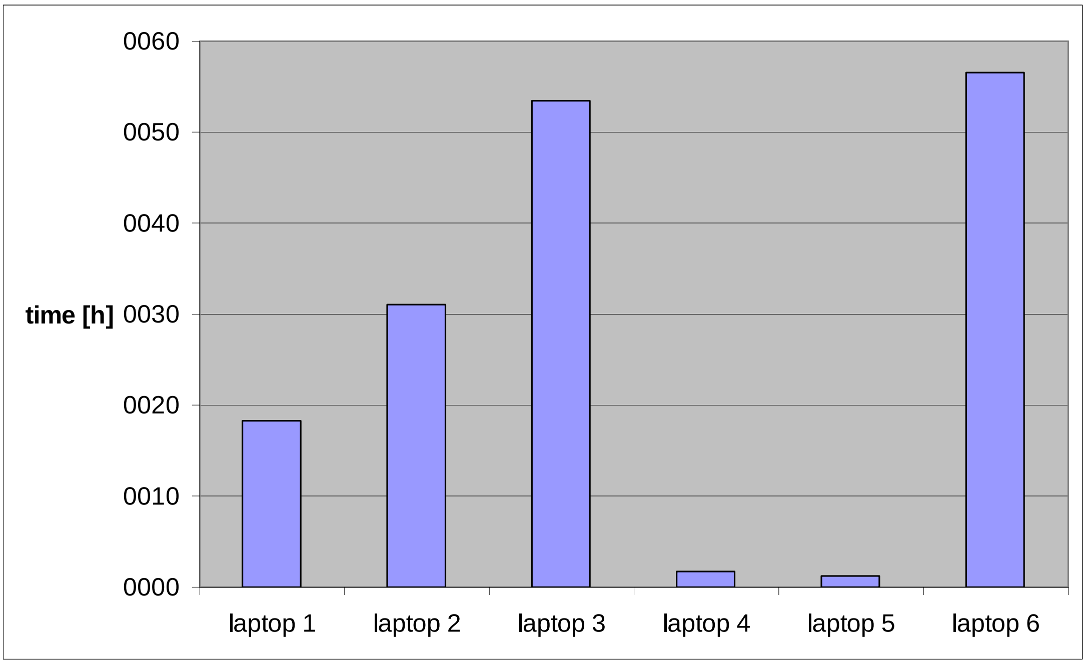

Figure 32.Connection time to WLAN Tuusula per laptop

In the users' opinion the connection worked well except at the beginning of the pilot. The reason was that a lot of residents had their own APs in the building and the frequency band in 2.4 GHz started to be full. The problem was solved by monitoring what frequency channels the other APs used. The best frequency channels for the APs of WLAN Tuusula were selected according to the monitored data. Interference between APs can become an issue in a residential building when WLANs get more popular. One solution could be that a certain frequency channel would be allocated to each apartment.

The connection from the residential building to internet was 23 Mbit/s downlink and 3 Mbit/s uplink. If the throughput were divided by the amount of families, the throughput per family would be 4.3 Mbit/s downlink and 0.5 Mbit/s uplink. Most likely all of the families are not using internet at the same time so the throughput is higher. According to the users this was enough and they did not have a need for a faster connection. On the other hand the users only used internet for surfing. If the users had used services that require high throughput the connection to outside world would have not been fast enough, though the wireless connection between laptops and WLAN Tuusula would have most likely been good enough. As discussed earlier one AP can achieve a throughput of over 100Mbit/s.

6.2 Access to WLAN Tuusula

As explained in Chapter 5, users need to go through an access portal to gain a right to use internet. In other words, they need to watch an advertisement before getting the access to use internet. According to the users the accessing part was clear and simple. The part when the users ran out of access time caused frustration. When the user runs out of access time, the access is declined and after the following click the user will be automatically forwarded to the main page of the advertisement portal. Why did this cause frustration? Let’s explain this through an example. Consider that you have written a long email and when you click the send button the browser directs you to the main page of the advertisement portal because you are out of access time. The connection to email server is lost and due to this the unsent message is lost as well.

6.3 The advertisement portal

The idea of the advertisement portal is explained in Chapter 5. Nine advertisers participated in the pilot in addition to the users. The advertisers consisted of shops and restaurants that were located near the pilot location. All the companies were parts of nationwide chains.

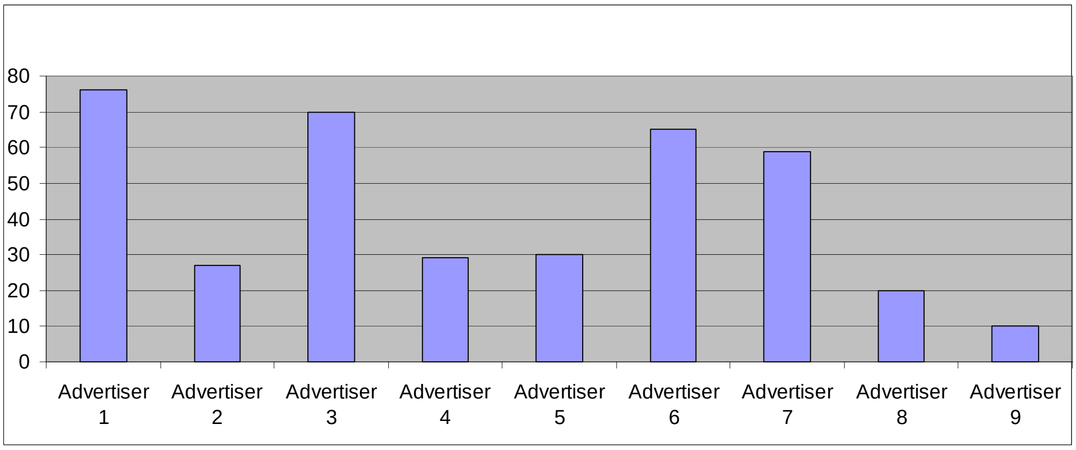

Figure 33.The number of times the advertisements were watched

Figure 33 describes how many times the advertisements per advertiser were watched during the pilot. Figure 34 describes the watching frequency per advertisement. From Figure 33 it can be seen that the advertisement of advertiser 1 was the most popular. The reason was not that it was the most interesting advertisement or it offered the best offers or the advertisement was dynamic. At the beginning the advertisement was watched rarely and towards end the watching frequency started to increase. The reason was that the advertisement was the shortest one. It was the quickest way to gain access time. It took about one month before the majority of users realized this.

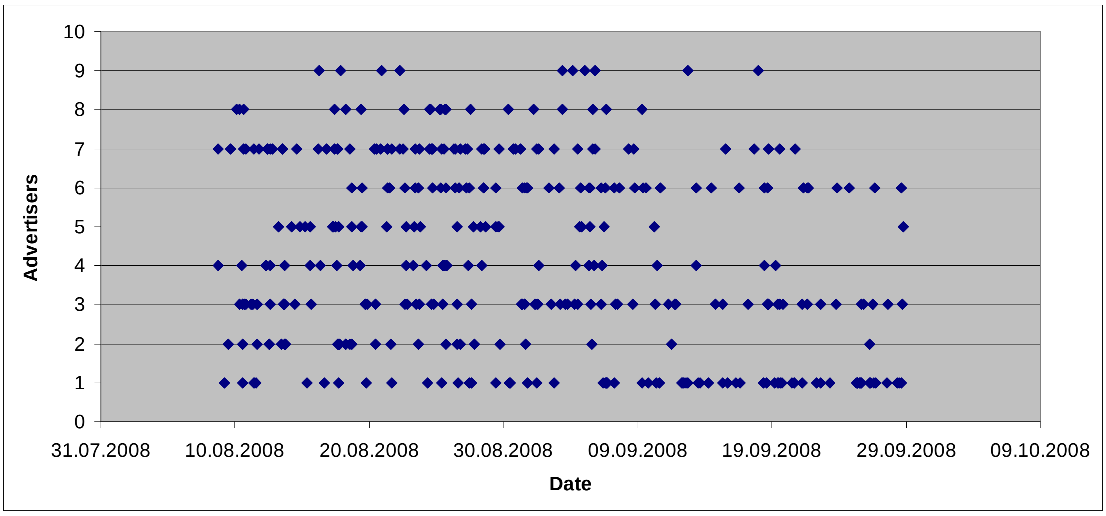

Figure 34. Watching frequency per advertisement in the period of pilot

The second and third most watched advertisements were from advertisers 3 and 6, respectively. These two advertisers advertised offers that changed once in a week on average. From Table 9 it can be seen that these two advertisements were the two most dynamic ones. From Figure 34 it can be seen that for the advertisements that were static the watching frequency decreases towards the end.

Table 9. The number of times the advertisements were changed

Advertiser	The number of times the advertisement was changed
Advertiser 1	1
Advertiser 2	3
Advertiser 3	8
Advertiser 4	1
Advertiser 5	1
Advertiser 6	6
Advertiser 7	1
Advertiser 8	1
Advertiser 9	1

The most interesting aspects that were found out from the users' interviews are the following:

- The advertisements need to change often or otherwise the users will get bored.
- The advertisements that offered direct benefit were found to be most interesting and beneficial.
- The brand advertising doesn't work in the advertisement portal.
- The users who were interested in offers in general were also interested in advertisements that had offers.
- 80% of the users remembered the informative question from one of the advertisements in the interview
- Even the users that considered the advertisements painful would be interested in using the advertisement portal if they had the internet connection in half price.

From the data above and from the users' interviews it can be concluded that to keep up users' interest towards the advertisement portal, the advertisements need to change frequently and they need to provide something that is useful for the users, such as offers. If they fail to do so, the advertisements are more likely a pain than a benefit and even if they did not fail, the advertisements can be a pain for some of the users. The interaction in advertisements brings more value to the advertisements. In that way the users remember advertisements longer than in a normal push type advertisement model.

The most important facts that make an advertisement good in the advertisement portal from the users' point of view are described as a radar plot in Figure 35. The bigger the area, the better the advertisement is.

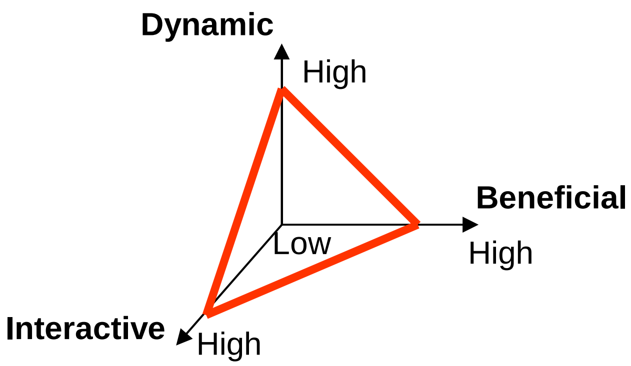

Figure 35. Radar plot of the quality of the advertisement from users' point of view

The most interesting points found out from the advertisers interviews are listed below:

- The need for a customized local advertising is high, especially for companies that work in a franchise model. In the franchise model some of the advertising becomes on behalf of the franchisee and the rest of the advertising becomes from the franchiser. The different franchisers in the same chain might have totally different needs or viewpoints of what kind of advertising is needed in their area.
- The biggest income for a supermarket comes from regular customers. The regular customers live near the supermarket. If the supermarket has a theme week or weekend, customers will visit from further distances than usually, therefore the advertising is needed to be done in further distances as well.
- Supermarkets that have regular customers' cards have exact information on their users' buying habits.

- One company had published their advertisement (including offers) in the same newspaper for several years. Some of their customers were used to read it from there and if for some reason it was missing the customers would complain. The idea of this example is that some of the advertising medium have a long tradition.
- For the restaurants almost half of the income comes during the lunch time.
- Material and distribution for one flyer cost 15 cent.
- The advertisement portal is a new kind of advertising medium, therefore its customers (advertisers) need more education than for the traditional media.

The most important conclusions from the interviews of the advertisers are that a need for local advertising is high and the brand advertising that is used in TV and radio does not work in the advertisement portal.

6.4 Future planning of WLAN Tuusula

This section concentrates on how the WLAN Tuusula could be improved in the future. Also a network planning method is discussed. The structure of this section is such that first the problem is introduced and then the solution in the following paragraph.

In Chapter 4 it was found out that the best way to build a WLAN in the pilot location is to locate the APs in the staircase and one AP per floor. However, layouts of buildings vary and, therefore this might not be the case in all the residential buildings. The other thing that was found in Chapter 4 was that the multi wall model for the radio propagation in indoor environment does not provide reliable results. The attenuation of walls was based on an estimation, which would be most likely the case for all buildings. In addition, multipath propagation, furniture and people are neglected.

In the future APs would be located in the staircase. To find out how many access points and where should be located in a particular floor requires measurements. For the measurements a professional software is needed.

Architecture of WLAN Tuusula was explained in Chapter 4. An important point to notice is that the APs are independent. If a user moves to an area of an other AP, the user needs to reconnect to the network manually. The other drawback is that WLAN Tuusula cannot monitor if another device is using the same frequency. Monitoring service like this is needed to ensure that the network is not interfered. If the WLAN Tuusula would be built in a residential building, certain frequencies would be reserved for it and other devices would not be allowed to use those frequencies in that particular building.

The best way to solve these problems is to change the controller of WLAN Tuusula to a professional controller. The drawback of the professional controller is that it costs about 7000€ and it only works with professional access points which also cost twice as much as the regular ones. The professional controller supports 96 APs. Therefore it would control many separate residential buildings. The architecture is shown in Figure 36. In addition buildings may need own switches depending on how the connections between the controller and the APs are implemented. Each AP could have its own ADSL connection and in this case the switch is not needed.

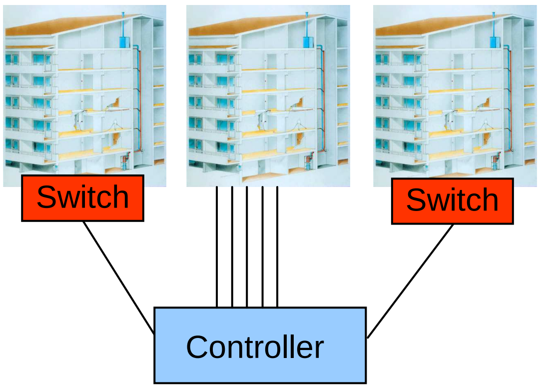

Figure 36. Architecture of developed WLAN TUUSULA

The benefit of the professional controller compared to the current controller is that each building does not need an own controller and the APs get their power over the Ethernet (PoE) cable.

The professional equipment also provides more services, which make monitoring, controlling and maintaining of the network straight forward. The advertisement portal would be integrated to the controller as it is integrated in the WLAN Tuusula.

6.5 Market analysis for the advertisement portal

In Section 5.3 the supportive information for the market analyse is presented and in Section 6.3 the results from the pilot are presented. According to this information the market analysis for the advertisement portal is performed.

The bottleneck of the advertisement portal is to get enough users. If the advertisement portal is implemented with the common WLAN in the residential building, the potential user base is too small. In Finland 42.3% of the population lives in residential building and of course not all of the residential buildings would take a common WLAN. Let’s assume that a 20% penetration could be achieved. In this case the advertisement portal would have only 8.5% of the all users. The advertisement portal should be a service that everybody who has an internet connection can have. The ways that this could be achieved are not discussed in this thesis.

6.5.1 Target market

From Sections 5.3 and 6.3 it can be concluded that the local market is the target market for the advertisement portal. The local market consists of advertisers that have a need for advertising in a small geographical area. In the following sections, the market analysis for the local market is presented.

<u>Competitors</u>

The competitors in the local market can be derived from Figure 31. The competitors are the local newspapers and the flyers that are delivered to consumers’ homes. The strengths of the advertisement portal in this market against these competitors are the following:

- Cost efficiency is achieved from the fact that deterministic distribution and material costs can be cut off, these are 15 cents per contact for flyers.
- Dynamic (see Chapter 5)
- Nature friendliness (see Chapter 5)
- Interactiveness (see Chapter 5)

The weaknesses of the advertisement portal as compared to the competitors in the local market are the following:

- Traditions, people are used to read from the traditional media
- Local newspapers offer other benefits to readers, such as news and articles
- Currently, majority of people rather read paper than from a screen. In the future, this is most likely going to change.

Strategic customers

In a process of analysing strategic customers for the advertisement portal, it is crucial to bear in mind the question, what makes an advertisement good from the users' point of view. The answer can be found in Chapter 6.3 from Figure 36. Suitable advertisers would be for example shops that have offers changing frequently and restaurants that have home deliver service. In the restaurant case, because of interactivity users could order the food at the end of the advertisement and it would be delivered home. It would also be beneficial to the user.

Size of the market

Especially the market size of the local market makes it attractive. In 2006, the market was over 3 billion euros in Finland. For example if market penetration of 10% would be achieved, the income would be 300 million euros.

Environment (nature)

The advertisement portal is very nature friendly as compared to its competitors. It does not pollute nature like the flyers and the local newspapers do through the used material and distribution. Currently nature friendliness is a significant trend and, it could be a big benefit in marketing.

6.5.2 Potential target markets

The local market is not probably the only market that would be suitable for the advertisement portal. One suitable market could be a special events market, which would consist of advertisers that have a need to advertise events, like for example sales in a shopping centre or an event in an exhibition hall. An example of benefit is that the advertising portal is dynamic. Therefore the offers in the sales in a shopping centre could be changed in no time or in the event case if there are a lot of tickets left a few days before the show, they could be sold via the advertisement portal. There is not enough data to analyse whether these markets would be potential and therefore they are just mentioned here.

7 Conclusion

The thesis can be divided in primary and secondary parts. The primary part concentrated on a WLAN in a residential building and the secondary part concentrated on an advertisement portal based on the WLAN.

The purpose of the primary part was to evaluate whether a WLAN could be built in a residential building in a way that it would make sense in the technical and in the business points of view. Calculations, measurements and tests in practice were performed to find this out.

The best place for the access points is in the staircase and there should be at least one access point per floor. The location and number of access points per floor depends on the layout of the building.

In the coverage planning it was found out that the multi wall model did not provide accurate results. The reason was that multipath propagation, furniture and people were neglected. To obtain accurate models, professional software is needed.

The purpose of the secondary part was to study a new kind of advertising medium, the advertising portal. The advertisement portal was planned from the very beginning and it was implemented in co-operation with University of Turku. It was also tested in real life.

The most suitable market for the advertisement portal would be a local market, but there are other potential markets as well. The bottleneck of the advertisement portal is to get enough users. Without a lot of users the advertisers will not be interested in it. The advertisement portal has benefits over its competitors and weaknesses as well. The core competences of the advertisement portal are that it is dynamic, interactive, nature conservative and that it provides cost savings from distribution and materials.

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