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School of Design, Engineering & Computing

Wi-Fi, WiMAX and LTE e-Learning Aid

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Abstract

This project is centred on the development of a web-based, e-learning tool to assist students in studying WiFi, WiMAX and LTE. It provides a “blended learning” experience which embraces a number of multimedia modes such as text, video and audio. The learning aid teaches

- Basic Digital Communication Theory to ensure that a rudimentary understanding of the terminology has been acquired.
- Wi-Fi, WiMAX and Long-term Evolution (LTE)

As a basis for the development of the content, material from the Advanced Networks Systems course on myBU provided the starting point. Further extensive research was then carried out to enlarge and extend the coverage of Wi-Fi, WiMAX and LTE.

Key words

e-learning tool, blended learning, Wi-Fi, WiMAX, LTE, LTE-Advanced, IMT-Advanced, 2G, GSM, EDGE, 3G, HSDPA, SAE, OFDMA

Declaration

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Signed: Keith Amoah

Name: Keith Amoah

Date: 04/05/2011

Programme: BSc (Hons) Multimedia Communication Systems

Original Work Declaration

This dissertation and the project that it is based on are my own work, except where stated, in accordance with University regulations.

Signed: keith Amoah

Acknowledgements

I would like to thank my younger brother Joey Amoah for being my cameraman, Mum and Dad for their constant support and my supervisor Dr. Kanyaru for his encouragement and expert advice.

1 Contents

1 Project Brief

1.1 Project Background

An introduction to Wi-Fi, WiMAX and Cellular networks is currently taught under Advanced Networks Module through lectures supported by PowerPoint presentations and lecture notes which are posted on the student site, my BU.

This proposal seeks to extend, widen and enrich the variety in the delivery of the content. It offers an e-learning aid on Wi-Fi, WiMAX and Long Term Evolution of cellular networks which will feature videos, animation and opportunities for self assessment by way of an on-line quiz.

1.2 Objectives

The objective of this project is to offer academic material on the Web in various multimedia formats that supports students of Advanced Networks, helping them to grasp the concepts and challenges posed by Wi-Fi, WiMAX and Long Term Evolution of cellular networks.

It is envisaged that the material will enable both self study and further support the lectures in this exciting area.

The solution, while catering for full time students, acknowledges that there could be more part time and distance learning students in the future with the changing profile of Higher Education costs.

As the technology and standards are still evolving especially in the area of LTE-Advanced, the solution must be easily maintainable and allow for material to be updated.

1.3 Requirements

The key requirement is for delivery by 6th May but other deadlines may include the schedule for planning courses and content for academic year 2011/2012.

The solution should be able to run on standard browsers Internet Explorer, Firefox, Safari etc with minimal additional software.

1.4 Scope

The scope of this project includes

1. Brief review of Multimedia in Higher Education
2. Study and Research of Wi-Fi, WiMAX, LTE and LTE-Advanced
3. Comparison of the Technologies and how they compete and/or complement each other
4. A software project following the appropriate design methodology delivering a multimedia e-learning solution.
5. The solution should be designed for standard Laptops and desktop (i.e. no high end processors or special graphics cards – the solution should run on a 3 year old PC)

Exclusions in this project

1. Whereas consideration will be given to ensuring that the multimedia solution is not too large and than it can run efficiently over a 1 Megabit ADSL/3G broad band connection, no sizing is being carried out on Web-servers, Media Servers or any database servers.
2. The initial solution is not designed to run on small mobile devices like I-phones, Blackberries etc are currently out of scope due to their small screen size.

1.5 Interfaces Affected

In the first phase of the project it is not envisaged that any data on students will be captured but considerations should still be given to security. (Future versions might provide the lecturer anonymous information of the progress students and information on areas where they find the subject matter challenging)

If this Multimedia project is widely rolled out and becomes template for course delivery those responsible for capacity planning must be informed because of potential impact on networks, servers etc.

1.6 Approach

The approach used will be an phased approach.

1. Phase one: brief review of Multimedia in Higher Education
2. Phase two: development of content – study and research into Wi-Fi , WiMAX and LTE

3. Phase three: design and development of e-learning solution using appropriate software project delivery methodologies.

1.7 Risks

The student/author did not take Advanced Networks Module in final year so:

1. This puts the development "content" at potential risk as the student is studying and researching this subject independently
2. Student is relying on feedback from colleagues who did take this course to explain which areas they found challenging and where a learning aid would be beneficial.

1.8 Alternative Solutions

Alternative solutions could include

1. Recording lectures on video camera and using minimal multimedia software
2. Distributing information by CD or DVD.

1.9 Open Issues

None

1.10 Profitability /Project Justification

In industry, projects are normally decided on by their Return On Investment (ROI). Industries usually often have an internal return rate of say 15% that projects have to exceed. The Net Present Value (NPV) is then calculated. If this is positive, the projects are then ranked in order to compete for the available capital and resources.

This project is a final year dissertation project so its approval is based on its academic content and suitability as final year project.

However, potential costs include:

1. Software Development License costs.
2. Roll out and deployment Costs

Potential benefits include:

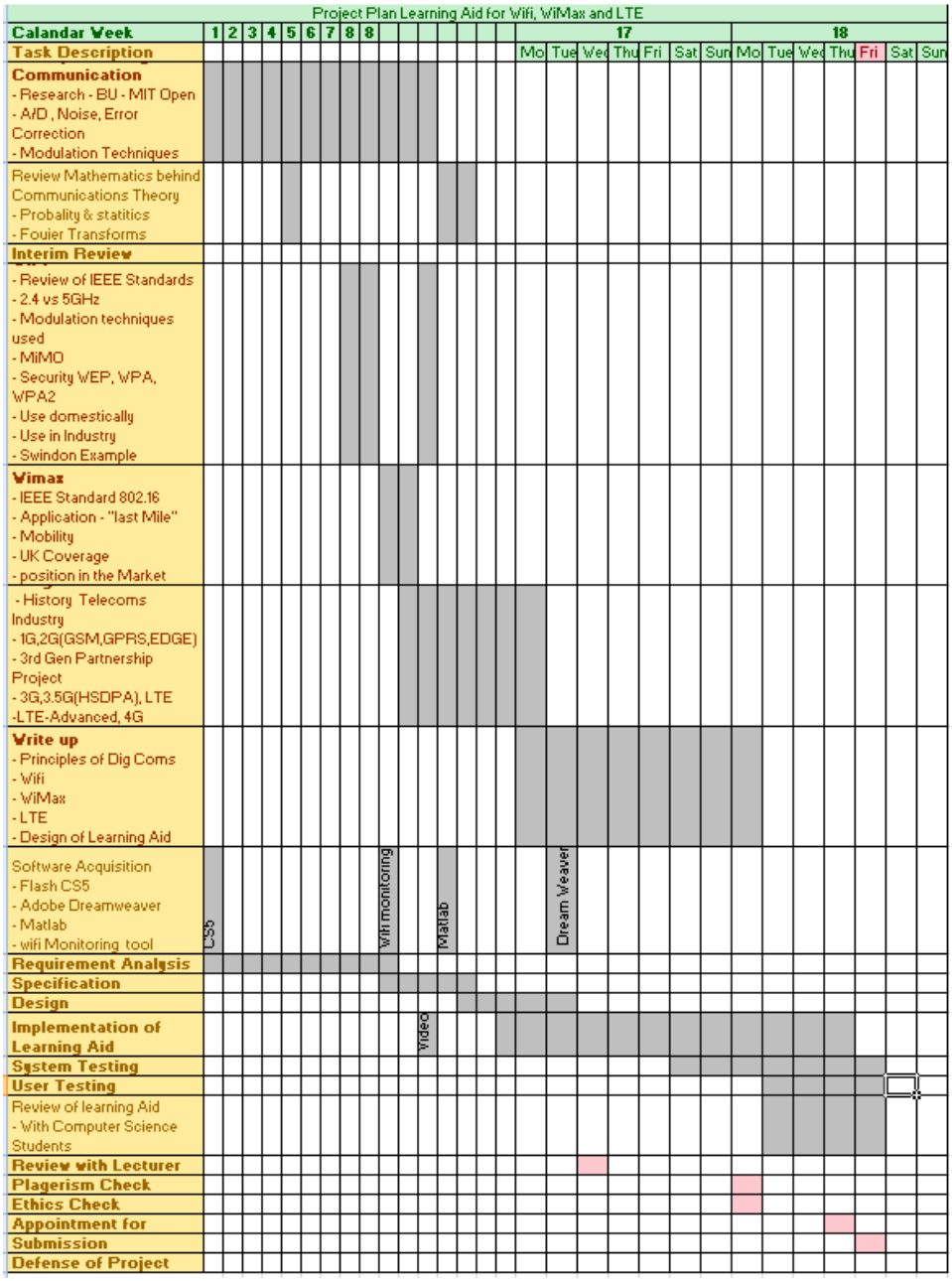
1. Learning Outcomes – does multimedia improve student success rate?
2. Does Supporting Multimedia allow for larger lectures /reduced course provision cost?
3. Attractiveness of Bournemouth University to potential students.

1.11 Project Organisation

From my placement year in industry I learnt that individuals have specific roles on projects, i.e. Project Leader, Software Development, Quality Assurance, Test Manager, Deployment Manager, etc

In this project, I will be performing multiple roles under the guidance of the project Supervisor

1.12 Project Planning



1.13 Stake Holders

Client	Dr. Reza Sahandi
Other Stake Holders	Bournemouth University Students
Supervisor:	Dr. John Kanyaru

Project Delivery Keith Amoah

2 Methodology

2.1 Introduction

There were two aspects to this project

- Research Project for "content" development. This includes
  - Research
  - Taking measurements on Wi-Fi performance
  - Taking measurements on 3G performance
  - Testing the reliability of 3G /HSDPSA while travelling
  - Capturing results as on-screen videos, images etc.
- In the development of e-learning Tool, the methodology used is shown in the rest of this document.

2.2 Requirement Analysis

2.2.1 Interview with Client

An interview was conducted with Client Dr. Reza Sahandi in Nov 2010. Further correspondence was carried out by email.

The key requirements were

- The basis of the content of the learning aid should be what was available on MyBU under the Advance Network module. However, the content should be expanded by further research into Wi-Fi, WiMAX and LTE.
- The content should last about 30 minutes and students should be able to use it independently.
- The content should contain animation and illustrate concepts and ideas to the student.
- Students could be Advanced Network Students or any other students under software systems framework.

2.2.2 Student Questionnaire

A questionnaire was used to interview fellow students as they were also stake holders on this project. (*Answers are in italics*)

- What parts of the course did you find difficult?
  - *All of it was difficult. A lot of independent study was required. The exams were more in depth than what was presented in the lecture theatre.*
- Would animation help with these topics
  - *Yes, for the basic concepts.*
- Did you understand the principles of digital communications? For example did you understand why different modulation techniques improved throughput?
  - *We need for spectral efficiency, but not necessarily how it was achieved.*
  - *We understood the impact of noise and interference on transmissions*
  - *We know from practical experience that the further away you are from an access point, the poorer the performance.*
- Did you understand the mathematics involved i.e? Probability, Statistics, Fourier Transforms etc?
  - *The reason why probability and statistics are important yes but we were not to required to go into depth on these subjects*
  - *Fourier Transforms - not required*
- What prior knowledge would have helped you on the course?
  - *Basic Network courses in year 1 & 2*
  - *Basic Networks year 4*
- Please state what specific topics you found challenging.
  - *Understanding where the various technology were targeted at*
  - *Why the better technology did not always win out*
  - *Predicting the future*
- Would a web based multimedia learning aid be useful?
  - Yes
- How would you use such an application?
  - *Prior to a lecture*
  - *As a reminder of the lecture*
  - *And as a revision aid*
  - *From my flat.*
- Would self assessment be useful?
  - Yes
- Would you mind if your lecturer knew your scores?
  - Yes
- Even if the collection of these results was anonymous?
  - Mixed response but more “No”s.

2.2.3 My Own Experience

I am not a student covering the Advanced Network module so I did not attend any of the lectures. My learning experience was based on personal study of the on-line material and researching the topics of Wi-Fi, WiMAX and LTE in the library, in professional journals and on the internet.

The areas that I found challenging were.

- The sheer number of acronyms
- Various modulation techniques used to increase spectral efficiency.
- Terminology was used by marketing departments which was not strictly correct.
- The nuances of all the different standards and their updates.
- The politics behind the allocation of spectrum.
- Understanding the difference between standard setting bodies like the IEEE and the industry group like Wi-Fi Alliance and WiMAX Forum.

2.3 Specification

The system should be read-only with only the administrator being able to update it.

The system should run on the standard web browsers i.e. Internet Explorer 7, 8 and 9, Safari and FireFox 3.6, 4.0 etc.

Any plug-in required must be free and commonly available.

The WEB interface should be intuitive and suggest routes through the technical information for basic users while letter experts directly access the topics of specific interest.

The system should run satisfactorily over a 1Mbits-1 ADSL network to allow students to access the system remotely from their flats.

Video show should be held in compressed format to minimise storage and bandwidth requirements.

A variety of multimedia techniques should be used (i.e. video, audio, appropriate animations). This will allow the individuals to find a mode that suited their learning style.

The system must run on any normal PC and laptops up to age of 3 years old. (i.e. no high power CPU or graphics cards should be required.

The system should try to be as modular as possible and re-use code wherever possible.

It should be possible to replay animation or video without having to re-load the page.

There must be a self-assessment quiz after each section.

Explanation of acronyms must be available on-line.

2.3.1 Specification Test Plan

Check on local laptop

Test	Success /Failure
Check for broken links	
Check results in different browsers	
Check Flash for voice / video synchronisation	
Check directory structure.	

Load to remote web-server

Test	Success /Failure
Check for broken links	
Check general performance and that streaming is acceptable ▪ Over 10Mbit ADSL ▪ Over 3G dongle (1Mbit)	

End User Testing

Test	User Feedback
Look and Feel – intuitive?	
Logic and walk through	
Performance	

2.3.2 Software Tools to be used

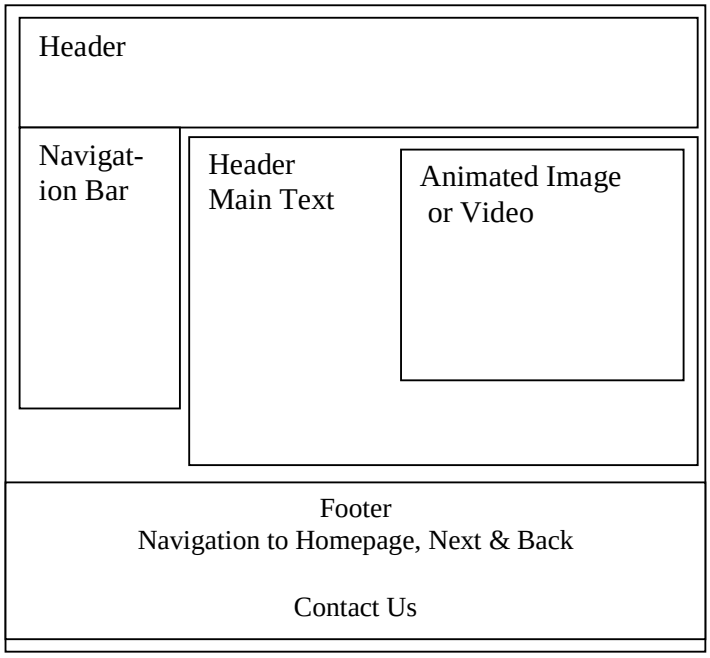
Software	Reason
Adobe CS5 Flash	• Leading animation software. • Ability to place items on different layers. Each layer can be locked so that when you are editing one thing, you don't accidently edit another item. The ability to hide layers also helps this. • Ability to view animations from previous frames without being able to edit them. • Ability to include videos. • Ability to use buttons to play, pause or rewind animation and sound. • Player plug-in is free and is available from adobe.com
Adobe CS5 Dreamweaver	• Edit the source code while being able to see the end product. • Colour code of source code • View Line numbers • Ability to publish to web server • Recomputed directory structure when items are moved between release and development
Debut video Capture software	▪ Capture and record areas of the screen
inSSIDer 2.0	▪ Wireless LAN network analysing software. o Wi-Fi channels being used o Receiving strength signal indicator
Skype	▪ Testing VoIP on 3G
Riva FLV Encoder	▪ Converting Large AVI to smaller FLV files
MetLAB & SIMULINK with digital signal processing	▪ Used to investigate modulation wave forms FSK,BPSK, OOK, QSPK

2.3.3 Other Resources required

Hardware	Reason
Sony Laptop VGN-FZ21M	▪ Development environment
Sony Video Camera	▪ Capturing Interviews
Huawei HSDPA Modem E160	▪ Measuring 3G performance ▪ Testing webpages over slow link
200Mbyte of Web Space	▪ For testing and demonstrating solution

2.4 Design

2.4.1 Standard Page Layout



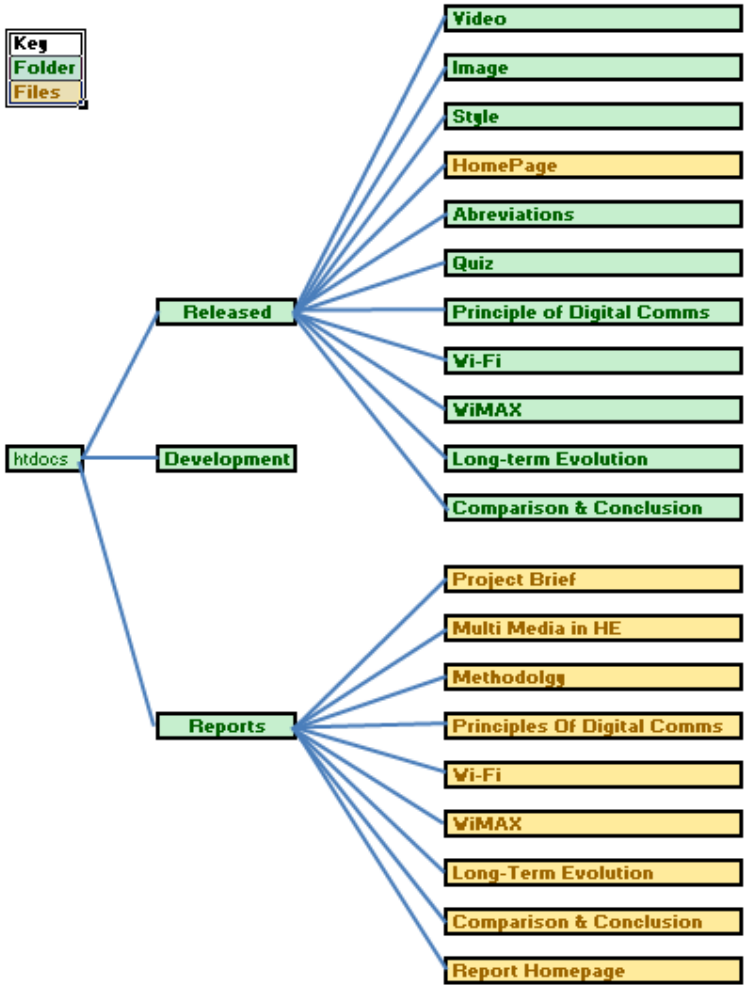
To keep the size of the webpages on the screen, images would designed to enlarge when the cursor is over the image.

The minimum screen size the webpage is designed for is 1080 by 1024.

2.4.2 Design constraints

In Xhtm, the use of tables and frames has been deprecated. Therefore no tables or frames will be used in the solution.

2.4.3 Directory Structure



Note the “development” directory structure is the same as “Release” directory structure. Details of development directory structure are suppressed for clarity.

2.5 Implementation

The early versions of e-learning aid were loaded up to

http://www.keith-amoah.webspace.virginmedia.com/Mainpage.html

where I have 200Mbyte of webspace. This was in order to prove the concept of e-learning tool.

The implementation was done using wherever possible re-usable code. This was to

1. Keep it structured
2. Limit the amount of time spend on development.

The animations were developed in Flash and all video were converted from various formats (.avi, .mov etc.) to FLV to limit the size and to allow streaming.

2.6 Testing

2.6.1 System Testing

Testing according to test plan as declared in specifications

Test results.

- No issues with links within Html
- However, problems were detected with links between Flash animation files and over-laid audio – corrected issues discovered on local tests
- On web server performance was inconsistent over 3G modem. Intermittent hesitation rather than an out-right performance. (Reduce the encoding of FLV files to reduce size)

2.6.2 End User Testing

Waiting feedback

3 Multimedia in Higher Education

3.1 Tomorrow's Workforce

As Trybus [301] says, the composition of today's workforce is increasingly made up of people who have never known a world without the plethora of multimedia systems - videogames, iPods, mobile phones and the internet. Therefore, it is only to be expected that in preparing a competent workforce for tomorrow's world, these same technologies that are used daily on a social basis, should also be applied to their education experience.

3.2 Disenchanted Learners

Herrington [302] agrees with other educators and points out that "many learners are failing to engage with didactic and outmoded instructional methods, and are unwilling to use technology that simply replicates the one-way transfer of information from teacher to student". In the 21st century, it is a widely held view that the use of multimedia has a legitimate place in education and can be an effective teaching tool in motivating and engaging the jaded learner in a novel way.

3.3 H.E. Embraces Change

Institutions of Higher Education are facing this new challenge and are increasingly embracing education–technology initiatives and innovations in order to cater for the diverse needs of their students. Llorenç Valverde [303] Vice-Rector of Technology at The Open University of Catalonia (UOC) Spain, passionately declares "Our aim and the aim of all of those involved in education, distance or not, should be to use technology in a more proactive and interactive way, to help students in their learning process… the greatest challenge is aligning educational content and interaction with the right channels."

3.4 The New Learning Ecology

Professor Henry Jenkins [304] on Games-based Learning at SxSWi 2009, talks about the new learning ecology. Today, most forms of learning in the classroom continue to be autonomous and almost all forms of collaboration are classed as "cheating". In the real world, collaboration and the trading of ideas and thoughts take place all the time and students need to

be prepared for this environment. Jenkins describes why games are great learning tools, and how new multimedia paradigms can change the educational system so that it embraces the resources of the digital age. In his vision, the convergence of the ever increasing array of technologies - still images, text, animation, audio and varying levels of interactivity- will shape the curricula and promote what he calls “blended learning”. Is this an unrealistic expectation of multimedia’s revolutionary advantage and applicability?

3.5 Good Multimedia /Bad Multimedia

Research findings on the true value of using multimedia in terms of measurable learning outcome are unclear. Educators have to select from a wide array of multimedia options and it is important that real improvements are obtained in learning outcomes. So how is their effectiveness evaluated? What characterizes an effective and successful e-learning experience? Based largely on the work of Brown et al [305,306], it is defined as: ‘the notion of learning, knowledge and skills in contexts that reflect the way the knowledge will be useful in real life.’ The learning tasks need to be authentic, matching as closely as possible, the real world tasks that have to be carried out in practice.

A successful example of e-learning is from the world of Mechanical Engineering in Northern Illinois University. M.J Mayo [307] argues that the complex principles of Science and Engineering can be taught not only by playing games but also by designing games as well. Students who used Brianno Coller’s [308,309] Race Car game/Numerical Methods course were observed to be able to describe a significant number of defining features to the main topic more than the control group who did not participate in the game design and playing. Coller demonstrates that in this instance, multimedia can be an effective learning vehicle by both stimulating interest and increasing the time students voluntarily spend on the task. Even the exam in this learning experience is innovative and styled differently. Students have to drive a car around a track that they have not seen before by writing a programme to do the driving.

From the Howard Hughes Medical Institute and Harvard University comes another resounding multimedia success story. BioVisions, under the directorship of Dr Robert Lue, is a group of Harvard scientists, lecturers, students and multimedia professionals working in the area of biology. The aim of the collaboration is to teach “how biological processes occur by combining the highest quality multimedia development with rigorous scientific models. In addition, this new generation of science visualizations are not meant to simply be simulations

or mirrors held up to reality, rather they are designed with a specific pedagogical goals in mind. This means that each decision made on how to represent a given biological process also includes consideration of how best to visually communicate particular aspects of the process". [310]

In short, Mayer R. [311] says according to the cognitive theory of multimedia learning, that students are likely to learn more deeply and understand difficult concepts more readily because they are engaging in processing information simultaneously on many different levels.

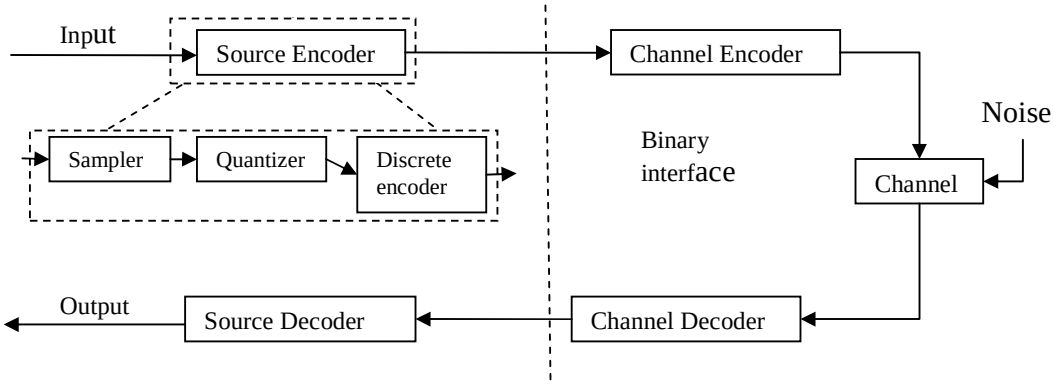
4 Principles of Digital Communications

4.1 Introduction

The purpose of this chapter is to explain the concepts that are widely referred to in the later chapters of Wi-Fi, WiMAX and Long-Term Evolution (LTE).

Wireless spectrum is a finite resource. The only way to increase data throughput is to find ways to use spectrum more effectively – This is called Spectral Efficiency.

4.2 Binary Interface



Source [401], Separation of source and channel coding

For the purposes of this report we are particularly interested in what happens to the right hand side vertical dotted line in the figure above, the Binary Interface.

As far as Wi-Fi, WiMAX and LTE are concerned, the “channels” are wireless and the objective is that whatever is sent to the channel encoder is what comes out of the channel decoder. To add to this challenge, with each progressing year we want to improve the spectral efficiency and send data ever faster.

To use the “channel”, data needs to be converted into a form that is appropriate for the channel – i.e. we have to modulate our digital data onto an analogue carrier for the channel. What we are particularly interested in is how we can efficiently transmit as much data as possible.

4.3 Modulation techniques

4.3.1 Introduction

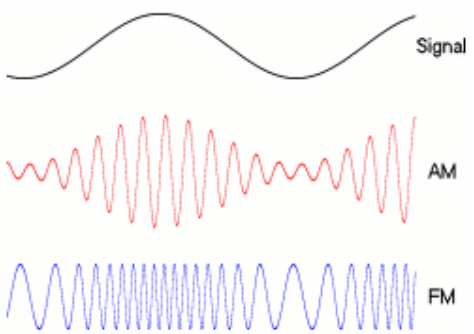
Modulation is the process of varying the high frequency carrier wave that is appropriate for the channel in such a way that it transports our binary data.

4.3.2 Amplitude Modulation (AM)

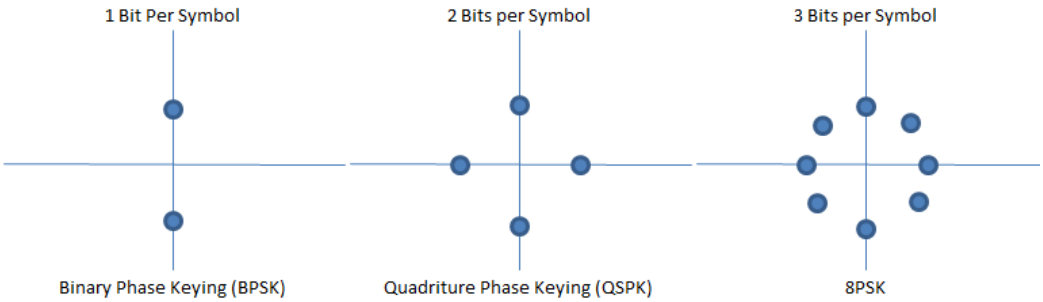
Amplitude Modulation varies the amplitude depending on whether a “1” or “0” is being sent.

4.3.3 Frequency Modulation (FM)

Frequency Modulation uses varying frequencies in relation to the information being sent. Below is a diagram showing AM and FM.



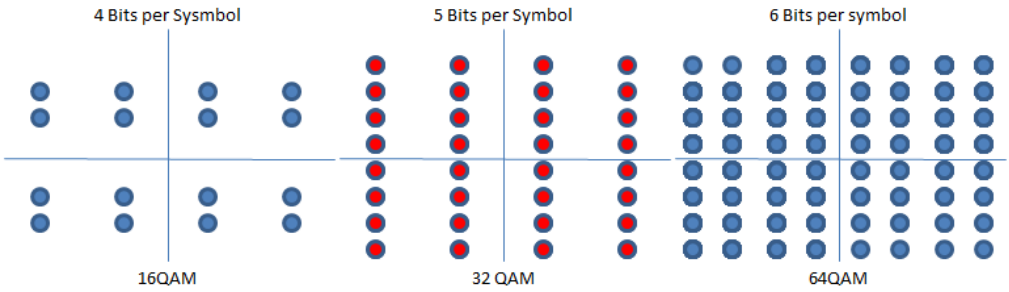
4.3.4 Phase Modulation



In phase modulation, the carrier phase is altered. In BPSK, it is modified by +/- 180 to represent a zero or one. The aim of a Communications Engineer is to transfer data as efficiently as possible. In QPSK, 00,01,10,11 are represented by modifying the carrier by +0, +90, +180, +270. In 8PSK 000,001,010,011,100,101,110,111is represented by carrier shifts of +0, +45, +90,+135,+180, +225, +270,+315. The more granular the angle shift,

the more data that can be sent per symbol. However, the channel decoder finds it more difficult to discriminate especially when there is noise on the channel.

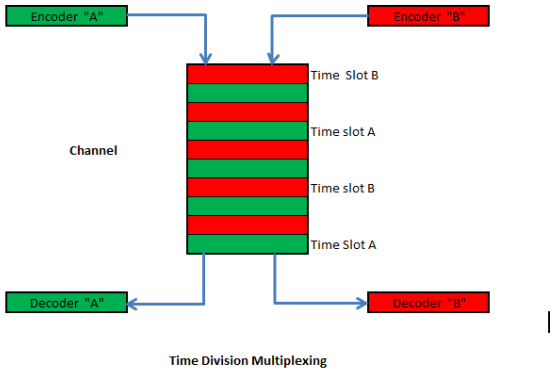
4.3.5 QAM



In QAM, two physical properties of the wave are varied, amplitude and phase. It can be considered as a mixture of amplitude and phase modulation. The goal is to achieve ever higher spectral efficiency. 16QAM delivers 4 bits per symbol, 64QAM delivers 6 bits per symbol and 256QAM would deliver 8 bits per symbol.

4.4 Multiplexing

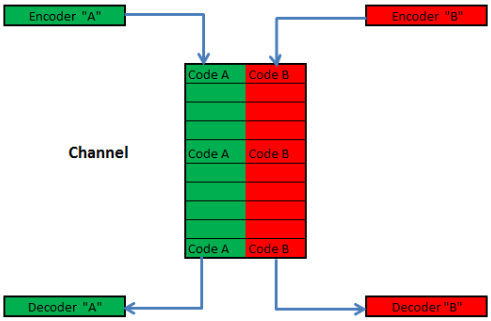
4.4.1 Time Division Multiplexing



Time Division Multiplexing

In time division multiplexing, the capacity of the channel is higher than what has been allocated to encoder A or B. Each encoder is allocated a time slot in which to transmit. The decoders only accept information in their respective time slots.

4.4.2 Code Division Multiplexing

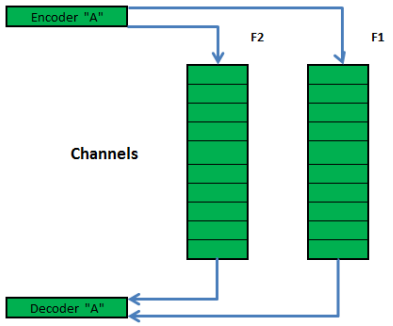


Code Division Multiplexing

In code division multiplexing, the channel again is larger than the service that has been allocated to either encoder A or B. Each encoder encodes its messages with a code. The receiving decoders only decode the messages that they have the key for. They treat the other messages as noise and discard them.

4.4.3 Spatial Multiplexing

4.4.4 Frequency Division Multiplexing



Frequency Division Multiplexing

In frequency and spatial multiplexing, the allocation of bandwidth to the encoder is more than can be handled by one channel. In frequency multiplexing, additional channels are added at different frequencies i.e. F1 and F2. The encoder splits its data between the two channels and the decoder reassembles the data at the other end.

In Spatial multiplexing, additional spatial streams are added to achieve the same effect.

In noisy or poor signal environments the same information can be sent down both channels. This improves the signal to noise ratio. The decoder can compare the messages that were sent down both channels and it has a better chance of assembling the data correctly.

4.4.5 TDD and FDD

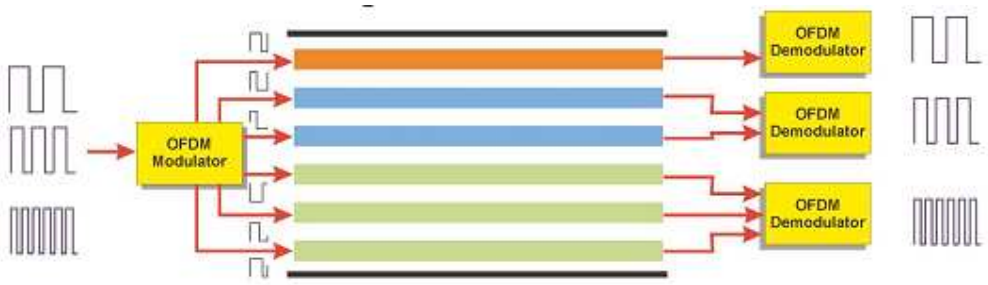
In time division duplex, the channel is divided into downlink and uplink time slots. These time slots do not have to be equal (i.e. if you expect more downlink traffic you could allocate a higher proportion of the time slots to the downlink traffic.

Frequency Division Duplex is when channel frequencies are divided between downlink and uplink traffic. Here again, the frequency bandwidth does not have to be allocated symmetrically. If more downlink traffic is expected a larger portion of the bandwidth can be allocated to it.

4.4.6 OFDM

Orthogonal Frequency Division Multiplexing is frequency division multiplexing where the total bandwidth has been divided into sub-carriers which are placed very closely together at ninety degree phase shift (hence the name orthogonal).

4.4.7 OFDMA



Source [404] OFDMA

Orthogonal Frequency Division Multiple Access is the process of dividing a radio carrier channel into several independent sub-carrier channels that are shared between simultaneous users. The OFDMA system dynamically allocates sub

carrier channels or groups of sub channels to users. The data rates provided to each user depends on the number of sub carriers that are allocated to that user.

4.5 Noise and probability

4.5.1 Gaussian noise

The bane of all communication engineers is noise. Without noise, engineers could modulate at ever higher and higher QAM achieving eventually, an infinite number of bits per symbol. However with noise, it is impossible for the decoder to discriminate between minor changes in phase and amplitude.

Gaussian noise is noise which has a probability density of a normal distribution. White Gaussian noise is present at all frequencies at equal power amplitude.

4.5.2 Error Detection and correction

The challenge of transmitting data is that the channel is subject to noise and interference so the data may get corrupted while it is being transmitted. In order to detect errors, the source encoder may transfer extra bits of data so that the decoder can use probability to work out what the correct data is. In the example below, triplets are sent.

Triplet Received	Interpreted As
000	0 (no errors)
001	0
010	0
100	0
111	1 (no errors)
110	1
101	1
011	1

Source [1] Forward Error Correction

Obviously, this is quite wasteful of bandwidth and there is no actual guarantee that 010 is 0. It only has a 67% probability that it is zero. Alternatively, the receiver can ask for the data to be retransmitted to have further confirmation of the actual values.

4.6 Conclusion

This chapter is only an introduction to the principles of Digital Communications. Its aim is to cover just enough material to make the comprehension of the subsequent chapters on Wi-Fi, WiMAX and LTE easier.

Communication engineers are always battling to achieve ever higher spectral efficiency by using higher order modulation techniques but they have to balance this with ensuring that data quality at the receiving node is high by sending extra correction data bits or at worst asking for the data to be re-transmitted at a lower order of modulation.

In the experiments carried out under “Wi-Fi, section 5.3.4 Modulation and Performance”, we demonstrate that the Wireless Access Point and the Laptop are communicating at 64QAM, with Forward Error Correction (FEC) of 5/6 and the communication channel is using one spatial stream. If the signal quality were to drop, it would reduce the order of modulation to for example, 16QAM or even to QPSK and increase the ratio of error detection bits i.e. FEC of 1/2.

5 Wi-Fi

5.1 Background

Wi-Fi is the name given to short-range wireless broadband technology. In Europe, the maximum power of the transmitter is limited to 100mW in 2.4 and 5 GHz bands.

The IEEE 802.11 standard defines the standards for Wireless Local Area Networks. [1]

Wi-Fi is the commercial name for this class of systems. The Wi-Fi Alliance is an industry-led, not-for-profit organization which has the goal of driving the adoption of a single worldwide standard for high-speed wireless local area networking. [2]

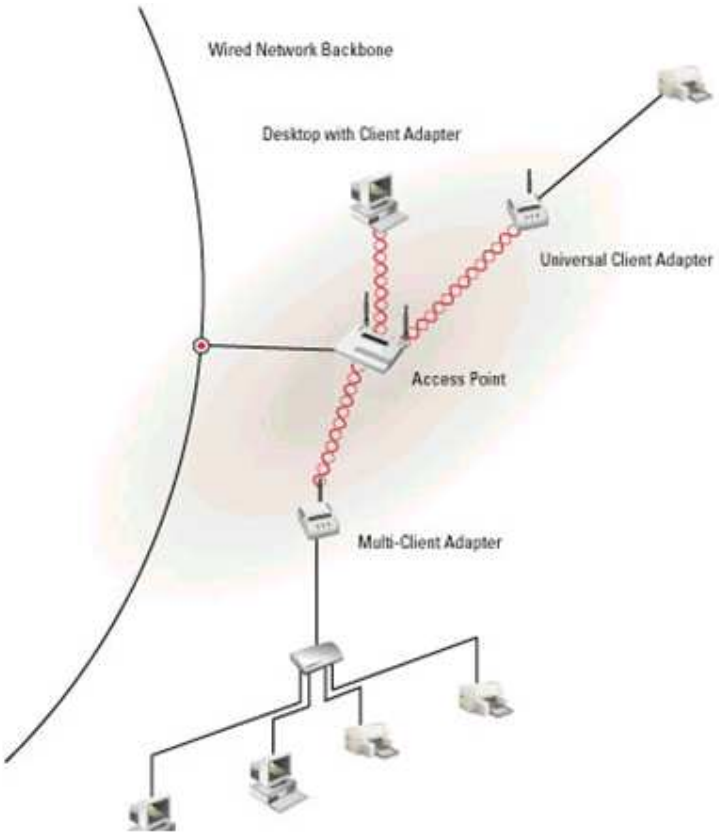


Fig 1 Wireless LANs Source www.bournemouth.ac.uk

5.2 History

In 1985, the Federal Communications Committee (FCC) opened up the frequency 900Hz, 2.4 and 5.8HHz for use without a government licence. These frequencies were known as the "garbage bands" as they were used for things other than just communications i.e. Microwave ovens etc.

In 1988, the company NCR wanted to use the unlicensed band to link its cash registers together. They approached the IEEE about creating a standard similar to 802.3. A new group 802.11 was set up. In 1997, the first basic specification was agreed on and it allowed transfer speeds of 2mbits. Two variants of the standard, 802.11a and 802.11b, were ratified in December 1999 and January 2000 respectively.

Today, the latest standard is 802.11n which, when using 40 MHz of bandwidth with 4 spatial streams, allows for speeds up to 600 $Mbits^{-1}$

5.2.1 Fixed Access

Wi-Fi Standard	Frequency	Bandwidth	Speed
802.11a	5GHz	20Mhz	Up to $54Mbits^{-1}$
802.11b	2.4 GHz	20 MHz	Up to $11Mbits^{-1}$
802.11g	2.4 GHz	20 MHz	Up to $54Mbits^{-1}$
802.11n	2.4, 5 GHz	20 or 40Mhz	Up to $600Mbits^{-1}$

Table 1 802.11 details

5.3 Wi-Fi

5.3.1 Simple Installations

Wireless LAN comprises of

- Wireless Access Points
- Wireless Clients

In the UK, Ofcom limits the maximum equivalent isotropically radiated power (EIRP) from a 2.4GHz Access Point to 100mW [4]. This gives a range in free air of about 100 metres within a building. With walls and furnishings, this is considerably less.

Therefore, single wireless access points are really designed to provide coverage to a small area. In a domestic dwelling, normally the access point is also a router. The

range of this access point can be extended by using repeaters near the edge of the range of the primary access point/router.

Wireless Networks can be configured as

- Independent Basic Service Set (often referred to as adhoc , peer to peer relationship)
- Basic Service Set (often referred to as infrastructure, all wireless clients attach to a wireless access point that is broadcasting a SSID)
- Extended Service Set. (this is where multiple APs share the same SID) Clients are able to move seamlessly from one AP to another. Multiple Wireless APs are used where larger coverage or resilience is required.

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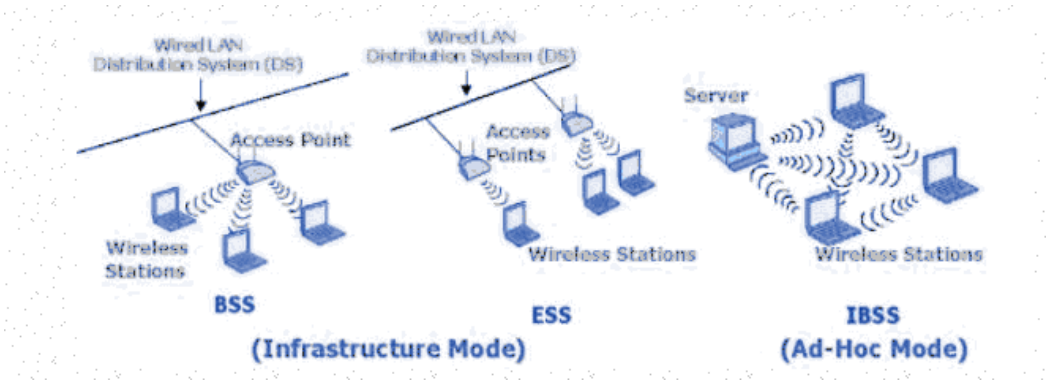


Fig 2 Wireless LAN configurations BSS, ESS and IBSS
Source: www.bournemouth.ac.uk

5.3.2 Sharing the Medium

Wireless is a shared medium so an algorithm called Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is required. This means that wireless stations all listen and if all is quiet, back-off for a further random time before transmitting data.

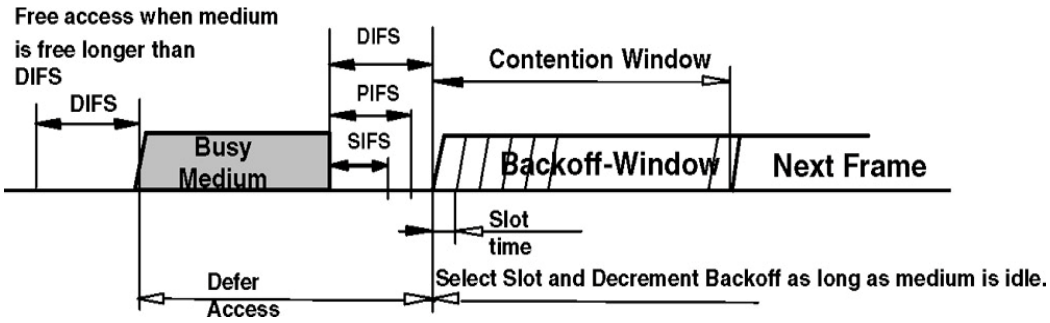


Fig 3 IEEE 802.11 inter-frame space (Prasad and Prasad 2005)

5.3.3 Spectrum

Wi-Fi can operate in 2.4GHz and 5GHz. (5.8GHz). As stated before, it is an unlicensed spectrum.

In Europe, there are 13 overlapping channels in the 2.4 GHz band starting from Channel 1 at 2.412GHz in 5MHz stepping up to Channel 13 at 2472Ghz. (America only uses channels 1->11).

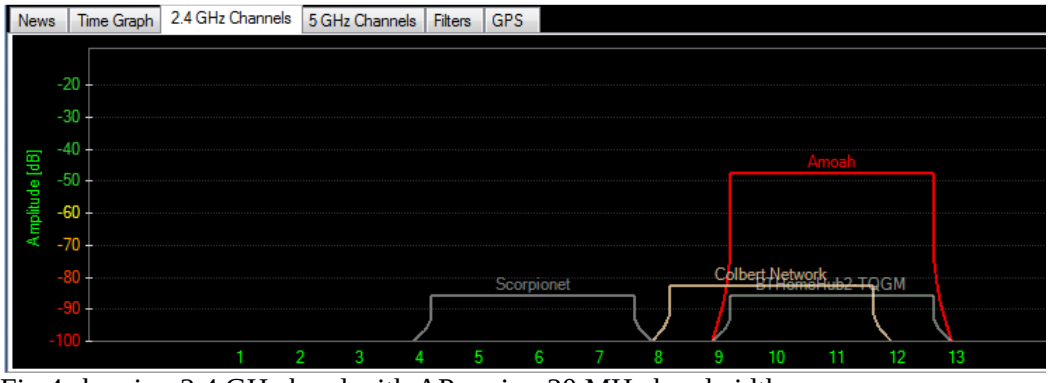


Fig 4 showing 2.4 GHz band with APs using 20 MHz bandwidth

In the UK, the 2.4 GHz Spectrum is more widely used domestically than the 5 GHz spectrum (see figures 1 & 2).

In the 5 GHz band, Europe uses Channels 36, (5.180GHz), 40(5.200 GHz), 44, 48, 52, 56, 64(5.320GHz), 100(5.500GHz), 104, 116, 120, 124, 128, 132, 136(5.680GHz).

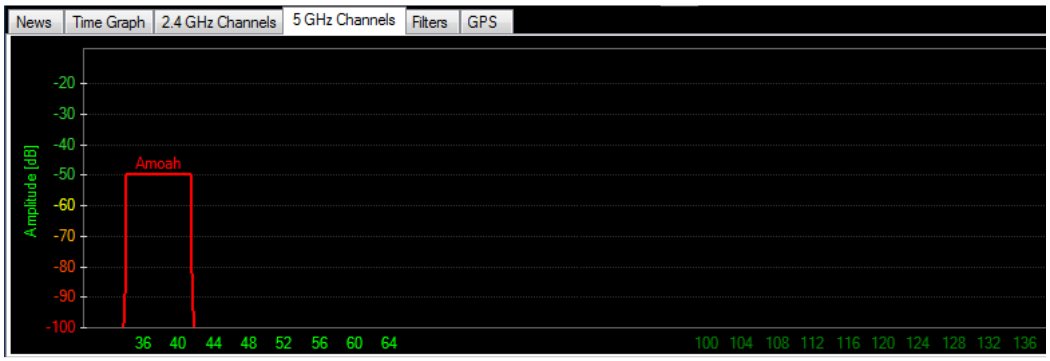


Fig 5 showing the 5GHz bandwidth 40 MHz band with AP using channels 36+40

5.3.4 Modulation and Performance

Performance of Wi-Fi depends on

- Whether the equipment is 802.11a, 802.11b, 802.11g, 802.11n
- Signal strength and Quality
  - Distance Wireless Access Point
  - 2.4 or 5GHz (5 GHz less interference but higher attenuation)
- MIMO (spatial Multiplexing)
  - 1x1, 2x2, 4x4

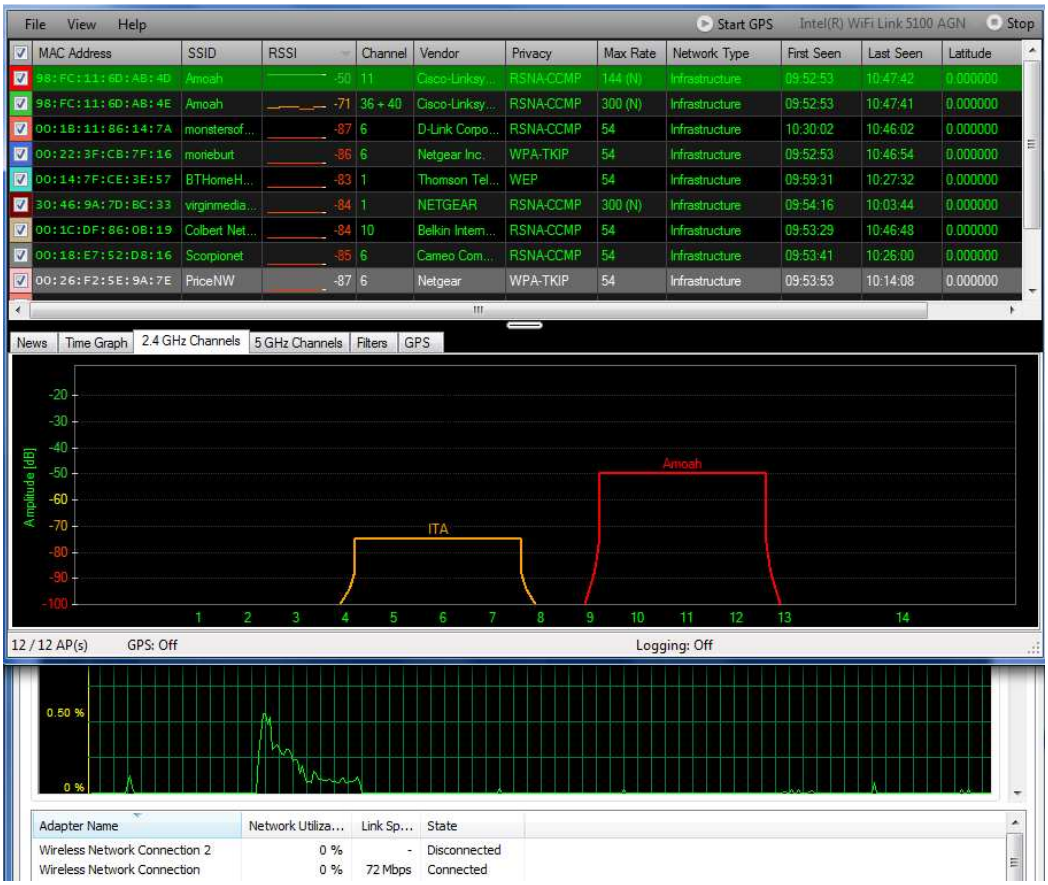


Fig 6 shows connection to WAP Amoah at 72Mbits

Adaptive Modulation

Wi-Fi uses adaptive modulation dynamically adjusting the modulation type of a communication channel based on specific criteria (e.g. signal quality – signal strength, interference and noise), dropping down from 64QAM near the wireless access point down to BPSK at the edge of the access points range.

MIMO

802.11n can use Multiple Input Multiple Output to either increase the throughput through spatial multiplexing or to improve the signal to noise ration.

MCS Index	Type	Coding Rate	Spatial Streams	Data Rate (Mbps) with 20 MHz CH		Data Rate (Mbps) with 40 MHz CH	
				800 ns	400 ns (SGI)	800 ns	400 ns (SGI)
0	BPSK	1 / 2	1	6.50	7.20	13.50	15.00
1	QPSK	1 / 2	1	13.00	14.40	27.00	30.00
2	QPSK	3 / 4	1	19.50	21.70	40.50	45.00
3	16-QAM	1 / 2	1	26.00	28.90	54.00	60.00
4	16-QAM	3 / 4	1	39.00	43.30	81.00	90.00
5	64-QAM	2 / 3	1	52.00	57.80	108.00	120.00
6	64-QAM	3 / 4	1	58.50	[illegible]	121.50	135.00
7	64-QAM	5 / 6	1	65.00	72.20	135.00	150.00
8	BPSK	1 / 2	2	13.00	[illegible]	27.00	30.00
9	QPSK	1 / 2	2	26.00	28.90	54.00	60.00
10	QPSK	3 / 4	2	39.00	43.30	81.00	90.00
11	16-QAM	1 / 2	2	52.00	57.80	108.00	120.00
12	16-QAM	3 / 4	2	78.00	86.70	162.00	180.00
13	64-QAM	2 / 3	2	104.00	115.60	216.00	240.00
14	64-QAM	3 / 4	2	117.00	130.00	243.00	270.00
15	64-QAM	5 / 6	2	130.00	144.40	270.00	300.00
16	BPSK	1 / 2	3	19.50	21.70	40.50	45.00
...	...	...	...	...	...	...	...
31	64-QAM	5 / 6	4	260.00	288.90	540.00	600.00

Table 2 Modulation schemes Source 802.11n Wireless LAN standard.

From the example in Fig 6 and table 2, it can be seen that the laptop is communicating with the Wireless Access Point using 64-QAM, coding rate 5/6, with 1 spatial stream and 20 MHz Channel.

5.3.5 Security

There are several steps that can be taken to improve the security of wireless LAN.

1. Access List of allowed clients (based MAC address wireless clients)
2. Suppress the broadcasting of the Wireless APs SSID
3. Reduction of Transmit Power (this reduces the range of coverage by AP)
4. Encryption.

Encrypting the communication stream is the main security measure in wireless LANs. In a small wireless network, identical encryption keys are typed in to Wireless Access Point and the user end equipment.

Wired Equivalent Privacy **(WEP)** was the security scheme that was introduced with the original 802.11 standard in 1999. 64-WEP relies on a 40 bit key concatenated with 24 bit initialisation vector to create 64bits. This is passed through an RC4 encrypting algorithm to generate a traffic key. This traffic key is then "exclusively or" with the bit stream to create an encrypted stream.

Unfortunately, WEP had some flaws and can now be compromised so Wi-Fi Protected Access (WPA) was developed. This also used RC4 encryption algorithm so could be deployed with most existing Wi-Fi equipment with a firmware upgrade. WPA introduced temporal Key Integrity Protocol (TKIP) which mixes the Key with the initialisation vector rather than just carrying out concatenation as is the case in WEP.

WPA2, which is more secure than WPA, uses a more secure encryption algorithm AES.

Description	WEP	WEP	WPA-PSK	WPA2-PSK	WPA2-PSK
Key length	64bit	128bit	128bit	128bit	256bit
Encryption Algorithm	RC4	RC4	TKIP+RC4	AES	AES
Level of security					

Figure 7 Domestic Security

The Wi-Fi Alliance which certifies new wireless equipment only wishes to support WPA2 from 2013 [508, 509]. This means if your Wireless Access Point goes faulty and you have to replace it, it will only support WPA2. If your wireless clients do not support this, they will have to be replaced also.

Description	WEP	WEP	WPA-PSK	WPA2-PSK	WPA2-PSK
Key length	Dt	128bit	128bit	128bit	256bit
Encryption Algorithm	RC4	RC4	TKIP+RC4	AES	AES
Level of security	WEP and WPA will no longer be supported in new equipment from 2013			Only supported form of encryption for new equipment from 2013	

Fig 8 Retirements of WEP and WPA

5.3.6 Enterprise Installations.

Even with high gain antennae the range of wireless AP is limited. In order to cover large factory floors and to provide resilience a large number of APs are required.

By way of example, Cisco has a scheme of Controller based wireless LANs which used Wireless Service Module (WiSM) to control light weight wireless access points [509]. Each light weight wireless access point is connected to two WiSM (see figure below). The wireless access points are installed with a 40% overlap. If a wireless access point fails, the WiSM boosts the transmitting power of the surrounding wireless access points to maintain coverage. Failures can be mathematically modelled to ensure the building always has adequate coverage.

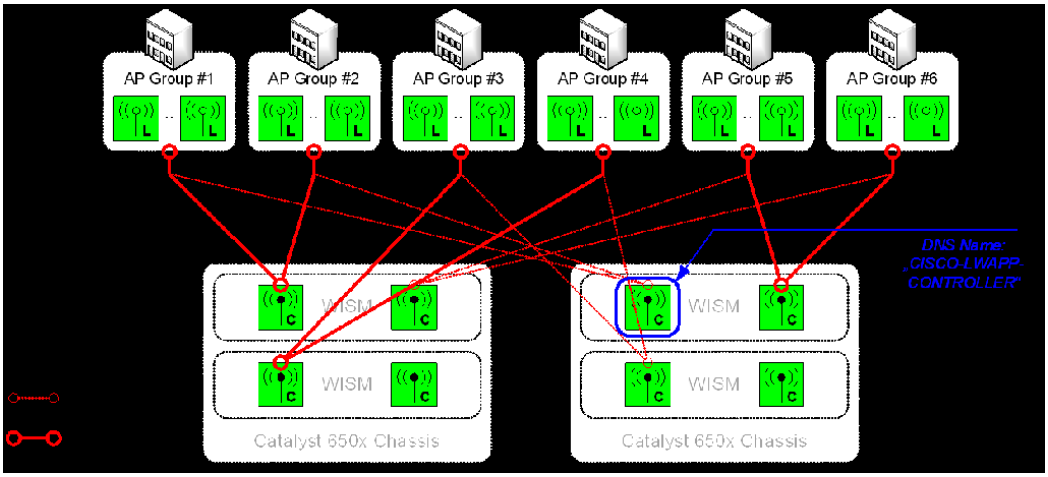


Fig 9 Enterprise Wireless LAN. [510]

Security

In larger organisations, RADIUS servers with Protected Extensible Authentication Protocol (PEAP) are used to authenticate Wireless Clients and to pass keys through tunnels between Wireless Access Point and Clients.

Description	Legacy LEAP	Legacy PEAP	WPA Enterprise LEAP	WPA Enterprise PEAP	WPA2 Enterprise PEAP
Authentification	IEEE 802.1x w/ LEAP	IEEE 802.1x w/ PEAP	IEEE 802.1x w/ LEAP	IEEE 802.1x w/ LEAP	IEEE 802.1x w/ LEAP
Encryption	Dyn WEP	Dyn WEP	WPA/TKIP	WPA2/TKIP	WPA2/AES
Level of security					

Fig 10 Enterprise Security

5.4 Wi-Fi Meshes

My local Borough Council of Swindon in Wiltshire has teamed up with a digital technology firm aQovia to set up a company called Digital City UK, to install a wireless (Wi-Fi) broadband mesh of 1,400 access points covering the whole borough with internet access to 186,000 citizens. [506]

The pilot for this project was in the town of Highworth. Unfortunately, this project was suspended in March 2011.

I did try to contact Mr Riki Hunt the director of Digital City on his choice of technology. I personally tested the system in Highworth before its suspension. I was not able to hold a connection as I walked around Highworth and I did not get positive feedback from the businesses in the High Street that I interviewed, Brooks Café and the Kebria Tandoori Restaurant. The local inhabitants interviewed were also disparaging of the “unreliable internet service that was always losing connection”.

6 WiMAX

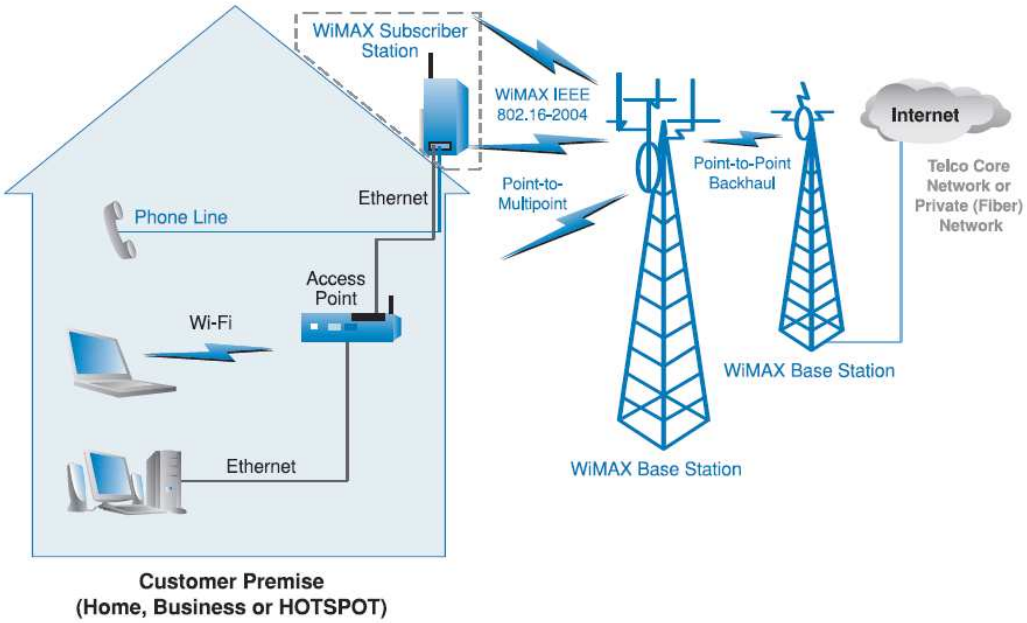
6.1 Background

Worldwide Interoperability for Microwave Access (WiMAX) is a wireless communication system that allows computers to remotely connect to high-speed data networks like the Internet.

The IEEE 802.16 standard defines the standards for Broadband Wireless Metropolitan Area Networks. [601]

WiMAX is the commercial name for this class of systems. The WiMAX Forum is an industry-led, not-for-profit organization formed to certify and promote the compatibility and interoperability of broadband wireless products based upon the harmonized IEEE 802.16/ETSI HiperMAN standard [602].

WiMAX systems are composed of subscriber stations, base stations, interconnecting switches, and databases. WiMAX provides an alternative solution to ADSL for the "Final Mile" broadband Access.



Source: Advanced Network Module, www.bournemouth.ac.uk

6.2 History

6.2.1 Fixed Access

The IEEE 802.16 Group was formed in 1998. Its original focus was on Line Of Sight (LOS). The Original IEEE 802.16 standard was completed in 2001. An amendment to the standard produced IEEE 802.16a to include Non-Line of Sight (NLOS)

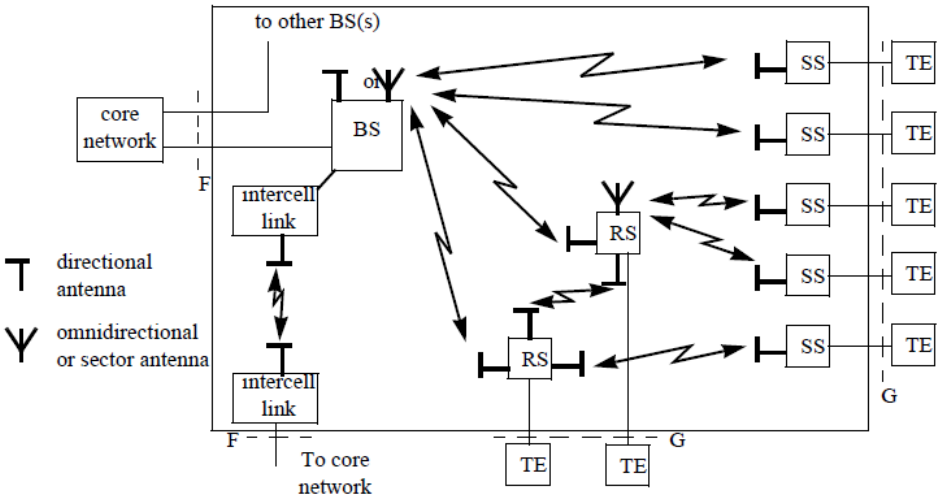
A revised standard, IEEE 802.16-2004 was produced for fixed subscribers.

6.2.2 Introduction of mobility

Subsequently in 2005, the IEEE 802.16e standard was produced to support mobile subscribers.

6.3 WiMAX

6.3.1 Fixed Broadband Wireless Access (FBWA)



Source [601] IEEE 802.16-2004 Reference diagram for FBWA systems

BS Base Station

RS Relay Station
SS Subscriber Station
TE Terminal Equipment (i.e. PC, Phone etc)

6.3.2 Spectrum

WiMAX can operate in the radio spectrum from 2GHz to 66GHz.

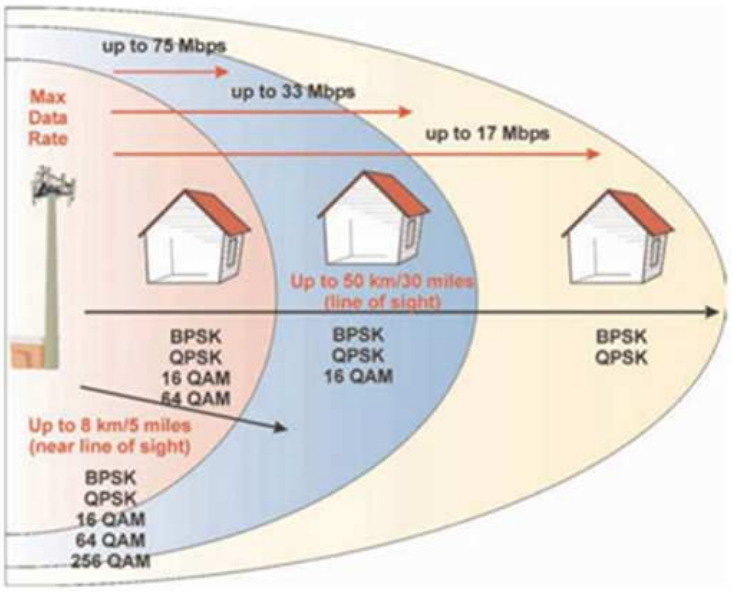
Though WiMAX can operate in the unlicensed spectrum, nearly all providers prefer to provide service in the licensed spectrum. The unlicensed spectrum can be unpredictable in terms of noise and interference and normally regulators insist that transmitters in this spectrum are very low power.

In the UK, Ofcom is the independent regulator and competition authority for the UK communications industries. Amongst its brief is the allocation/sale of radio spectrum. For example, Urban WiMAX which provides coverage in central London has 112MHz licence at 28.1925 and 29.2005MHz [604].

In America it is the Federal Communicate Commissions (FCC) that is responsible for allocating Spectrum.

6.3.3 Performance characteristics

Performance of WiMAX depends on the bandwidth allocated. For a typical 20MHz bandwidth, peak speeds of up to 75mbits^{-1} can be achieved.



Source [609] WiMAX Explained

6.3.4 Modulation in WiMAX

OFDMA

WiMAX uses Scalable Orthogonal Frequency Division Multiple Access (SOFDMA) for both the down and uplinks. WiMAX supports Frequency Division Duplex (FDD), Time Division Duplex (TDD) as well as adaptive Time Division Duplex. This means channel bandwidth can be divided in both the frequency and time domain and also between down links and uplinks.

Adaptive Modulation

On each of its sub-carriers, WiMAX uses adaptive modulation dynamically adjusting the modulation type of a communication channel based on specific criteria (e.g. signal quality – signal strength, interference and noise), dropping down from 256QAM near the base station down through BPSK at the edge of the cell.

Channel Bandwidth	Modulation	QPSK	QPSK	16 QAM	16 QAM	64 QAM	64 QAM
	FEC Coding	1/2	3/4	1/2	3/4	2/3	3/4
1.75 MHz		1.04	2.18	2.91	4.36	5.94	6.55
3.5 MHz		2.08	4.37	5.82	8.73	11.88	13.09
5 MHz		4.16	6.28	8.32	12.48	16.63	18.7
7 MHz		4.15	8.73	11.64	17.45	23.75	26.18
10 MHz		8.31	12.47	16.63	24.94	33.25	37.4
20 MHz		16.62	24.94	33.25	49.87	66.49	74.81

Source: "Wireless Broadband Spectrum Recommendation," A. N. Muragappan, June 2006

Source "Wireless Broadband Spectrum Recommendation," A. N. Muragappan, June 2006

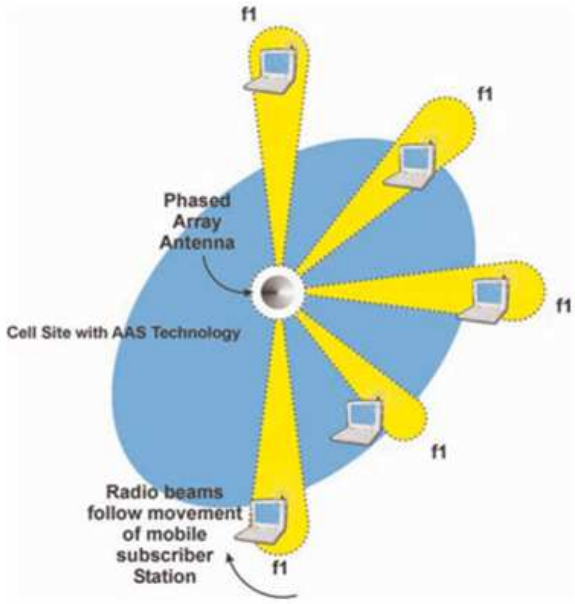
6.3.5 Sectoring, beam forming Diversity MIMO

Sectoring

WiMAX can re-use frequency within a cell by dividing the cell into sectors and positioning the base stations aerials in positions such that they form beams in particular directions. The frequency can be re-used between the individual beams.

Beam Forming

WiMAX can be built with Adaptive Antenna System (AAS). This is a form of sectoring where the beams follow the subscribers within a cell. Again, the frequencies can be re-used.



Source [609] Beam Forming, WiMax Explained

Diversity Transmissions

WiMAX uses diversity transmission (frequency, temporal and spatial) to improve the signal to noise ratio and extend the range of the base station. The subscriber station can combine the streams of information to build error free frames.

MIMO

WiMAX can use Multiple Input Multiple Output to either increase the throughput through spatial multiplexing or to improve signal to noise ration as stated above.

6.3.6 Network Topology

WiMAX networks can be point to point (this is normally used for backhaul network), Point to multipoint (i.e. Base Station to many Subscriber Stations) and mesh.

Mesh is where subscriber stations can be connected to multiple Base Stations and multiple base stations are connected to each other. This allows for redundancy, potentially better load balancing allowing packets to travel through many alternative routes.

6.3.7 Quality of Service (QoS)

WiMAX supports 5 classes of QoS in descending priority.

- Unsolicited Grant Services (UGS)
- real-time Polling Services (rtPS):
- extended real-time Polling Service (ertPS)
- non-real-time Polling Services (nrtPS):
- Best Effort Services (BES):

For example, Best Effort Service whereas Voice over Internet Protocol (VoIP) uses ertPS. (Use rtPS or UGS could be used but it would waste bandwidth as there are so many silences in speech)

QoS Category	Applications	QoS Specifications
UGS Unsolicited Grant Service	VoIP	• Maximum Sustained Rate • Latency Tolerance • Jitter Tolerance • Grant Interval
rtPS Real-Time Polling Service	Streaming Audio or Video	• Minimum Reserved Rate • Maximum Sustained Rate • Latency Tolerance • Traffic Priority
ertPS Extended Real-Time Polling Service	VoIP with Voice Activity Detection/ Silence Suppression	• Minimum Reserved Rate • Maximum Sustained Rate • Latency Tolerance • Jitter Tolerance • Traffic Priority
nrtPS Non-Real-Time Polling Service	File Transfer Protocol (FTP)	• Minimum Reserved Rate • Maximum Sustained Rate • Traffic Priority
BE Best-Effort Service	Data Transfer, Web Browsing	• Maximum Sustained Rate • Traffic Priority

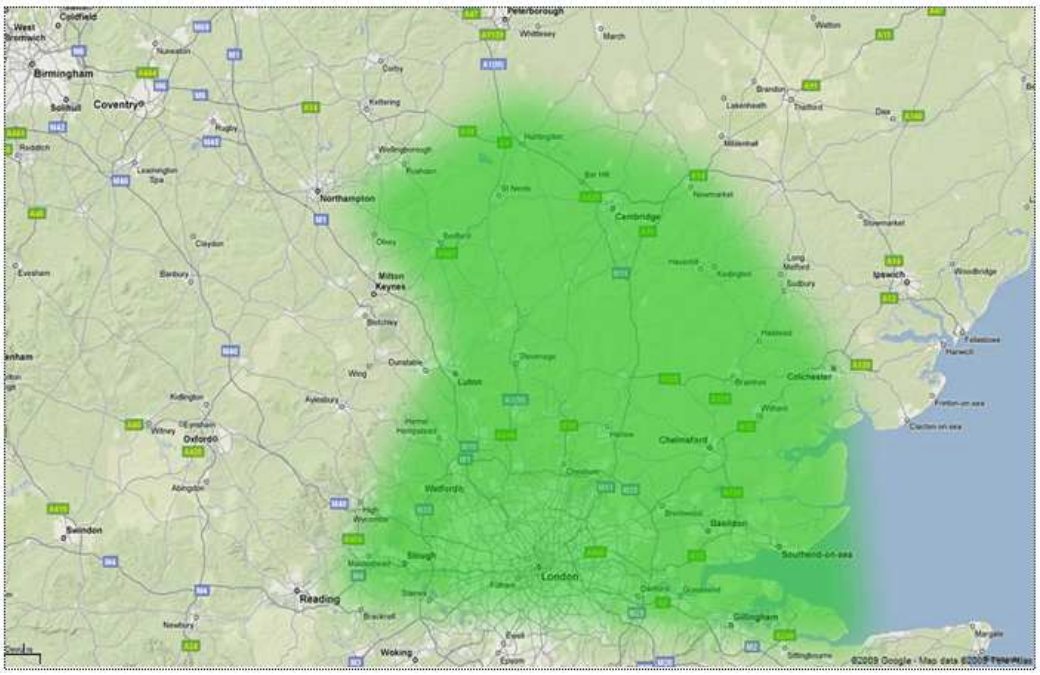
Source: "IP Design for Mobile Networks," Mark Grayson, Kevin Shatzkamer, Scott Wainner

Source [612]

6.3.8 WiMAX Coverage

In the UK, coverage of WiMAX is limited to 5 small service providers.

- Attend 2 Ltd, a WiMAX service that covers the South East of England.
- ConnectMK, Milton Keynes
- Digital Teesdale, Teesdale area in the North of England.
- LiveWave, Newcastle-upon-Tyne, Tynedale, Northumberland
- Urban WiMAX, Central London (travelcard Zone 1 and some of Zone 2).



Source [615] Attend 2 Ltd. Coverage

Rural UK Coverage

Digital Teesdale is backed by Durham County Council in conjunction with One North East. The Digital Teeside web site states that the WiMAX was a cost-effective method of providing broadband to rural locations. Speeds of up to $2Mbits^{-1}$ are now being offered. This contrasts with the project to cover Swindon with a 1,400 Wi-Fi-Mesh. This project has now been put on hold due to financial constraints.

Coverage in America is considerably more with Sprint and Clearwire leading the way.

WiMAX is also quite successful in developing countries where the roll out of fixed wire Broadband would very capital intensive.

6.4 Mobile WiMAX

IEEE 802.16e is the standard for mobile WiMAX. In practice, it is significantly different from Fixed WiMAX. Whereas the range from a Base station to a Subscriber unit could be up to 50Km, mobile subscriber units in a laptop or small mobile device are far less powerful and require Base stations every 3-5Km.[614]

It also requires greater technology in the Base Stations to allow for handover between cells. The modulation technique is also likely to be asymmetric with higher down link speeds than uplinks.

6.4.1 Costs of Mobile Coverage

Due to the number of base stations required and their added complexity, the cost of providing mobile WiMAX is much higher than providing fixed WiMAX.

Area covered by single sector base station with 90 degree antenna

WiMAX Solution		Range (Km)	Area (sq-Km)	Cost ($)	Cost/Area ($/sq-Km)	16e/16d
16d	pico BS	5	20	$1,850	$94	45
	pico BS	40	1257	$1,850	$1	2883
	Macro BS	5	20	$7,000	$357	12
	Macro BS	40	1257	$7,000	$6	762
16e	Macro BS	3	7	$30,000	$4,244	

$1,850 *Tranzeo TR-WMX-35-pBS
$7,000 *Aperto public pricing
$30,000 *Estimated Huawei 16e BS

Source [614]

UK Mobile WiMAX

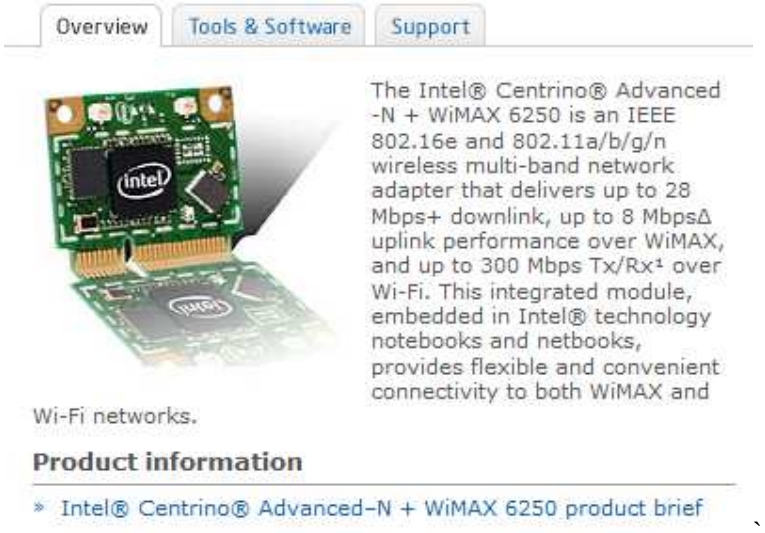
I could not find any evidence from any of UK WiMAX service providers of Mobile Coverage. – Though Nomadic coverage within a Cell was supported no true Mobile coverage was found.

6.4.2 Markets & Competition

Whereas Fixed WiMAX competes with DSL Broadband suppliers, Mobile WiMAX competes with 3G HSDPA in Mobile Telecommunications Market which has very large players (i.e. Vodafone, O2, T-Mobile).

6.4.3 Mobile Terminal Equipment

A brief survey in the UK market for Laptops with WiMAX built in showed very few devices available. Intel, a major backer of WiMAX has developed combined Wireless Wi-Fi-n and WiMAX cards (Note: WiMAX and Wi-Fi cannot be used simultaneously)



Source [604] Intel

The situation is different in the USA. The American Amazon web site advertises mobile WiMAX devices.

6.5 The Future WiMAX

6.5.1 Future Standards

The developing 802.16m standard offers new capabilities and efficiencies to meet the challenging International Mobile Telecommunications IMT-Advanced requirements.

Using 4x2MIMO in an urban microcell with a single 20MHZ channel the system will support 120Mbits^{-1} downlink and 60 Mbits^{-1} uplink.

The WiMAX Release 2 will incorporate improved latency, spectral efficiency and capabilities for VoIP. The WiMAX Forum hopes to see WiMAX release 2 commercially available within the 2011-2012 timeframe.

"As is evidenced here today, there is a broad ecosystem ready to deliver WiMAX as the first IMT-Advanced compliant technology to market," said Ron Resnick, president of the WiMAX Forum. "One of our top priorities is to bring WiMAX Forum Certified Release 2 networks and devices to market by the end of 2011. Even better, with double digit WiMAX deployment growth every month, the next release of WiMAX will have an even more substantial installed base upon which to build."[617]

7 LTE

7.1 History

7.1.1 Cellular Networks

The concept of cells was developed by Bell labs of the ISA in 1947. It allowed the capacity of the network to be increased substantially by dividing the coverage into small cells each with its own base station operating at a different frequency. Given that cells will have the same overall throughput capacity, cells in densely populated area will be of a reduced size whereas cells in more rural locations could span many kilometres.

7.1.2 First Generation Systems

The first commercial mobile networks were analogue and arrived in the 1980s. These developed independently and there was no global standard.[719]

- AMPS – Analogue Mobile Phone System – Used in America
- TACS – Total Access Communication System – Europe
- NMT – Nordic Mobile Telephone – Europe
- J-TACS – Japanese Total Access Communication System – Japan & Hong Kong

One advantage that these analogue systems had over their digital successor GSM was its range which made it ideal for sparsely populated areas

7.1.3 Second Generation Systems (2G)

Global **S**ystem for **M**obile communication (GSM) was developed collaboratively by companies working under the European Technical Standards Institute (ETSI). This was a digital, voice connection oriented system which allowed roaming across European countries. The first GSM network was launched in 1991 in Finland.

GSM uses Time Division Multiple Access (TDMA) to divide the carrier frequency into slots for individual phones use.

GSM has become the dominant standard for mobile telecommunications, offered in over 218 countries worldwide and having a coverage of over 80% of the world, with active GSM – *3GSM* subscriptions exceeding 4.5 billion [712, 713].

General Packet Radio Service (GPRS) was an enhancement to GSM standard developed by the 3rd Generation Partnership Project (3GPP). The class of a GPRS phone determines the speed at which data can be transferred. The class refers to the number of timeslots available for transmission of data. The maximum speed GPRS is 48K (for 5 Slots). [712]

Enhanced Data rates for GSM Evolution (**EDGE)** achieves higher data throughput by using more slots and higher encoding rate (8PSK) (i.e. 3 bits per symbol) giving a transmission rate of up to 473Kbits^{-1}. [712]

Evolved EDGE achieves even higher rates through, among other things, higher order modulation (16QAM and 32QAM) rates. Edge like GPRS will reduce its modulation and coding scheme according to the quality of the radio signal. [712]
GPRS and EDGE are a best effort service (i.e. there is no guaranteed quality of service as in a switched circuit). Several subscribers share the same bandwidth. I have experienced data rates as low as 25 Kbits^{-1} while connected to EDGE in spite of there being excellent signal quality.

7.1.4 Third Generation Systems (3G)

To offer third generation (3G) technologies, the 3GPP group developed Universal Mobile Telecommunication System (UMTS). UMTS is set up as part of the International Mobile Telecommunication (IMT) and its task is to specify the requirements of 3G technologies. UMTS has a completely new designed radio access network introducing Wideband Code Division Multiple Access *(WCDMA) [719]*.Currently, the 3GPP group has evolved UMTS in Releases 5, 6 and 7.

Release	Functional freeze	Main UMTS feature of release
Rel-99	March 2000	Basic 3.84 Mcps W-CDMA (FDD & TDD)
Rel-4	March 2001	1.28 Mcps TDD (aka TD-SCDMA)
Rel-5	June 2002	HSDPA
Rel-6	March 2005	HSUPA (E-DCH)
Rel-7	December 2007	HSPA+ (64QAM downlink, MIMO, 16QAM uplink) LTE and SAE feasibility study
Rel-8	December 2008	LTE work item – OFOMA/SC-FDMA air interface SAE work item – new IP core network Further HSPA improvements

Table 701: Evolution of the Universal Mobile Telecommunications (UMTS) specifications. Source [714] (Note: The Table does not include advance in GSM specification i.e. EDGE and EDGE+)

Mobile operators had to build entirely new networks and license entirely new frequencies (2100MHz), especially to achieve high-end data transmission rates of up to $2mbits^{-1}$ for stationary or near stationary users and $384kbits^{-1}$ for mobile users.

The UK Government scooped £22bn from the sale of licences for 3G. Many commentators view that the mobile operators paid too much for their licenses and left them without the funds to invest in their networks, leaving companies like Vodafone with the challenge of generating £600 pounds from each subscriber just to cover their £6bn 3G license costs.

High Speed Downlink Data Access (HSDPA) is an enhancement to 3G and is part of UTMS standards since release 5. High downloads speeds of $14Mbits^{-1}$ are achieved through higher order modulation 64QAM, reduced radio frame lengths and new functionalities within the radio networks [708].

HSDPA+ an evolution of HSPA was specified resulting from studies in Release 7 which added multiple input/ multiple output (MIMO) antenna capability and 16QAM (Uplink)/ 64QAM (Downlink) modulation.

In reality the speeds, observed by UK consumers is considerably lower. BBC News reported that consumers in towns in Britain were receiving between 1.7-3.6 $Mbits^{-1}$ for their down link connections.

With the advent of I-phones, tablets and other such sophisticated mobile devices and applications there is a requirement for ever higher bandwidth.

7.2 Long-Term-Evolution

7.2.1 LTE Introduction

The Long-Term-Evolution (LTE) project was started in November 2004 by 3GPP to develop a standard for the next generation cellular mobile technology. The first version of LTE is documented in Release 8 of the 3GPP Specifications.

The LTE stated requirements [711, 719] included

- Increased user data rates – *100Mbps^{-1} downlink, 50Mbits^{-1} uplink*
- Reduced connection time and plane latency – *<100ms connection time, <10ms two way radio round trip.*
- Lower cost per bit through spectral efficiency
- Simplified network architecture
- Greater flexibility in use of spectrum
- Seamless mobility – *sustained connections at speeds up 350km/h (for high speed trains)*
- Reasonable power consumption for user equipment.

LTE which involves the evolution of the Universal Terrestrial Radio Access Network (E-UTRAN) has been accompanied by a parallel 3GPP project called System Architecture Evolution (SAE) an all new IP packet based network known as Evolved Packet Core (EPC). Together LTE and SAE are referred to as the Evolved Packet System (EPS). However, in literature depending on the context, long term evolution LTE is often used to apply to both the LTE and SAE.

Another misnomer is that LTE is often referred to by suppliers, consumers and in the news as a 4th Generation (4G) systems. However LTE does not meet the International Mobile Telecommunication – Advanced (IMT-Advanced) specifications for 4G technologies. LTE-Advanced, is aimed to meet these standards.

LTE has been developed as an evolution of existing 3G technologies. This allows for a simplified, less expensive upgrade from the existing network technology.

7.2.2 LTE and SAE

LTE and SAE were developed to support packet switched services rather than circuit switched services as was the case in the earlier models on cellular networks. This trend to focus on data rather than voice started with 3G. LTE and SAE is entirely Internet Protocol based. In contrast to GSM and 3G where the User Equipment (UE) was allocated temporarily an IP address for data transmissions, in LTE the UE is permanently allocated an IP address. (In GSM and 3G the UE could be reached over circuit switched network). In LTE, without an IP address the UE cannot be reached.

At High level, LTE the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) consists of evolved NodeB (eNB) or base station whereas the evolved packed network consists of several logical nodes.

- PDN-Gateway (P-GW). The Packet Data Network Gateway is responsible for IP address allocation for the User Equipment (UE) as well as the Quality of Service (QoS) enforcement.
- Serving Gateway (S-GW). All user packets are transferred via the serving gateway. It serves as the anchor for bearers as users move from eNodeB to eNodeB (i.e. Base Station to Base Station)
- Mobility Management Entity (MME).

7.2.3 LTE Quality of Service

LTE is implemented on IP based network. The importance for Quality of Service (QoS) when sharing resources between critical and non-critical data transfer is very high. Applications like VoIP do not tolerate delayed packets where application like email would be perfectly happy with a best effort service.
Release 8 offers a classed based QoS concept for delivering real time and non-real time traffic, with current and future QoS in mind. A network initiated QoS system is implemented offering control based on Guaranteed Bit Rate (GBG) and Non-Guaranteed Bit Rate (Non-GBG) [714].

7.2.4 LTE Radio Architecture

Downlink and OFDM

New Radio Spectrum cannot be invented only used more efficiently. On the downlink LTE uses Orthogonal Frequency Division Multiple Access (OFDMA). This is a variant of Orthogonal Frequency Multiplexing (OFDM). In OFDM carriers are made orthogonal by the use of a Fourier Transform. This allows for a large number of closely spaced orthogonal carriers that can be transmitted in parallel.

Each subcarrier is modulated using QSPK, 16QAM or 64QAM (providing 2, 4 and 6 bits per symbol). Link adaptation is used to determine data rate or error probabilities by adapting modulation and channel coding schemes to current channel conditions.

OFDMA is more efficient than Wideband Code Division Multiple Access (WCMA) used in UMTS 3G. The European Telecommunications Standards Institute (ETSI) first looked at OFDM for GSM back in the late 1980s however, the processing power required to perform the many Fast Fourier Transforms (FFT) operations at was too expensive. In 1998 the 3GPP seriously considered OFDMA for 3G UMTS but the decision went in favour of WCDMA. Today, cheap computing power has made OFDMA viable [714, 719].

Uplink and SC-FDMA

One of the main disadvantages of OFDMA is the high Peak Power to Average ratio of the signal. This requires powerful amplifiers for the sending device making it unsuitable for user equipment. This led the 3GPP to choose Single Carrier Frequency Division Multiple Access (SC-FDMA) for the uplink. Having an efficient (energy) transmission scheme ensures that the mobile devices with little power available are both efficient and cost effective. [710,714]

MIMO

To increase throughput, LTE uses spatial multiplexing, a technology that uses two multi-antenna transmissions: Transmit Diversity and Multi-stream Transmission. At both network and user level, Multi-stream Transmission uses multiple antennas in order to provide increased peak data rate. This is achieved by simultaneous transmissions over a single radio link. Multilayer antenna solutions also generate High peak rates, for example 2x2 or 4x4 multiple in multiple out (MIMO). Extended coverage is achievable by beam forming.

Multi User scheduling

The eNodeB is responsible for managing the resources for both the uplink and down link channels. The objective is to fulfil the expectations of many users while meeting the QoS requirements of their applications.
Two extremes of scheduling are opportunistic scheduling and fair scheduling. Opportunistic scheduling attempts to maximise the data transferred by the entire network whereas fair scheduling pays more attention to the latency for each user rather than total data achieved through the network.

7.3 LTE Advanced

Even though LTE is a high speed data network it does not meet the standards set by IMT-Advanced for 4G technology.

Release 10 from 3GPP, a project known as Long-Term-Evolution-Advanced (LTE-Advanced) is designed to be 4G technology meeting IMT-Advanced requirements.

The 3GPP LTE-Advanced will

- Enhanced Data rates –
    - peak data rates of $1Gbs^{-1}$ downlink and $500mbs^{-1}$ low mobility
    - and $100Mbs^{-1}$ high mobility
- LTE Advanced should be able to aggregate non contiguous carriers (a bandwidth of 100MHz is likely to be required to achieve $1Gbs^{-1}$ downlink, this spectrum may not be found contiguously)

- High order spatial multiplexing (MIMO) up to eight transmit aerials and for receive aerials at the enodeB
- Coordinated MIMO schemes involving multiple cells to improve overall spectral efficiency.
- The use of relays nodes to improve data rates to edge of cell users
- Backwards compatibility, mobility between LTE-Advanced, LTE, GSM/EDGE, HSPA and CDMA200.

7.4 Implementation of LTE and 4G

7.4.1 First implementation of LTE

Nordic carrier TeliaSonera deployed what it claims are the world's first two commercial LTE networks in December 2009 in Stockholm and Oslo, offering maximum throughput speeds of 100Mbits/s. Ericson provided Swedish network whereas the Norwegian kit was provided by Chinese vendor Huawei.[715]

7.4.2 Strategies for implementing LTE

It is envisaged that carriers will adopt several strategies for implementing LTE. Some will implement data over LTE while using the older 3G and 2G networks for voice. Nearly all of them will have a fall back strategy of fall back HSDPA and EDGE for areas where no LTE coverage

7.4.3 Comparison of LTE with other technologies

In the 3G and HSDPA world service providers always prefer the customer to connect to their WI-FI hotspots in preference to their 3G and HSDPA networks. This gives an indication of the relative costs and performance of proving these services. It is unlikely that the cost model will change even with the introduction of LTE. Wide area license radio spectrum is likely always to be at a premium.

Probably more interesting, is to compare LTE with WiMAX. The initial release of WiMAX was not mobile but with the release of IEEE 802.16e, WiMAX gained mobile

capabilities. A comparison of the technologies and the business model is given in section 9.2.

7.4.4 Sale of 4G licenses in the UK

On 22nd March 2011, Ofcom the telecoms regulator launched a consultation on how best to sell off the rights to the next generation of mobile wireless networks. [717,718]

There are two blocks of frequency to be sold off. One block in 2.6 GHz band and the other in the lower frequency of 800MHz band a spin off from the migration from analogue to digital TV. The bandwidth being sold off is 80% more than what was sold in 3G auction in 2000. [718]

It is unlikely that that the Government will raise the £22 billion it raised through the sale of 3 G licenses. The German auction of 4G licences last year raised 4.3Bn Euros as against the 50bn Euros it raised from the sale of 3G licenses in 2000 .[716]

Most telecoms analyst believe that mobile providers over paid for 3G licences in 2000 [701,702,703,704,705]

7.5 Conclusion

Provided LTE and LTE Advanced live up to the hype and deliver the throughput in the specifications, they will radically change the way we conduct our working and social lives. The high data speed they will offer, will allow businesses to have more mobile and remote work force.

With the integration of high speed mobile devices into cars, it will allow better traffic management (Even with today's technology, Honda was able to open up its navigation systems after the Japanese earthquake to show what routes in northern Japan were open). Integration of LTE into vehicle entertainments systems will provide the ability for video conferencing, sharing of data and other collaborative activities.

Investment is essential to LTE and LTE-advanced. The Mobile operators must over pay for their 4G licences.

LTE provides an upgrade path from the currently deployed 3G and 2G Technologies

8 Comparison and Conclusion

8.1 Comparison between Wi-Fi and WiMAX

In general Wi-Fi and WiMAX complement each other rather than compete against each other.

Wi-Fi has been one of the great successes of the computer industry. Wi-Fi operates in the unlicensed band and is designed to provide wireless access to a small area. The technology can operate with other Wi-Fi networks competing for the same bandwidth. Though WiMAX can work in the unlicensed spectrum nearly all operators prefer to provide services from the licensed spectrum where they are guaranteed to be the only company using that bandwidth. Fixed WiMAX is positioned to compete against ADSL broadband providers. This is particularly true in rural areas and developing countries. It is said that WiMAX broadband service was the first to recover after the Asian Tsunami in Indonesia.

Where WiMAX and Wi-Fi do compete is in Wi-Fi meshes. Widespread Wi-Fi meshes on the whole have been unsuccessful – Swindon Project being one example. The Swindon Wi-Fi mesh project has been put on hold whereas the Teesdale WiMAX project is forging ahead. [901, 902, 903]

8.2 Comparison between WiMAX and LTE

The fundamental differences between the 2 technologies arise from the fact that they come from very distinct business quarters, each driven by different and sometimes opposing priorities. [906]

WiMAX is essentially driven by the Computer Industry with companies like Intel being big backers. It is based on the requirements for computers and is therefore architected for PCs. The fact that it has shrank in size to make it portable has been an added, secondary consideration.

LTE, on the other hand, has emerged from the Telecommunications Community. To all intents and purposes, it is a telephone for making calls. However, it has also evolved becoming more and more versatile in its uses. The convergence between the two has been coincidental with WiMAX end user devices becoming more “mobile” and LTE phones (e.g. I-phone) becoming “smarter”.

In the WiMAX business approach, goods are sold and services are subsidised while the LTE business approach does precisely the opposite. Goods like the PC, laptops etc have to be purchased whereas the services like Google are subsidised through advertising revenue.

In the Telecommunications sector however, it is the cost of the hardware that gets subsidised. As a result, the telephones and handsets themselves cost very little and even upgrades are available for next to nothing. It is the services and subscription contracts that generate the income and “talk time” is paid for by the minute.

Another difference lies in the nature of the architectures which are poles apart. In the Telecommunications architecture, the Value Added Services are crucially important. They have to be secure, customer care and support services matter and reliability is of the utmost importance. In contrast, the WiMAX architecture is based on IP and is relatively flat. There are no fiddly servers and the customers remain largely unknown. The concern has to be about the BIT PIPE and even then, it only has to be a “best effort” pipe. These differences mean that the competing technologies have different potentials and advantages in different market scenarios.

8.3 Comparison between my e-learning tool and traditional methods

The objective of the project was to produce an e-learning tool that would help students understand the complex concepts in Wi-Fi, WiMAX and LTE.

It was to encourage independent learning and to improve outcomes. To achieve this, the tool had to be engaging, different, full of practical examples and present the information in a multifaceted way. The tool includes video, audio and flash animations. It is hoped

that the variety will cater for a range of preferred learning styles and provide a blended learning experience.

I have tried to take the student along the journey of discovery that I took in learning the subject, showing them videos of the 3G masts I visited, the tests I carried out to improve the Wi-Fi performance in my flat by switching from 2.4GHz to 5GHz. I also showed the frustrations that I had with my HSDPA connection speeds being down at $1Mbits^{-1}$ instead of the advertised 7.2 [904, 905]. The hype on the peak rates that LTE-Advanced and WiMAX 2 offer must be taken with caution. LTE-Advanced and WiMAX 2 will definitely be faster than today's technology but it is unlikely that the end user will see the $100Mbits^{-1}$ that is currently being bandied about

Finally I hope that future students will enjoy my tool as much I did developing it.

9 Appendices

9.1 Ethics Checklist

Initial Research Ethics Checklist

Note: ***All researchers*** must complete this brief checklist to identify any ethical issues associated with their research. Before completing, please refer to the BU Research Ethics Code of Practice which can be found at http://www.bournemouth.ac.uk/researchethics/. School Research Ethics Representatives (or Supervisors in the case of students) can advise on appropriate professional judgement in this review. A list of Representatives can be found at the aforementioned webpage.

Sections 1-5 must be completed by the researcher and Section 6 by School Ethics Representative/ Supervisor prior to the commencement of any research.

1. RESEARCHER DETAILS	
Name	Keith Amoah
Email	f9016515@bournemouth.ac.uk
Status	Undergraduate
School	DEC
Degree Framework & Programme	BSC Software System Framework Multimedia communications systems

2. PROJECT DETAILS	
Project Title	Developing learning material for computer networks
Project Summary	For my project, I am developing learning material for computer networks on behalf of my client, Dr Reza Sahandi. The learning material is in the form of a multimedia presentation and will focus on topics of WiMAX, LTE and Wi-Fi. The presentation will be about 30 minutes long and is intended to be used as a tool to help students understand computer networks. Approach:To conduct

	research on existing multimedia presentations on the topic Research relevant material for inclusion in the presentation Develop a multimedia presentation to include animations illustrating network operations To evaluate the multimedia presentation from survey with students Improve presentation where possible and repeat process until satisfy with presentation. Write up a report
Proposed Start & End Dates	10/02/2011 to 22/04/201
Project Supervisor	Dr Mathenge Kanyaru
Framework Project Co-ordinator	Software System, Developing learning material for computer networks, Dr.F.Milsom

3. ETHICS REVIEW CHECKLIST – PART A		
I	Has a health & safety evaluation / risk assessment been conducted?	No
II	Is approval from an external Research Ethics Committee (e.g. Local Research Ethics Committee (REC), NHS REC) required/sought?	No
III	Is the research solely literature-based?	Yes
IV	Does the research involve the use of any dangerous substances, including radioactive materials?	No
V	Does the research involve the use of any potentially dangerous equipment?	No
VI	Could conflicts of interest arise between the source of funding and the potential outcomes of the research? (see section 8 of BU Research Ethics Code of Practice).	No
VII	Is it likely that the research will put any of the following at risk: Living creatures? Stakeholders? The environment? The economy?	 No No No No
VIII	Does the research involve experimentation on any of the following: Animals? Animal tissues? Human tissues (including blood, fluid, skin, cell lines)? Genetically modified organisms?	 No No No No
IX	Will the research involve prolonged or repetitive testing, or the collection of audio, photographic or video materials?	No
X	Could the research induce psychological stress or anxiety, cause harm or have negative consequences for the participants or researcher (beyond the risks encountered in normal life)?	No
XI	Will the study involve discussion of sensitive topics (e.g. sexual activity, drug use, criminal activity)?	No
XII	Will financial inducements be offered (other than reasonable expenses/ compensation for time)?	Yes
XIII	Will it be necessary for the participants to take part in the study without their knowledge /	No

	consent at the time?	
XIV	Are there problems with the participant's right to remain anonymous?	No
XV	Does the research specifically involve participants who may be vulnerable?	No
XVI	Might the research involve participants who may lack the capacity to decide or to give informed consent to their involvement?	No

4. ETHICS REVIEW CHECKLIST – PART B

Please give a summary of the ethical issues and any action that will be taken to address these.

Ethical Issue:	**Action:**
None	None

5. RESEARCHER STATEMENT

I believe the information I have given is correct. I have read and understood the *BU Research Ethics Code of Practice*, discussed relevant insurance issues, performed a health & safety evaluation/risk assessment and discussed any issues/concerns with a School Ethics Representative/ Supervisor. I understand that if any substantial changes are made to the research (including methodology, sample etc), then I must notify my School Research Ethics Representative/ Supervisor and may need to submit a revised Initial Research Ethics Checklist. By submitting this form electronically I am confirming the information is accurate to my best knowledge.

Signed: Keith Amoah	**DATE:** 28-11-2010

6. AFFIRMATION BY SCHOOL RESEARCH ETHICS REPRESENTATIVE/SUPERVISOR

Satisfied with the accuracy of the research project ethical statement, I believe that the appropriate action is:

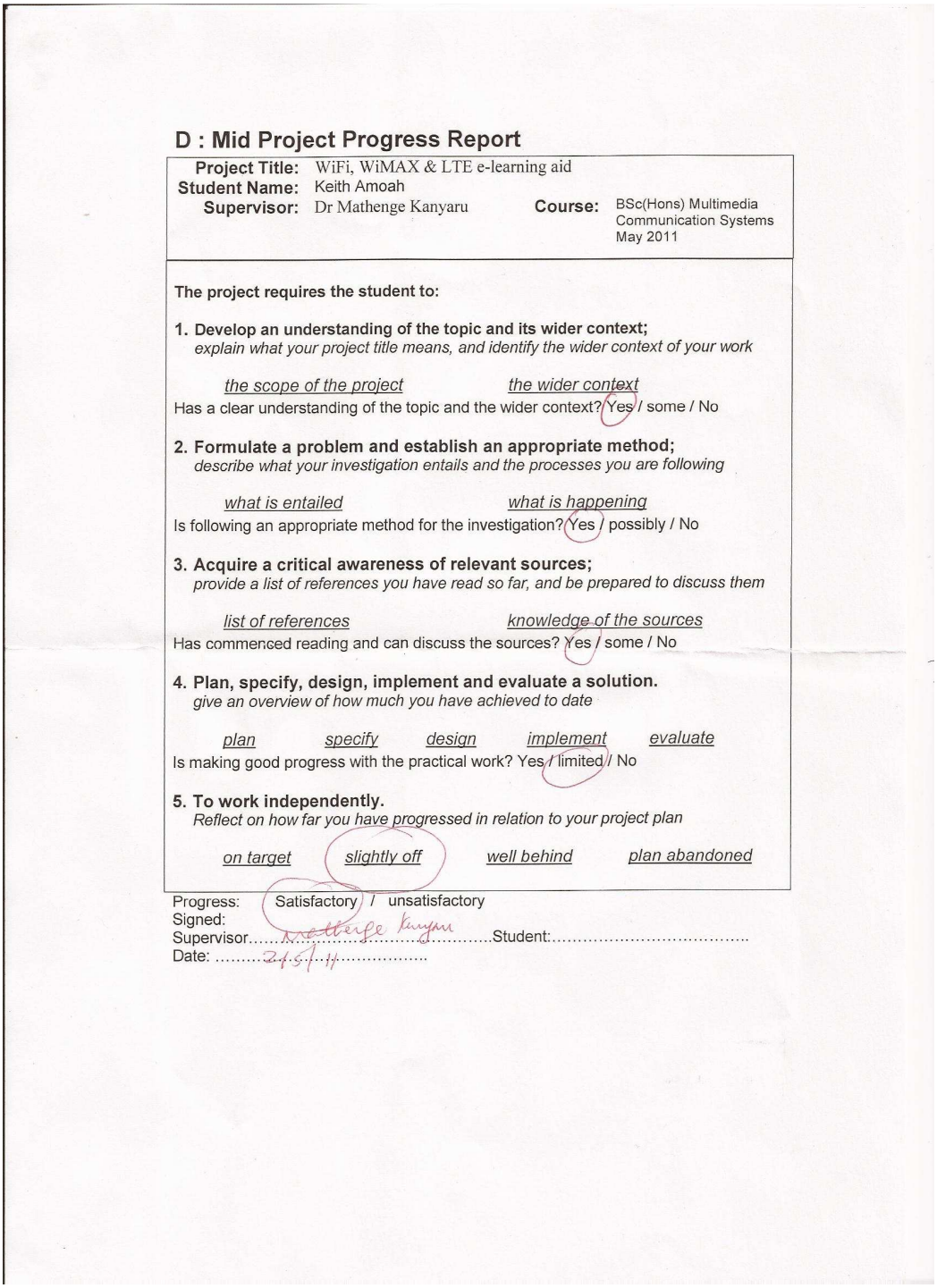
The research project proceeds in its present form	**YES**
The research project proposal needs further assessment under the School Ethics procedure*	**NO**
The research project needs to be returned to the applicant for modification prior to further action*	**NO**

** The School is reminded that it is their responsibility to ensure that no project proceeds without appropriate assessment of ethical issues. In extreme cases, this can require processing by the School or University's Research Ethics Committee or by relevant external bodies.*

Reviewer Signature: Mathenge Kanyaru	**Date:** 02/05/2011

Additional Comments:

9.2 Progress Report



D : Mid Project Progress Report

Project Title: WiFi, WiMAX & LTE e-learning aid
Student Name: Keith Amoah
Supervisor: Dr Mathenge Kanyaru **Course:** BSc(Hons) Multimedia Communication Systems May 2011

The project requires the student to:

1. **Develop an understanding of the topic and its wider context;**
   explain what your project title means, and identify the wider context of your work

   the scope of the project *the wider context*
   Has a clear understanding of the topic and the wider context? Yes / some / No

2. **Formulate a problem and establish an appropriate method;**
   describe what your investigation entails and the processes you are following

   what is entailed *what is happening*
   Is following an appropriate method for the investigation? Yes / possibly / No

3. **Acquire a critical awareness of relevant sources;**
   provide a list of references you have read so far, and be prepared to discuss them

   list of references *knowledge of the sources*
   Has commenced reading and can discuss the sources? Yes / some / No

4. **Plan, specify, design, implement and evaluate a solution.**
   give an overview of how much you have achieved to date

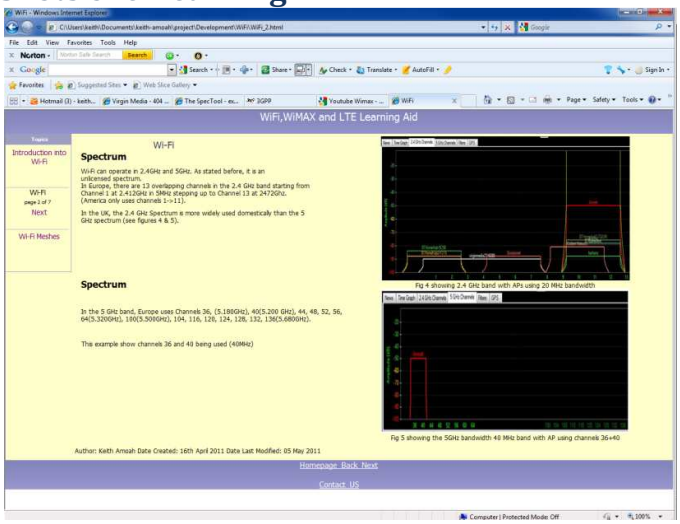
   plan *specify* *design* *implement* *evaluate*
   Is making good progress with the practical work? Yes / limited / No

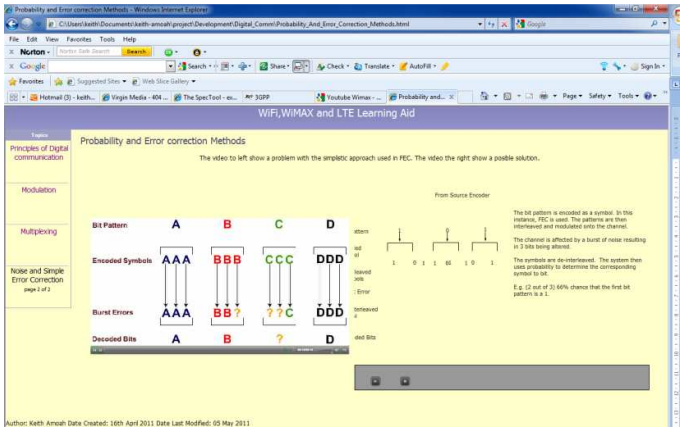
5. **To work independently.**
   Reflect on how far you have progressed in relation to your project plan

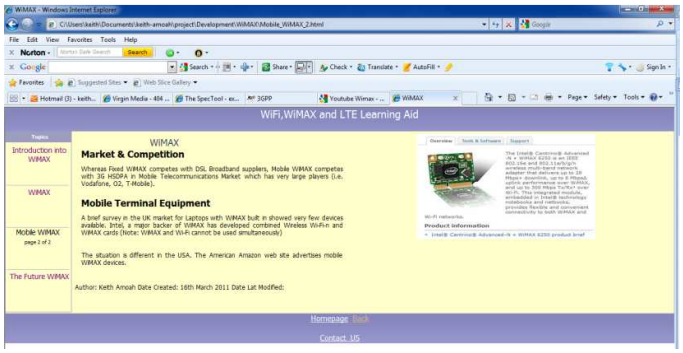
   on target *slightly off* *well behind* *plan abandoned*

Progress: Satisfactory / unsatisfactory
Signed:
Supervisor: Mathenge Kanyaru Student:
Date: 24/5/11

9.3 Screen Shots of e-Learning







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10.2 Methodology

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11 List of Abbreviations

3GPP - 3rd Generation Partnership Project
AAS - Adaptive Antenna System (AAS).
AMPS – Analogue Mobile Phone System
CSMA/CA - Carrier Sense Multiple Access with Collision Avoidance
E – UTRAN –Universal Terrestrial Radio Access Network (E-UTRAN)
EDGE - Enhanced Data rates for GSM Evolution
EIRP - Equivalent Isotropically Radiated Power
EPC - Evolved Packet Core .
ETSI - European Technical Standards Institute
FBWA – Fixed Broadband Wireless Access
FCC - Federal Communications Committee
FDD - Frequency Division Duplex
FDM - Frequency Division Multiplexing
FDMA - Frequency Division Multiple Access
GPRS - General Packet Radio Service
GSM - Global **S**ystem for **M**obile communication (GSM)
HSDPA - High Speed Downlink Data Access
IMT - International Mobile Telecommunication
J-TACS – Japanese Total Access Communication System
LOS - Line Of Sight
LTE - The Long-Term-Evolution
MIMO - multiple in multiple out
MME - Mobility Management Entity
NLOS - Non-Line of Sight
NMT – Nordic Mobile Telephone
OFDM - Orthogonal Frequency Multiplexing
OFDMA - Orthogonal Frequency Division Multiple Access
PEAP - Protected Extensible Authentication Protocol
QoS – Quality of Service

- Best Effort Services (BES):
- extended real-time Polling Service (ertPS)
- non-real-time Polling Services (nrtPS):
- real-time Polling Services (rtPS):
- Unsolicited Grant Services (UGS)

SAE - System Architecture Evolution
SC-FDMA - Single Carrier Frequency Division Multiple Access
SSID – Service Set Identifier
SOFDMA - Orthogonal Frequency Division Multiple Access
TACS – Total Access Communication System

TDD - Time Division Duplex
TDM - Time Divison Multliplexing
TDMA - Time Division Multiple Access
TDMA - Time Division Multiplexing Access
TKIP - Temporal Key Integrity Protocol
UMTS - Universal Mobile Telecommunication System
WCDMA - Wide Code Division Multiple Access
WCDMA - Wideband Code Division Multiple Access
WCMA - Wideband Code Division Multiple Access (WCMA)
WEP - Wired Equivalent Privacy
WiSM - Wireless Service Module
WiMAX - Worldwide Interoperability for Microwave Access
WPA -Wi-Fi Protected Access

End of Report – No more pages