Performance-aware Multimedia-based E-Leaning over Broadband Wireless Networks

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Abstract. This paper compares theoretically and practically the performance of a number of broadband wireless technologies when used for streaming high quality multimedia. Simulations that involve IEEE802.11a, IEEE802.11b and IEEE802.11g standards respectively assess the effect of range, user mobility and the increase in number of simultaneous subscribers on the multimedia streaming quality. In this context average throughput, packet loss and delay are compared.

1. Introduction

With the increasing penetration of broadband connectivity to homes and businesses, high quality rich multimedia-based services such as interactive TV, Video on Demand and gaming are getting more popular among users. At the same time wireless technologies provide advantages such as flexibility of viewer location, mobility and convenience that are determining many customers to use them for distribution of many services. Recently it seems that these two trends are merging in order to support the distribution of rich content, such as multimedia, to users anywhere, anytime and to any device, including personal computers, handheld electronics and smart phones.

Wireless technologies have evolved rapidly in recent years. The limited number of low use, very specialised technologies which existed years ago have been succeeded by a whole range of commercially available systems ranging from the original IEEE 802.11 standard offering up to 2Mbps to the proposed Ultra Wideband (UWB) technology which aims to provide transmissions in the region of 450Mbps. The growing confidence in the benefits offered by wireless technologies is evident from the findings of a Forrester report which stated that 77% of public sector firms and 60% of all enterprises planned to increase their deployment of Wireless LAN (WLAN) technology in the next twelve months [1]. Along with efforts to deploy WLANs, significant efforts are targeted towards

Wireless Metropolitan Area Networks (WMANs) and Wireless Personal Area Networks (WPANs). WMAN is used to offer high bandwidth network connections to an area around the size of a city through the use of roof-mounted antennas. WPANs on the other hand are designed for very short distances to allow devices in close proximity of each other to communicate without the need for wires.

This paper compares theoretically and practically the performance of a number of broadband wireless technologies when used for multimedia-based e-learning. It starts with a theoretical comparison of the standards from the IEEE802.11 family, IEEE802.16 family and the emerging UWB. The paper then studies practically, with the aid of the OPNET modeller and the associated wireless network simulator module [2], how the existing IEEE wireless standards: IEEE802.11a, IEEE802.11b and IEEE802.11g support high quality multimedia-based e-learning. Average packet loss, delay and throughput are computed and presented for each wireless technology under various scenarios. These scenarios assess the effect of user mobility and increase in number of simultaneous users on the quality of multimedia streaming. The paper ends with a presentation of the conclusions drawn and possible future work directions.

2. Broadband Wireless Technologies

The desire for systems that offer improved flexibility and mobility has stimulated people into considering wireless technologies as viable alternatives to the traditional wired networks. Wireless technologies also offer the potential of low deployment costs and broadband bandwidth capability. However the increased interest in the area has resulted in the necessity to develop new standards to cope with the consumers growing needs. As various bodies develop these new standards it is important that at all times the spectrum allocation process is carefully monitored and controlled. Loose regulation may accelerate the expansion of the WLAN market but could also create interference problems; by contrast strict regulation could allocate the spectrum well but might impede market development [3]. Therefore a compromise between these two tendencies seems appropriate.

2.1 802.11 Family

The 802.11 family started with the original 802.11 standard, comprises 802.11a, 802.11b, 802.11g and other proposals and now is the most popular group of wireless standards. It was initially developed to be a simple and cost-effective replacement for existing wired networks and to offer other potential services not possible with previous technologies.

Before the creation of 802.11 very few wireless standards existed and those that did were not widely implemented as they offered very little practical benefits. However in 1985 the Federal Communications Commission of the United States authorized three Industrial, Scientific and Medical (ISM) frequency bands. These ISM bands accelerated the development of WLANs because vendors no longer needed to apply for licenses to operate their products. In 1989, the IEEE 802.11 Working Group began elaborating on the Wireless LAN Medium Access Control (MAC) and Physical Layer specifications [3]. The IEEE802.11 WLAN standard was approved in June 1997 with data rates of 1 and 2Mbps [4].

The IEEE802.11 standard specifies two possible network configurations: Ad-hoc and Infrastructure. Ad-hoc networks require no base station. Devices discover others within range to form a network. Devices may search for target nodes that are out of range by flooding the network with broadcasts that are forwarded by each node. Infrastructure configuration relies on the fact that a base station acts as a central point between two or more wireless devices. The base station controls all traffic and communications on the network and therefore between the inter-networked devices.

IEEE802.11 makes use of the 802 Logical Link Control (LLC) protocol but specifies its own specialised physical layer and MAC sub-layers. The 802.11 MAC supports two basic medium access protocols: contention-based Distributed Coordination Function (DCF) and optional Point Coordination Function (PCF). When PCF is enabled, the wireless channel is divided into super-frames. Each super-frame consists of a Contention-Free Period (CFP) for PCF and a Contention Period (CP) for DCF. [5] The DCF setup can also be known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and is generally used in the case of Ad-hoc networks. PCF on the other hand is only used in the case of an Infrastructure setup.

The 802.11 standard specifies two physical layers: Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS) [5], both of which operate on the 2.4GHz ISM band. DSSS provides 2Mbps of peak rate and optional 1Mbps in extremely noisy environments. The FHSS physical layer operates at 1Mbps with optional 2Mbps in very clean environments. In addition to the radio frequency (RF) physical layer, an infrared (IR) physical layer is also specified. The IR physical layer supports both 1Mbps and 2Mbps for reception, and 1Mbps with an optional 2Mbps bit rate for transmission. The IR physical layer uses the reflected infrared energy for communications, which is called diffuse infrared transmission. A typical range of 10 m imposes strict limitations to IR wireless systems and therefore the RF techniques are generally preferred [3].

2.1.1 802.11b

On the 16th of September 1999 the 802.11b standard was introduced, promising interoperability among products of different vendors and compatibility with legacy 802.11 products [3]. It is often referred to as Wi-Fi, a term promulgated by the Wireless Ethernet

Compatibility Alliance (WECA). Products certified as Wi-Fi are interoperable with each other even if they are from different manufacturers.

Like its predecessor 802.11b operates in the 2.4 GHz ISM band. The standard uses DSSS, Time Division Duplexing (TDD) and digital modulation of Differential Binary Phase Shift Keying (BPSK), Differential Quadrature Phase Shift Keying (QPSK), and Complementary Code Keying [6]. It allows for higher data speeds (transmission rates of 1,2,5.5 and 11Mbps) and is less susceptible to multipath-propagation interference. Its sensitivity varies from -83 to -76dBm [7].

Although IEEE802.11b is the most popular form of WLAN, it does have problems. As the 2.4GHz ISM band is also utilised by medical equipment, household appliances (e.g. cordless telephones and microwaves) as well as newer technologies such as Bluetooth, major interference problems can occur [3].

2.1.2 802.11a

O With the aim of solving the radio interference problem in 802.11b the IEEE created an additional 802.11 standard which makes use of an alternative frequency band. The 802.11a standard, introduced in September 1999, operates in the 5GHz unlicensed national information infrastructure bands.

The standard allows high-speed data transfers of 6,9,12,18,24,36,48 and 54Mbps, between computer systems and various peripheral devices at speeds approaching that of fast wired local area networks [8]. The standard makes use of Orthogonal Frequency Division Multiplexing (OFDM), TDD and digital modulations of BPSK, QPSK, 16QAM and 64QAM [9]. The higher levels of modulation yield higher data rates but lower sensitivity due to limited signal energy per bit, this results in sensitivity ranging from -81 to -65dBm [7].

However 802.11a does have a number of disadvantages. As it operates in the 5GHz band, it is incompatible with the previous 802.11 and 802.11b standards which operate in the 2.4GHz band. This means that companies or individuals wishing to upgrade from the previous standards to benefit from improved transfer speeds and reduced interference must replace all existing products with the new 802.11a products. In addition to this, the 5GHz band in which the standard operates is not license-free in every country.

2.1.3 802.11g

O As a result of the problems with 802.11a it became desirable to create a standard that offered the improved data transmission rates of the standard whilst still maintaining backward compatibility with the existing 802.11 and 802.11b products. For that reason the IEEE proposed the 802.11g standard in November 2001 and was formally ratified in June 2003. Like 802.11a it is based on OFDM but instead uses the 2.4GHz ISM band. The standard specifies transmission rates of 6,12,24,36,48 and 54Mbps, similar to 802.11a. However, since 802.11g uses the same spectrum between 2.4 and 2.4835GHz and is inherently backward compatible with 802.11b, it is attracting more attention from industry than the earlier standardized 802.11a [5, 10].

2.1.4 Emerging Standards

Existing IEEE802.11 standards are designed for best effort services only. The lack of a built-in mechanism for support of real-time services makes it very difficult to provide Quality of Service (QoS) guarantees for throughput-intensive and delay-sensitive multimedia applications [5]. In this context it is hoped that the emerging IEEE802.11e standard will provide QoS capabilities that can be used to improve end-user perceived quality by allowing for dynamic prioritisation of multimedia services. Part of the same family, IEEE802.11i is concerned on the security, 802.11n - on improvements for achieving higher throughput; 802.11h looks at spectrum management, etc.

2.2 802.16 Family

IEEE Working Group 802.16 on Broadband Wireless Access Standards [11] has proposed the original IEEE 802.16 standard in December 2001 (ratified on the 8th April 2002) that specifies details about fixed point-to-multipoint broadband wireless systems operating in 10-66GHz licensed spectrum.

The 802.16 standard or WiMax (Worldwide interoperability for Microwave access) is the basis for WirelessMAN, a wireless communication network spanning a large area, similar in size to an average large city. It provides network access to buildings through exterior antennas communicating with central radio Base Stations (BS). WiMax offers an alternative to cabled access networks, such as fibre optic links, coaxial systems using cable modems, and digital subscriber line (DSL) links [11]. One of most appealing aspects of the WiMax standard is the ability to quickly and relatively cheaply set up the network infrastructure required to supply a large area with high bandwidth access. By installing a small number of base stations on tall buildings or elevated ground around the area, a wireless system can be installed in a matter of weeks as opposed to the months or years required for a traditional system. As well as the improved instillation speed the system also reduces the cost and disruption of instillation when compared to traditional systems where roads and hence traffic would have to be disturbed for the laying of the necessary physical infrastructure.

WiMax has a long transmission range (up to 31 miles) because regulations allow WiMax systems to transmit at high power rates and because the directional antennas produce focused signals [12]. This helps to bring network access to an entire building, users inside it connecting via conventional Ethernet (IEEE802.3) or wireless LANs (IEEE802.11) [11]. A variation is currently being developed whereby individual interior antennas could be used to connect to the network, removing the need for users to connect to a rooftop antenna.

WiMax allows data transport over multiple broad frequencies maximizing its ability to avoid interference with other wireless applications. WiMax technology achieves high data rates in part via OFDM which increases bandwidth and data capacity by splitting broad channels into multiple narrowband channels of different frequencies, so that they can then carry different parts of a message simultaneously. The channels are spaced very close together but avoid interference because neighbouring channels are orthogonal to one another and thus have no overlap. The line of sight nature of the signal reduces multipath distortion, which occurs when broadcast signals not following line of sight bounce off large objects and end up out of synch, thereby scrambling the received transmission and decreasing bandwidth [12].

The 802.16 MAC protocol allows for a variety of services that may be continuous or bursty. This can be achieved as the modulation and coding schemes are specified in a burst profile that may be adjusted adaptively for each burst to each subscriber station. The MAC use bandwidth-efficient burst profiles under favourable link conditions but shift to more reliable, although less efficient, alternatives as required to support the planned 99.999 percent link availability [11].

2.2.1 802.16a

The 802.16 working group was initially interested in the frequency range of 10-66GHz but in March 2000 the IEEE802.16a project was approved to deal with the 2-11GHz range. This project primarily deals with the development of a new physical layer specification, with supporting enhancements to the basic MAC [11]. The physical layer specifications include the option of using single carrier transmission with unique word pilot extension, for the implementation of efficient block equalizers at receiver [13].

The 2-11 GHz includes licensed and license-exempt frequencies, with the most commercial interest in the lower frequency ranges. At these lower ranges, the signals can penetrate barriers and thus do not require a line of sight between transceiver and antenna. This enables more flexible WiMax implementations while maintaining the technology’s data rate and transmission range [12]. This would allow for WiMax deployment in extremely built up or low lying areas where it may not be possible to get a line-of-sight connection. This type of signal could see a reduction in the necessity for expensive roof mounted antennas.

2.3 Ultra Wide Band

The growing number of media-intensive devices in the home such as PCs, digital camcorders and cameras, high-definition TVs and gaming systems need a high-bandwidth wireless solution for easy connectivity [14]. The existing wireless networking technologies such as Wi-Fi and Bluetooth are not optimized for multiple high-bandwidth usage models of the digital home. Although data rates can reach 54Mbps for Wi-Fi, for example, the technology has limitations in a consumer electronics environment, including

TABLE I
TECHNICAL DETAILS FOR MOST IMPORTANT WIRELESS STANDARDS

Standard	Frequency Band (GHz)	Data Rates (Mbps)	Range (m)	Use
802.11	2.4 - 2.4835 [3]	1, 2 [3]	50 - 100 (RF)/10 (IR) [3]	WLAN
802.11a	5.15-5.35, 5.725-5.825 [7]	6, 9, 12, 18, 24, 36, 48, 54 [7]	50 - 100 [3]	WLAN
802.11b	2.4 - 2.4835 [7]	1, 2, 5.5, 11 [7]	50 - 100 [3]	WLAN
802.11g	2.4 - 2.4835 [5]	6, 9, 12, 18, 24, 36, 48, 54 [7]	50 - 100 [3]	WLAN
802.16	10 - 66 [11]	Max 75 [12]	30 Miles [12]	WMAN
802.16a	2 - 11 [11]	Max 75 [12]	30 Miles [12]	WMAN
UWB	3.1 - 10.6 [14]	Max 450 [14]	10 [14]	WPAN

power consumption and bandwidth. Wireless technology needs to support multiple high data rate streams, consume very little power, and maintain low cost, while sometimes fitting into a very small physical package, such as PDA or cell phone [14]. Ultra-Wide Bandwidth (UWB) technology is currently investigated as one viable solution for high capacity short-range indoor systems, because of its robustness in dense multipath environment, low cost and low power implementation, and the high bit rates achievable [15].

UWB is defined as a radio technology that has a spectrum occupying a bandwidth greater than 20% of the center frequency, or a bandwidth of at least 500MHz. A traditional UWB transmitter sends billions of pulses across a very wide spectrum of frequencies several GHz in bandwidth. The corresponding receiver then translates the pulses into data by listening for a familiar pulse sequence sent by the transmitter [14]. The latest UWB systems use OFDM modulation with a frequency hopped pulse train in order to achieve full multipath diversity in multipath fading channels [15].

UWB's combination of broader spectrum and lower power improves speed and reduces interference with other wireless spectra [14]. UWB has achieved this by making use of recently legalized frequency spectrum from 3.1GHz to 10.6GHz. Each radio channel can have a bandwidth of more than 500MHz, but to allow for such a large signal bandwidth the FCC put in place severe broadcast power restrictions. This ensures UWB devices do not emit enough energy to be noticed by narrower band devices nearby, such as 802.11a/g radios. This sharing of spectrum allows devices to obtain very high data throughput whilst in close proximity of each other. However these strict power limits mean the radios themselves must be low power consumers. Because of the low power requirements, it is feasible to develop cost-effective implementations. With these features: low power, low cost, and very high data rates at limited range, UWB is positioned to address the market for a high-speed WPAN [14].

2.4 Brief Comparison of Broadband Wireless Standards

Table I summarises the comparison between the broadband wireless technologies considered in this paper.

3. Performance Comparison of Multimedia-based E-learning over Different Broadband Wireless Networks

3.1 Effect of Range and User Mobility on Multimedia-based E-learning Quality

This section investigates the effects that the mobility of a user has on the multimedia transmission quality during streaming process. Wireless standards IEEE802.11a, IEEE802.11b and IEEE802.11g are considered in turn as the underlying technology for multimedia streaming and their performance-related results in terms of average throughput, delay and loss are assessed and compared.

3.1.1 Scenario Details

In order to model the effects of mobility during multimedia streaming, the OPNET modeller and simulator and its wireless extension were used [2]. The simulation topology

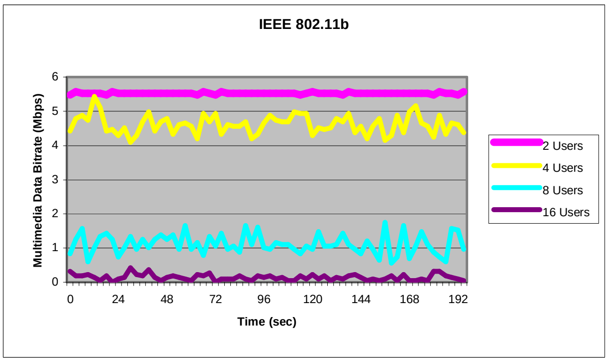

Figure 2a: Number of Users - Total throughput IEEE 802.11b

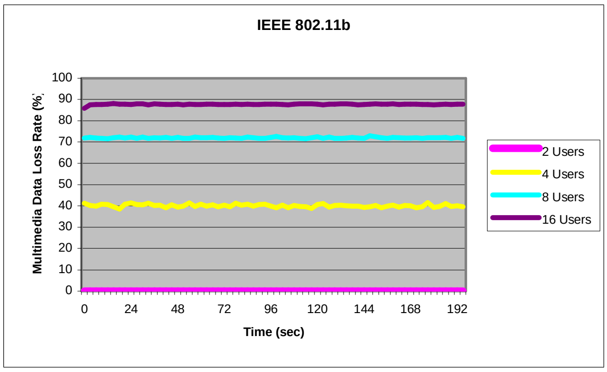

Figure 2b: Number of Users - Data loss rate IEEE 802.11b

includes a Base Station (BS) from where a server streams multimedia content to a client located at a mobile node that travels away from the BS on a linear trajectory. Multimedia data transmitted between the two units consists of variable bitrate MPEG2-encoded multimedia content, extensively used for high quality multimedia transmissions with average rate of 2.76Mbps. The simulation involves multimedia streaming for 15 minutes. At time 0 both the server and client are located at a position (0.1, 0.2) in the two-dimensional simulation space where these numbers are kilometres. When the simulation begins the client begins to move easterly along the x-axis before coming to rest at position (1.6, 0.2) after the fifteen minutes. The client travels with constant velocity during the simulation and so covers a distance of 1.5 kilometres in 15 minutes. Consequently the velocity was 6 km/h, similar to that of a walking user. The server remains stationary during the whole simulation. This scenario was repeated when each of the wireless standards IEEE802.11a, IEEE802.11b and IEEE802.11g was considered in turn.

Table II
MOBILITY – COMPARISON OF PERFORMANCE-RELATED STATISTICS

IEEE Wireless Standards	802.11a	802.11b	802.11g
Video Traffic Sent (Mbps)	2.76	2.76	2.76
Video Traffic Received (Mbps)	2.52	2.71	2.45
Data Dropped (%)	8.33	1.81	11.23
Delay (msec)	5.04	21.43	6.35

3.1.2 Simulation Results

Due to the movement of the subscriber station away from the location of the server the main factors that come into play in this scenario are the range of the wireless solutions used to support multimedia streaming and the variation of their performance characteristics. As mentioned in section II the IEEE802.11 standards are expected to have a range in the region of 100 m, higher for the 802.11b. However these tests that involve a single user and an ideal transmission environment, free from noise and interference, show that the throughput falls off dramatically at a distance of about 300 m from the server in the case of the 802.11a and 802.11g standards and respectively at approximately 930 m for the IEEE802.11b standard. Although the range obtained from the simulations is higher than could be expected in a real life situation, it maintains the proportion between the different wireless solutions. Figures 1a and 1b compare the three standards as the throughput and loss rate are plotted against the distance of the mobile multimedia client from the BS.

Table II presents a detailed performance statistics gathered during the simulation that highlights the differences between the three 802.11 wireless standards. These statistics are averaged over the length of the simulation after an initial transitory period has elapsed and before the transmission stops. The most important aspect is that during the period when all three wireless standards are still within transmitting range the average delay for the

IEEE802.11b is much higher than that of 802.11a and 802.11g. The loss rate that is 0% when the mobile client is in the transmission range increases sharply when approaching the range limit. However the average loss rates, although lower for the 802.11b (1.81%) than for the other two solutions (8.33% and 11.23% respectively), still ensure good end-user perceived quality if any error control strategy is employed.

3.1.3 Discussion

Performance-related issues play an important role in choosing the correct IEEE802.11 wireless type for particular requirements. If the emphasis of the network is going to be on the ability to provide highly mobile subscriber stations with long range transmissions then 802.11b will be the likely choice. However if high transmission rates are equally as important as mobility then the 54Mbps transmission rates of 802.11a and

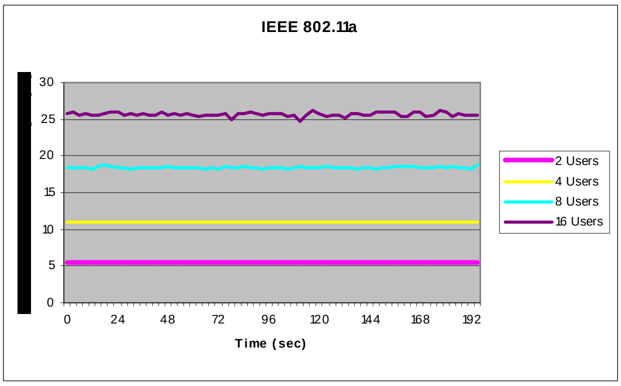

Figure 3a: Number of Users – Total throughput IEEE 802.11a

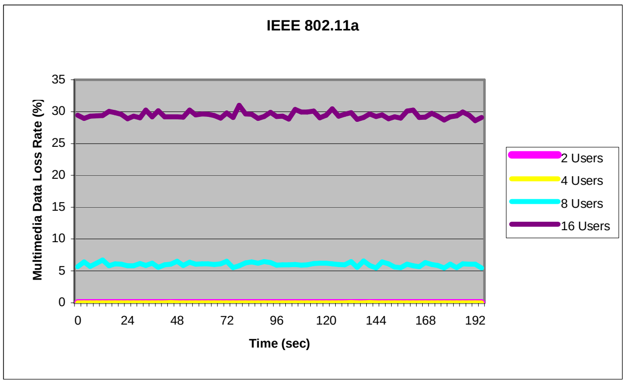

Figure 3b: Number of Users - Data loss rate IEEE 802.11a

802.11g are required. In the case of these two standards if the range of the mobile nodes is likely to be tested to the very limits, then the more suitable choice is 802.11a, with lower delays. Otherwise 802.11g is the preferred option.

3.2 Effect of Increased Number of Subscribers on the Multimedia-based E-learning Quality

The number of mobile multimedia clients to which a BS transmits multimedia content plays an important role in the quality of service obtained by each of the users. This section examines how the transmission quality is affected as the number of clients being served simultaneously with high quality multimedia content from a single BS is increased. Wireless standards IEEE802.11a, IEEE802.11b and IEEE802.11g are considered in turn and their performance-related results in terms of average throughput, delay and loss are compared.

3.2.1 Scenario Details

OPNET was used to model the topology and to design the scenarios that assess the effects of an increased number of simultaneous multimedia streaming clients on the quality of their received service. The simulation topology includes a BS from where a server streams multimedia content to a number of N wireless clients. These clients that remain stationary throughout the simulation are located at a distance of 100 m from the BS. Multimedia data transmitted between the BS and each of the clients consists of variable bitrate MPEG2-encoded multimedia content with average rate of 2.76Mbps. The simulation involves multimedia streaming for 15 minutes. The server is also stationary. Simulations were performed in turn with N=2, 4, 8 and 16 clients. This scenario was repeated when each of the wireless standards IEEE802.11a, 802.11b and 802.11g respectively was considered.

3.2.2 Simulation Results

Figures 2 and 3 show the total throughput and loss when IEEE802.11b and 802.11a technologies were used in order to stream multimedia content to increasing number of wireless users. The results for IEEE802.11g are similar to those obtained for 802.11g. By examining Figures 2b and 3b, it can be seen that no data is dropped for two users streaming on average 2.76Mbps each, regardless of the standard used. However when the number of users is increased to 4, data is lost for the 802.11b standard only. As the number of users is further increased to eight, in all three situations data is lost: when using 802.11a at a rate of 6.02%, 802.11g - at a rate of 9.63% and 802.11b - at a rate of 72%. The end-user perceived quality of the multimedia-based services is good for the first two situations but unacceptable in the third case. When the number of users is further increased to sixteen, a significant increase in the amount of data dropped for all standards is recorded. This indicates that the maximum number of users that can be served with good quality multimedia services via such a broadband wireless network was exceeded. Table III presents in detail performance-related statistics.

Looking at Figures 3a and 3b, it can be seen that the total throughput of multimedia traffic transferred over the 802.11a network grows with the increase in the number of users. However the increase seems to reach a limit at around 26Mbps as the associated loss rate increases to 30%, affecting the quality of the multimedia streaming process. Similar results were obtained when the IEEE802.11g was used as the underlying technology. Unlike this, in the case of the 802.11b, the throughput of multimedia data peaks at 5.53Mbps when the number of users is only two and then continues to fall rapidly as the number of users and therefore simultaneous streaming sessions is increased, reaching a low of around 0.14Mbps for the simulation involving sixteen users. The combined effect of a number of factors such as contention and collisions affects the throughput and ultimately the end-user quality of experience with the multimedia-based services.

3.2.3 Discussion

The performance-related results obtained indicate that, as expected, the 802.11b standard gives the worst performance in the IEEE802.11 family in terms of total throughput when streaming multimedia in a network containing a high number of subscriber stations. It consequently supports the lowest number of simultaneous streaming sessions. Of the other two studied technologies 802.11a performs slightly better in these conditions, showing superior throughput results and lower loss rates. Also, in comparison with the advertised theoretical bitrates of 11Mbps for the IEEE 802.11b and 54Mbps for the 802.11a and 802.11g, these simulations show that only half that can be achieved in practice, due to various factors related to wireless technologies.

TABLE III
NUMBER OF USERS – COMPARISON OF PERFORMANCE-RELATED STATISTICS

Standards	**802.11a**				**802.11b**				**802.11g**			
Users	**2**	**4**	**8**	**16**	**2**	**4**	**8**	**16**	**2**	**4**	**8**	**16**
Through. (Mbps)	5.53	11.06	18.41	25.67	5.53	4.62	1.12	1.14	5.53	11.06	17.93	25.34
Loss Rate (%)	0	0	6.02	29.46	0	40.12	72.02	87.64	0	0	9.63	30.12

4. Conclusions and Further Work

This paper compares the performance of a number of broadband wireless technologies from both theoretical and practical points of view when used for streaming high quality multimedia content. Mobility, range and the number of simultaneous streaming sessions supported are considered. The theoretical comparison included standards from the IEEE802.11 family, IEEE802.16 family and the emerging UWB. With the aid of a wireless network simulator, IEEE802.11a, IEEE802.11b and IEEE802.11g were contrasted. As expected 802.11a and 802.11g support a higher number of high bitrate simultaneous multimedia sessions than 802.11b, but the latter covers a wider area.

In terms of total throughput, simulation tests showed that regardless of the wireless technology used, only half the theoretical advertised bitrate could be achieved in practice due to wireless-related factors such as collusions and contentions.

Work in progress looks at assessing individual end-user perceived quality for each of the simultaneous viewers of multimedia content streamed using these wireless technologies. Future work aims at testing the effect of using 802.16 and UWB when serving multimedia content to an increased number of users. Their mobility characteristics and range will be also studied.

References

[1] N. Wilkoff, "The State of Technology Adoption", Forrester.com, May 2004

[2] OPNET Modeller, http://www.opnet.com/products/modeler/home.html

[3] J. Yeh, J. Chen, C. Lee, "WLAN Standards", *IEEE Potentials* 22 (4), 2003, 16-22

[4] H. Liu, J. Wu, W. Chen, "New frame-based network allocation vector for 802.11b multirate wireless LANs", *IEE Proceedings Communications* 149(3), 2002, 147-151

[5] H. Zhu, M. Li, I. Chlamtac, B. Prabhakaran, "A Survey of Quality of Service in IEEE 802.11 Networks", *IEEE Wireless Communications*, August 2004, 6-14

[6] IEEE 802.11b, "Supplement to 802.11-1999, Wireless LAN MAC and PHY specifications: Higher speed Physical Layer (PHY) extension in the 2.4 GHz band", 1999

[7] Z. Shi, R. Rofougaran, "A single-chip and multi-mode 2.4/5GHz RF transceiver for IEEE 802.11 wireless LAN", *IEEE Int. Conference on Microwave and Millimeter Wave Technology*, Aug. 2002, pp. 229- 232

[8] D. Leiss, "Co-interference between military radars and 802.11a WLAN networks", *IEEE Sys. Readiness Tech. Conf.*, Sep. 2003, 290- 293

[9] IEEE 802.11a, IEEE Standard for IT-Telecommunications and information exchange between systems - Local and metropolitan area networks-Specific requirements - Part 11: Wireless LAN Medium Access Control and Physical Layer specifications-Amendment 1: High-speed Physical Layer in the 5 GHz band, 1999

[10] V. Marks, "802.11g standard", 2001, http://www-106.ibm.com/developerworks/wireless/library/wi-ieee.html

[11] C. Eklund, R. B. Marks, K. L. Stanwood, S. Wang, "IEEE standard 802.16: a technical overview of the WirelessMAN air interface for broadband wireless access", *IEEE Comms Magazine* 40(6), 2002, 98-107

[12] S. Vaughan-Nichols, "Achieving Wireless Broadband with WiMax", *IEEE Computer* 37(6), 2004, pp. 10-13

[13] S. Tornasin, N. Benvenuto, "Performance comparison of frequency domain equalizers for the IEEE 802.16a WMAN standard", *IEEE Int. Conf. on Information and Communication Technologies*, April 2004

[14] Intel Corporation, "Ultra-Wideband (UWB) Technology", 2004, http://www.intel.com/technology/comms/uwb/download/wireless_pb.pdf, http://www.intel.com/technology/comms/uwb/download/Ultra-Wideband.pdf

[15] H. J. Park, S.H. Park, W. D. Cho, H. K. Song, "Ubiquitous home networking based on UWB communication systems", *IEEE Work. Soft. Tech. for Future Embedded & Ubiquitous Sys.*, May 2004, 127-131