Wireless Networks
Performance, Quality of Service and Interoperability

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Abstract

The popularity of Wireless Local Area Networks has increased strongly during past few years. During the increased interest also requirements of WLANs have grown, especially towards performance and quality of service they can provide. This is the main reason why newer and faster WLANs are developed with enhanced QoS features. One point of interest has been the interoperability level which different WLANs can offer between each other and towards other standards also. However the current WLANs provide quite little interoperability and there is much work required to achieve even some kind of interoperability between them.

This paper presents what are the performance characteristics of current IEEE 802.11b, IEEE 802.11a and ETSI HIPERLAN/2 wireless LAN standards and what kind of quality of service features they offer. In addition to this paper contains also information how interoperable these standards are with each other and some other current or upcoming standards.

1 Introduction

Wireless Local Area Networks (WLAN) are an essential part of wireless communication. Not only because they provide wireless connections to devices using network directly but also because they provide means to carry data belonging to other networks also. WLAN networks are based on standards which are provided mostly by two big standardization parties: the European Telecommunications Standards Institute (ETSI) and Institute of Electrical and Electronics Engineers, Inc (IEEE).

When wireless LANs have become more popular new demands on them have raised also. One of these demands is naturally higher bandwidth, especially when network has several users the currently most widely used IEEE 802.11b tends to be too slow for providing sufficient bandwidth for every user. That is the reason for development of new, faster wireless LAN solutions like HIPERLAN/2 and IEEE 802.11a. Although the provided bandwidth is one important aspect when using wireless technologies, also some other important matters must be discussed. They are the Quality of Service and interoperability. The QoS features people require from WLANs are mostly focused on features providing smooth voice and

Standard	Frequency (GHz)	Physical Speed	Range	Media interface
IEEE 802.11	2.4	2 Mbps	150 m	CSMA-CA
IEEE 802.11b	2.4	11 Mbps	150 m	CSMA-CA
IEEE 802.11a	5	54 Mbps	150 m	CSMA-CA
IEEE 802.11g	2.4	54 Mbps	150 m	CSMA-CA
ETSI HIPERLAN/1	5	23.5 Mbps	150 m	EY-NPMA
ETSI HIPERLAN/2	5	54 Mbps	30-200 m	TDMA-TDD
ETSI HIPERACCESS	40-43.5	25 Mbps	< 5 km	TDMA
ETSI HIPERLINK	17	155 Mbps	150 m	

Table 1: Performance overview of IEEE & ETSI Wireless LAN standards [10, 6]

video streams. Interoperability matters are not only between different standards but within same kind of WLANs in same coverage area also as especially the older WLAN standards working in 2.4 GHz spectrum has very limited capabilities to provide different spectrum areas to several WLAN networks within the same coverage area.

2 Performance of Wireless LANs

The WLAN performance is usually measured with the maximum range and bandwith which WLAN provides. In addition to this latency plays an important part of performance but this is usually seen as quality of service aspect and thus it is studied more in chapter 3. In addition to these, one important performance feature is the capability to serve several users simultaneously, which is a problem especially in 2.4 GHz WLANs as their spectrum area is reasonably small.

2.1 Performance Overview

Performance overview of IEEE and ETSI wireless LAN standards are provided in Table 1. Although the main focus of this paper is in currently most popular Wireless LAN standards, table includes also information of older Wireless LAN standards and information of standards currently under development. As the main focus is in IEEE 802.11a, IEEE 802.11b and ETSI HIPERLAN/2 their performances are described more details in subsections 2.2, 2.3 and 2.4. The media interface differs between IEEE and ETSI standards pretty much, when IEEE relies in Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) interface, the IETF uses Time Division Multiple Access - Time Division Duplex (TDMA-TDD). Speed of Wireless LAN is mostly affected by its environment and distance, in other words when WLAN access point is more away or environment causes a lot of interference the bandwidth of WLAN device will decrease. That is why the environment should be measured before installing WLAN system for making it as effective as possible. Subsection 2.5 discusses about these measurements. As the table shows, the speed of Wireless LANs is increasing thus making more and more complex data exchange possible in wireless environment.

2.2 IEEE 802.11b performance

IEEE 802.11b WLAN standard is the most common standard for current WLANs. IEEE 802.11b devices are provided by several different manufacturers like 3COM, Nokia and Cisco. Although the physical speed of IEEE 802.11b standard is 11 Mbps the real data speed is usually around 5 Mbps in ideal circumstances. If the environment causes lots of interference, contains obstacles or distance between devices is long the data speed is even slower. IEEE 802.11b physical media is Direct Sequence Spread Spectrum (DSSS) which means that the available spectrum area is divided into overlapping channels that are 22 MHz wide. DSSS uses a technique which is called chipping. Chipping spreads modulated data across available spectrum and it is designed so that some signal loss may occur without data loss. The chipping method which IEEE 802.11b uses is Complementary Code Keying (CCK). CCK increases the maximum physical speed to 11 Mbps instead of 1 or 2 Mbps with phase shifting keying which is used in IEEE 802.11 standard. CCK provides also means to change shifting rate dynamically from 11 Mbps to 5.5 Mbps to 2 Mbps to 1 Mbps thus making it possible to devices to adjust bandwidth depending from the strength of signal. Although the maximum physical speed of IEEE 802.11b is 11Mbps the real data speed is around 5 Mbps because of data integrity checking and retransmissions of lost packets. IEEE 802.11b is connectionless thus making it effective in data transfer but less usable in stream (voice, video) transfers. [6, 12]

As the available bandwidth of IEEE 802.11b is reasonably small (2.4 - 2.4835 GHz) and each channel require 22 MHz wide frequency area, it provides only three non-overlapping channels in one area meaning that the same coverage area can only contain maximum of three IEEE 802.11b networks.

As IEEE 802.11b is currently the most used WLAN standard, IEEE has created a work-group for developing IEEE 802.11g WLAN standard which provides higher bandwidths in 2,4 GHz frequency. The IEEE 802.11g includes techniques from both IEEE 802.11a and IEEE 802.11g and it is often counted as a transitional form between IEEE 802.11a and IEEE 802.11b. IEEE 802.11g is fully downwards compatible with IEEE 802.11b making it possible to use IEEE 802.11b devices in IEEE 802.11g WLAN. However these devices can not use full IEEE 802.11g potential but they are limited to performance provided by IEEE 802.11b. IEEE 802.11g standard specifies that devices using it must support two different physical medias: DSSS and Orthogonal Frequency Division Multiplexing which is also used in IEEE 802.11a. Although IEEE 802.11g uses advanced technologies like OFDM its main problems are same as with IEEE 802.11b, the 2.4GHz band is becoming too crowded and it provides only three non-overlapping channels thus making new solutions necessary. [11]

2.3 IEEE 802.11a performance

IEEE 802.11g and IEEE 802.11a elemental techniques are very similar. However the IEEE 802.11a uses the 5GHz frequency band instead of 2.4GHz which IEEE 802.11b and IEEE 802.11g use. This means also that IEEE 802.11a devices can not be used in IEEE 802.11b network and vice versa.

IEEE 802.11a does not use regular DSSS as IEEE 802.11b but OFDM which makes it possible to store more data within each channel (54Mbps). IEEE 802.11a does have a wider frequency range (for example 5.15-5.35 GHz and 5.725-5.825 GHz in United States) making it more suitable for several users networks. However the 5GHz frequency area raise some new problems in usage of WLANs which are the facts that the available bandwith area in Europe, Japan and United States are not the same. Even the available spectrum in Europe is 455MHz, in United States 300 MHz and in Japan 100 MHz.

The amount of non-overlapping channels in IEEE 802.11a is 12 in United States (4 indoor, 4 indoor/outdoor and 4 outdoor). However the performance of IEEE 802.11a network decreases much more faster than IEEE 802.11b when distance between devices increases, initial results show that the 802.11a is usually 3 times faster than IEEE 802.11b at typical indoor ranges. As IEEE 802.11b the IEEE 802.11a standard can also lower the data exchange speed if signal is too weak or distance too long. IEEE802.11a supports speeds from 54Mbps to 6Mbps (supported speed 54,48,36,24,18,12,9 and 6 Mbps) by modifying modulation, coding ratio, bits coded per supporting carrier wave, coded bits per one ODFM symbol and data bits per one ODFM symbol. IEEE 802.11a may use also two channels simultaneously when its maximum physical speed can be as high as 108Mbps. [11, 10]

As mentioned in table 1 IEEE 802.11a and ETSI HIPERLAN type 2 offer the same physical speed. However their target application areas are slightly different and they work in quite different ways.

2.4 ETSI HIPERLAN/2 performance

ETSI High Performance Radio Local Area Network type 2 (HIPERLAN/2) is an WLAN solution providing some extra functionalities in comparison with IEEE 802.11a and IEEE 802.11b standards. However the maximum physical speed of HIPERLAN/2 is same as maximum physical speed of IEEE 802.11a: 54Mbps. Also the sub-carrier modulation types of HIPERLAN/2 are same as modulations of IEEE 802.11a: BPSK, QPSK, 16 QAM and 64 QAM and the signal modulation is OFDM as in IEEE 802.11a standard. Channel spacing of HIPERLAN/2 is 20 MHz which is same as in IEEE 802.11a which contain 52 sub-carriers (as in IEEE 802.11a).

As in IEEE standards, also HIPERLAN performance decreases when distance between devices increase, the possible speeds HIPERLAN/2 may operate are 54, 36, 27, 18, 12, 9 and 6 Mbps. [4]

2.5 Measuring environment

When creating a WLAN network designer should measure the area carefully before beginning of the networking work because WLANs are quite sensitive to the signal interference and obstacles between devices and access points. Designer can measure the signal levels with sensitive spectrum analyzers which are capable of measuring the spectrum area WLAN uses, however this does not necessarily tell anything about the working of the real WLAN network. This is the reason why signal level measurements should be done with real device using the wanted WLAN standard as they usually can measure the signal level and tell it to the measurement tools which come with the device. Devices inform the signal level usually with decibels or percents. The decibel amount required depends mostly from the sensitiveness of device however the measurement result should be notably higher than the minimum signal level device requires.

In addition to signal level the amount of signal interferences in environment should be carefully measured. This is usually informed as signal to interference ratio in percentages where 100% is same as no interferences at all. Low signal to interference ratio cause unnecessary packet loss and retransmissions which directly affect the performance of WLAN. [3]

3 Quality of Service in WLAN

The Quality of Service (QoS) in Wireless LANs has been one point of interest since the first WLANs came available. The major problem with every available WLAN quality is the latency which transferring data through air with radio frequencies causes.

The nature of WLANs cause one big QoS problem which is the performance in bad conditions when practically every current WLAN solution begin to drop their packets thus decreasing the availability. That is the reason why every IEEE and ETSI standard also offer ways to simplify the modulation thus making the connections more reliable. Unfortunately this also decreases the maximum throughput of the network also. IEEE 802.11 WLAN standards have several extra functionalities in their Media Access Control (MAC) layer which are not usually performed within this layer as they are usually performed by upper level layers. These functionalities are fragmentation, packet retransmission and acknowledges. [2]. The reason why these are included in IEEE 802.11 MAC layer is probably the fact that losing packet is much more probable in wireless environment than wired.

When using voice or video applications in WLAN networks the delay caused by data transmission is one of the most critical service features in addition to availability. That is why the current WLAN solutions provide means to provide and guarantee delay levels which are low enough for these transmissions.

3.1 IEEE QoS features

Both IEEE 802.11a and IEEE 802.11b contain the same feature for even some kind of QoS which is Point Coordination Function (PCF) which can be used instead of Distributed Coordination Function (DCF). IEEE has also a working group IEEE 802.11e which is developing enhancements for QoS features of MAC layer of IEEE 802.11 standards. These enhancements are called as Enhanced Distributed Coordination Function(EDCF) and Hybrid Coordination Function (HCF).

These feature enhance mainly the delay WLAN causes in transfer thus enhancing the usability of WLAN to voice and video transmissions which are typically strongly delay dependent.

3.1.1 Point Coordination Function (PCF)

IEEE 802.11a and IEEE 802.11b uses usually DCF as coordination function. In DCF WLAN all connected stations have control to the network and stations try to access network with CSMA/CD media interface which causes the result that other stations may have only a little or none available bandwith to use. If one station wants to send and receive some streaming data like voice or video, it is critical to have bandwith constantly available. That is the reason why PCF control is available in IEEE 802.11a and IEEE 802.11b networks. In PCF mode one specific access point has control over network and it polls all network stations regularly giving every station possibility to send and receive data for a certain amount of time and moving to the next station after that. This guarantees that the network has certain predefined maximum latency and throughput. However PCF is not very effective in larger networks as one access point is responsible for the control and it has to poll all stations. [1]

3.1.2 IEEE 802.11e QoS features

As stated earlier the basic QoS features of IEEE 802.11a and IEEE 802.11b are simply not effective enough to fulfil the growing quality of service demands of WLAN users. This is the reason why IEEE formed group IEEE 802.11e to define enhanced quality of service features to these WLAN standards.

IEEE 802.11e EDCF is an enhancement to the regular DCF of IEEE WLANs which adds possibility to define priorities to packets sent within WLAN network. The purpose of EDCF is especially to increase the possibility to transfer voice and video in IEEE WLAN networks. EDCF provides means for prioritization of data based on Access Categories (AC). Each AC may have one or more User Priorities (UP) assigned. If AC has more than one UP assigned each of these have their own queue and Arbitration IFS (AIFS) and contention window parameters. Each AC contends for medium access with one CSMA instance using the parameters in its lowest UP simultaneously corresponding to the priority of AC as a whole. [5]

IEEE 802.11e HCF is another new operation mode which is based on similar polling mechanism that legacy PCF mode has. The advancements of HCF are that it allows HC to start contention-free Controlled Access Periods (CAPs) at any time during a CP after the medium has been idle for at least a PIFS interval. The HCF makes legacy PCF practically useless although IEEE 802.11e terminals are allowed to support legacy PCF also.

IEEE 802.11e network devices are backward compatible with devices which do not support extended QoS capabilities IEEE 802.11e introduces but they do not gain any IEEE 802.11e QoS advantages in these IEEE 802.11e supported networks.

Simulations show that the advantages of even using PCF increases the usability of IEEE WLANs in voice and video transmissions. If only DCF is used, even about 5 bursty data sessions cause huge increasement of average delay in voice transmissions and even more delay in video transmissions. However using PCF with DCF decrease the latency to around 30 ms when network has as many as 20 bursty transmissions in both voice and video transmissions. Using technologies introduced in IEEE 802.11e the latency drops as low as around 10ms for both voice and video transmissions with 20 bursty data sessions. When using advanced QoS capabilities minimum VoIP latency requirements are met easily even in quite heavily encumbered networks as the recommended maximum latency is 200 ms and maximum jitter delay is 75 ms. [5, 7]

3.2 HIPERLAN/2 QoS features

Unlike IEEE 802.11 standards, HIPERLAN/2 offers also connection-oriented data transfers in addition to connectionless transmissions. Already this makes HIPERLAN/2 more usable for transferring stream-based data like video or voice.

HIPERLAN/2 provides the following three QoS service models for IP traffic :

- Best Effort Service
- Differentiated Services
- Integrated Services

Best Effort Service provides only basic connectivity without guarantees. Best Effort Service is a single service model where applications send whenever it wants to and without any data quantity parameters. Application does not request permissions or inform the rest of the network about the transmission in any way and network delivers the data as well as it can without any assurance of reliability, delay or throughput. Therefore the Best Effort Service QoS service model is also called as lack of QoS. [9]

Differentiated Services (DiffServ) is a service model with service classes. Traffic is grouped in several service classes which network serves differently. One class may have higher QoS demands than another thus it is treated better making higher bandwith or lower loss rate available to specific classes packets. People call DiffServ often as soft QoS because it does not provide hard guarantee to transmissions but only statistical preference which makes the network to try to deliver the packets according to the QoS parameters assigned to the packets service class. [9]

Integrated Services (IntServ) is the most accurate QoS service model HIPERLAN/2 can offer and thus it is also called as hard-QoS. In IntServ service model specific traffic reserves absolute amount of network resources for its own use. In IntServ model the application which is willing to send data through the network requests a specific kind of service with explicit signals from the network before sending the data. In other words, the application sends information about its traffic profile and requests a specific service which qualifies bandwidth and delay requirements to the network nodes before sending the actual data. IntServ has two service models, Controlled Load Service and Guaranteed Service which are suitable for a little different data transfers. Controlled Load Service guarantees a level of service equivalent to best effort service in lightly loaded networks and it is designed for adaptive real-time applications. Controlled Load Service works fine as long as the network is lightly loaded but in heavy loaded networks its performance degrades fast. Guaranteed Service guarantees maximum bandwidth and delay for end-to-end connections thus making it usable for audio and video applications with high delay requirements. [9]

4 Interoperability

As both 2.4 GHz and 5 GHz spectrums contain several different wireless networking standards, the interoperability between networks is an important aspect. This does not only include the interoperability between different WLANs but also two or more WLANs overlapping and other data transfers in these spectrums, including for example Bluetooth which use will most probably increase a lot in near future. Interoperability is not only the possibility to coexist but also possibility for different kind of devices to use same base network.

Current WLANs does not provide good interoperability and that's why there is practically none existing interoperable WLAN solutions. However some WLANs may well coexist in same area as they do not cause interferences to each other.

4.1 IEEE 802.11 and Bluetooth

Bluetooth will most probably become more and more popular thus filling the 2.4 GHz spectrum which is used also by IEEE 802.11, IEEE 802.11b and IEEE 802.11g. Most current mobile phones with advanced data features already use Bluetooth to communicate with other devices near them thus increasing the amount of Bluetooth data transfers. Bluetooth is also becoming more and more popular in laptops and even in regular desktop computers.

However it seems like IEEE 802.11 standards utilizing the 2.4 GHz spectrum can cope with the Bluetooth devices quite well. However the interference Bluetooth causes increases when the distance between WLAN station and access point increases thus making the connections from more far away less effective. In addition to range the Bluetooth interference increases when WLAN is using packets with heavier payload especially if the Bluetooth devices are sending data as fast as they can. For example when using IEEE 802.11b in area with no Bluetooth devices the maximum throughput with maximum payload packets can achieve as high as 7 Mbps transmission rates, but if the area is 100% utilized by Bluetooth the transmission rate drops to around 3.5 Mbps. With small payload packets the difference is not this high, without Bluetooth the maximum throughput is around 2Mbps and with 100% Bluetooth utilization a little over 1 Mbps. So it seems like 2.4 GHz spectrum can be very well used by both WLANs and Bluetooth devices however requiring that the range between WLAN stations and access points does not grow too long. [13]

4.2 IEEE 802.11b and IEEE 802.11a

Although IEEE has developed both IEEE 802.11b and IEEE 802.11a these standards are not co-operative. This is because they utilize different spectrums and their media interfaces are different (IEEE 802.11b uses DSSS when IEEE 802.11a uses OFDM). However because they utilize different spectrums they can easily coexist in same area without causing interference to each other. For example Synad Technologies already offer a circuit which includes support for both IEEE 802.11b and IEEE 802.11a in a way that the used standard is invisible to the user. However as the future WLANs will mostly utilize the 5GHz spectrum, it is more interesting than the co-operation of 2.4GHz and 5GHz WLANs. [10]

4.3 IEEE 802.11a and HIPERLAN/2

In addition to IEEE and ETSI several other parties are working on solutions which could provide co-operation between IEEE 802.11a and HIPERLAN/2. Although the physical level of these standards are similar, upper levels differs from each other causing the conclusion that HIPERLAN/2 data can not be sent in IEEE 802.11a network and vice versa. The first stage will probably only include devices which has similar physical layers and separate upper level implementation for IEEE 802.11a and HIPERLAN/2. These devices could work in both IEEE 802.11a networks and HIPERLAN/2 networks but not simultaneously.

Some companies has introduced harmonization suggestions which would make it possible to use both IEEE 802.11a and HIPERLAN/2 simultaneously within same network devices. One of these companies is hLAN which proposal defines enhanced access points which could contain simplified HIPERLAN/2 support which could be used with IEEE 802.11a Media Access Layer (MAC). However this would require new kind of access points and some changes in standards. After all, harmonization of these two standards require a lot of work and the interoperability may never come true and thus this can be seen as work for more interoperable standards in future. [10]

4.4 HIPERLAN/2 interoperability

Although HIPERLAN/2 is not very well interoperable with IEEE 802.11a ETSI has done a lot of work to make it interoperable with several other existing and upcoming standards. This is done with the convergence layer of HIPERLAN/2. First of all HIPERLAN/2 supports both cell-based transmissions and packet-based transmissions via separate convergence layers. Convergence layer is divided into two separate parts, Common Part Convergence Sublayer (CPCS) and Service Specific Convergence Sublayer (SSCS) where CPCS is HIPERLAN/2 specific part and SSCS defines the packet or cell modifications for supporting specific service.

Cell-based convergence layer provides the capability to transfer transparently User Service Data Units (User SDUS) between user and convergence layer. These user SDUs are like ATM cells thus making ATM connections via HIPERLAN/2 possible.

As cell-based also packet-based convergence layer is divided into two separate parts, common and service specific. Common part contains both CPCS and segmentation & reassembly (SAR) function. The service part is dependent from the service using HIPERLAN/2 network, it might be Ethernet, IP, Point to point protocol (PPP) or IEEE 1394 (Firewire).

Also third type of convergence layer is under construction. This convergence layer would make it possible to use Universal Mobile Telecommunications System (UMTS) with HIPERLAN/2 via own convergence layer. However the work with this convergence layer is quite complicated as it should include also billing and subscription administration. The first version drafted in late 2000 proposes two different solutions, loose and tight integration which could be used to make interoperability of HIPERLAN/2 and UMTS possible. [8]

5 Conclusion

As the density of WLANs is increasing all the time with growing interest for using them the requirements of wireless solutions increase also. This means that upcoming WLAN proposals should be more scalable to higher amount of users simultaneously providing higher data speeds. In addition to speed requirements the upcoming WLANs should be interoperable and provide good quality of service features. Currently the most popular WLAN standard IEEE 802.11b is quite well working right now, but it will become too slow in near future. Another problem with this standard is low amount of non-overlapping spectrum areas which cause interferences between same standards whenever several WLAN networks are established near each other causing the result that growing user amount decreases the usability of this standard. The IEEE 802.11g standard will provide some kind of solution to this but it will neither be very long solution as the spectrum area is similar to IEEE 802.11b. So the future WLAN will most probably be either IEEE 802.11a or HIPERLAN/2. Currently it seems like IEEE 802.11a will win the 5GHz round as more and more companies are going behind it, mostly because of quite slow development in HIPERLAN/2. As a matter of fact there seems not to be any products using HIPERLAN/2 in end user market yet. For example Ericsson which used to be behind HIPERLAN/2 has also started to research IEEE 802.11a solutions.

However the target areas of IEEE 802.11a and HIPERLAN/2 are slightly different, IEEE 802.11a is strongly meant for only wireless Ethernet solution when HIPERLAN/2 aims to several other higher level standards also, like Firewire and ATM.

The interoperability between different WLANs is quite poor, although future might change this because of co-operative work of IEEE and ETSI and other companies to define harmonized layers for wireless networking. However only time will show if this achieves any success.

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