DRFT

Improving multiple broadcasting of multimedia traffic in wireleess ad-hoc networks

Christos Chousidis
School of Engineering and Design
Brunel University
London, UK
christos.chousidis@brunel.ac.uk

Rajagopal Nilavalan
School of Engineering and Design
Brunel University
London, UK
rajagopal.nilavalan@brunel.ac.uk

***Abstract*—The increasing use of multimedia streaming applications in addition with advent of internet television and radio, demands from today's wireless networks to handle with reliability multiple broadcasting and multicasting sources. However, the way that 802.11 standard, which is the primary technology in wireless networking, handle this type of traffic raises a series of problems mainly related to the lack of an effective feedback mechanism [1]. This lack in turn, limits the capability of random backoff process to eliminate collisions and reduce reliability and fairness. This inherited drawback of the standard is affecting the way broadcast [2] and multicast traffic is transmitted as well as the overall performance of the network. In this paper initially we are highlighting the drawback of the IEEE 802.11 MAC algorithm in handling multiple stations "media type" data broadcasting in an ad-hoc wireless network [3]. Then, we propose two different approaches in alleviating these problems. The first approach is the simple linear increase of the contention window (CW) while the second propose a linear increase of the CW implementing an exclusive backoff number allocation (EBNA) algorithm. In addition we are modifying the 802.11 medium access control (MAC) algorithm to use the clear to send to self (CTS-to-Self) protection mechanism prior to every transmission. Both the above techniques are simulated and compared with the classic 802.11 MAC. The result sows that the overall performance of the network can be improved using these alternative MAC methods.**

Keywords—Broadcasting, ad-hoc, contention window, CTS-to-Self, EBNA algorithm

I. Introduction

The IEEE 802.11 standard (Wi-Fi) is the primary technology in wireless networking and has made wireless networks widely available and inexpensive [4]. Every day more and more devices and application are adopting this standard and many of them are using this network platform to transmit multimedia type data. Internet TV and radio, VoIP, video conferencing, network gaming, and live audio networking are some of the application that demand reliable and efficient wireless networks [5]. Many of those applications are setting an ad-hoc network and use broadcasting or multicasting to stream their data. Broadcasting is a good practise in media networking because it can distribute simultaneously data to multiple users. IEEE 802.11 standard supports broadcasting without any type of feedback (e.g. acknowledgment ACK) from the recipients. Therefore, broadcasting does not provide any kind of delivery guarantee which in the some cases like live media transmission is not critical as due to the nature of this information the time needed to retransmit a lost packet causes additional delay and synchronization problems. The luck of ACK is affecting primarily the broadcasting station (STA), which is unable to obtain any kind of information about the network's traffic. IEEE 802.11 implements a carrier sense multiple access with collision avoidance (CSMA/CA) mechanism to minimize collisions. This mechanism uses a random backoff algorithm to reduce the probability of collisions and fairly arbitrate the wireless medium by allocating random waiting time values from a predefined CW to every station intended to transmit. Packets that failed to be transmitted cause an exponential increase of the CW window and consequently a better distribution of the waiting time over the network. Positive ACK is the only mechanism in order for a STA to identify an unsuccessful transmission. According to the IEEE 802.11 standard, in broadcasting the size of the CW remain unchanged and always hold the minimum value. This results in busy networks for broadcasting STAs to unfairly compete for the access to the medium. This drawback becomes even more significant when the number of broadcasting STAs increases. On the other hand, the exponential increase of the CW it alleviates the network but dramatically affects the broadcasting information delivery causing unacceptable levels of delay. A second technique used by the CSMA/CA mechanism to arbitrate the medium access is the distribution of the network allocation vector (NAV). According to the IEEE 802.11 2007 amendment, STAs that gain access to the medium are able to exchange request to send, clear to send (RTS/CTS) control messages. In order to inform all members of the network for the time they are intended to occupy the wireless medium. This causes for the rest of the STAs to defer and freeze their backoff process. CTS-to-Self control message is an alternative to RTS/CTS process used in the cases were a CTS is not possible. It is broadcasted from a STA with destination address its own address and lower transmission rate. This technique is strictly used as protection mechanism for mixed-mode environments where extended rate physical (ERP-802.11g) and/or high throughput (HT-802.11n) devices coexist with legacy 802.11 technologies[6]. As long as broadcasting is not implementing NAV distribution and taking into consideration the heavy load of the multimedia traffic we can understand that non-broadcasting stations are forced to drop packets after the number of attempted retransmissions reaches the maximum retry count.

To address the above problems a modified MAC mechanism is proposed in this paper. The amendments focus on two main areas, the NAV distribution and the random backoff algorithm. The 802.11 MAC is reprogrammed to send a CTS-to-Self message prior to every broadcasting packet using the operational-high data rate. The random backoff process is also modified using two different approaches. In the first one, a linear increase of the CW is applied taking into account the changes in the number of broadcasting STAs. In the second approach, again a linear increase of the CW is performed according to the variation of the broadcasting STAs, but in this case an exclusive backoff number allocation (EBNA) algorithm is implemented. This algorithm allocate exclusive backoff numbers to each STA while maintain fairness in waiting periods between STAs over the time.

The remaining of this paper is organized as follows: In section II, the 802.11 MAC process is summarized and the drawbacks of random backoff algorithm in the case of multiple broadcasting are analysed. In section III, the proposed modifications are thoroughly described. In Section IV, the simulation's characteristics are described and comparative results are presented and commented while in Section V the conclusions of this work are presented.

II. Analysis and Drawbacks of IEEE 802.11 Medium Access Mechanism

A. *General description*

The IEEE 802.11 MAC is mainly designed for wireless unicast communication and for unlimited number of users in the network. In Distributed Coordination Function (DCF) which is its primary medium arbitration method, Random Backoff in conjunction with virtual and physical carrier sense provides a level of protection from collisions. The 802.11 2007 standard provide an additional protection mechanism using RTS/CTS or CTS-to-Self control frames. This is mainly used for Network Allocation Vector (NAV) distribution in mixed-mode environments where different 802.11 technologies coexist. Although RTS/CTS it is used to address the hidden node problem, CTS-to-Self is used strictly as a protection mechanism for mixt-mode networks using data rates and modulation method that legacy 802.11 technologies can understand. NAV is distributed by setting the duration field of the control frame with the time in microseconds required in order for the two parties to complete transmission including ACK. It is clear however that there is no MAC-Level recovery mechanism in broadcasting [7]. In multimedia broadcasting the focus must be on preventing the loss of packets and the collisions instead of recovery and retransmission. NAV distribution is possible in broadcasting, only in mixed mode networks, by using the CTS-to-Self control frame [4]. CTS-to-Self is a standard CTS frame transmitted with a destination address of the transmitting station. The transmitting STA cannot hear its own transmission in a half-duplex medium but all nearby STAs are alerted that a frame broadcast is pending and they can also update their NAVs with the value included in the duration field of the CTS-to-Self frame. As mentioned above, the use of CTS-to-Self is strictly limited in mixed-mode environments and it is using lower data rates that reduce throughput and increase delay. The possibility of modifying the 802.11 MAC to use CTS-to-Self as a main NAV distribution method, using also high data rates will significantly contribute to the performance of the protocol especially in broadcasting. However, the use of CTS-to-Self alone cannot eliminate the collisions occurrence which is caused by the drawbacks of 802.11 MAC Random Backoff mechanisms. This mechanism significantly contributes in collision avoidance but cannot totally eliminate them, especially when the number of STAs increases. In heavy data loads, there is a high likelihood that two or more STAs will choose the same backoff value. In this case the collision cannot be avoided regardless of the use of CTS-to-Self. For this reason an alternative EBNA algorithm can be used to overcome the Random Backoff algorithm drawbacks in the case where multiple broadcasting is taking place

B. *Analysis of IEEE 802.11 MAC algorithm*

IEEE 802.11 MAC Layer is the lowest part of the Link Layer and it is placed between the Physical (PHY) and the Logical Link Control (LLC) sub-layer. MAC architecture is based on two basic coordination functions, Point Coordination Function (PCF) and Distributed Coordination Function (PCF). PCF is a contention free access method which provides polling intervals to allow uncontended transmission opportunities (TXOP) for participating STAs. This function is outside the scope of this paper, firstly because it demands the use of an AP and secondly, because the manufacturers never applied it to their devices. In this study the fundamental DCF contention-based access mechanism is used.

DCF's timing diagram is illustrated in figure 1 and its function is described as follow. A STA with a packet to transmit waits for the channel to become idle. When an idle period equal to DCF Inter-Frame Space (DIFS) is detected, generates an initial Backoff time value. This value indicates the period that the STA has to additionally defer before transmitting. The random backoff process is the most important mechanism used in IEEE 802.11 CSMA/CA to prevent collisions. CW increases exponentially for every retransmission, (unique per station). Under low utilization, stations are not forced to wait very long before transmitting their frame. If the utilization of the network is high, the protocol holds stations back for longer period of times to avoid the probability of multiple stations transmitting at the same time. When we are referring to Contention-Based access, random backoff is actually the primary mechanism for contention. This value is extracted from the following formula:

Backoff_Time = INT (CW x Random (0, 1)) x aSlotTime (1)

Random (0, 1) is a pseudo-random number between 0 and 1 drown from a uniform distribution. CW is an integer within the range of values CWmin and CWmax. CWvalues=2x-1 (x starts from an integer defined by the station and goes up to 10). For example, for x=4, CW4=24-1=15, CW5=31, CW6=63 ….. CW10=1023. The aSlotTime duration is the value of the correspondingly named PHY characteristics. The Backoff timer is decremented with one slot as long as the channel is idle. When a transmission is detected, the Backoff timer freezes and start to decrease again when the channel is sensed

Identify applicable sponsor/s here. If no sponsors, delete this text box (*sponsors*).

idle for a DIFS. When the timer reaches zero the data packet is finally transmitted.

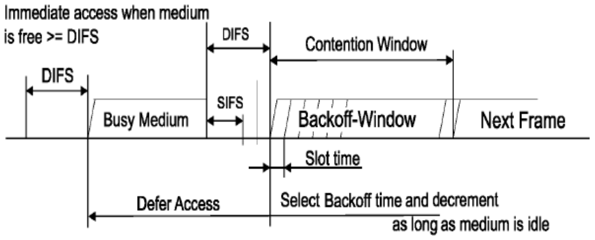

Fig 1: IEEE 802.11 basic access method

C. *Drawbacks of random backoff in 802.11 broadcasting*

There is plenty of research on the Reliable Broadcasting over wireless ad-hoc networks and many protocols have been proposed [8] [9] [10]. These protocols can be divided into four main categories according to the methods they use.

1) **Simple Flooding Methods**: Requires each node to retransmit all packets
2) **Probability Based Methods**: Use some basic understanding of the network topology in order to assign a probability to a node to rebroadcast.
3) **Area based Methods**: Rebroadcasting is based on the possible additional area that will be covered.
4) **Neighbour Knowledge Methods**: Maintain a state of neighbours, obtained by "Hallo" messages. This stage is used in the decision to retransmit

All the above methods require a sort of retransmission which is unsuitable for media networking. Reliability in media broadcasting is reduced by the drawbacks of random backoff process, which cause channel access delay and collisions no matter the available bandwidth of the wireless technology that is used.

The IEEE 802.11 standard defines that the CW size exponentially increases for each retransmission attempt of the same packet. However, as there is no retransmission in broadcasting, the CW size always holds the CWmin value. Under high utilization due to increasing number of STA and/or high data production, CWmin appears to be extremely small. In this case we are facing two major problems. The first one is that it is possible for a STA that just completed a transmission and has a new packet to send, to choose zero as its initial backoff time and start transmitting immediately after a DIFS. As we can see from (1), backoff time is a random outcome based on a uniform distribution but its range increases proportionally with the size of CW. This consecutive transmission will give other STAs no chance to backoff. This problem is refereed as the backoff counter consecutive freeze process (CFP), and was extensively analysed by Xianmin Ma and Xianbo Chen in [11]. They show, with their model and simulations, that the solution would be the ability to increase CW in broadcasting. The second and most significant problem in the case of wireless audio broadcasting is that there is a high likelihood for two or more STAs to choose concurrently equal backoff value. It is easy to understand that when we have fifty or more STAs producing continuous data and they are performing the backoff process using a CW=15 (like in 802.11g & 802.11n) this is highly possible. In this case a collision is occurring and a data packet is lost as there is no recovery mechanism and no time for retransmission.

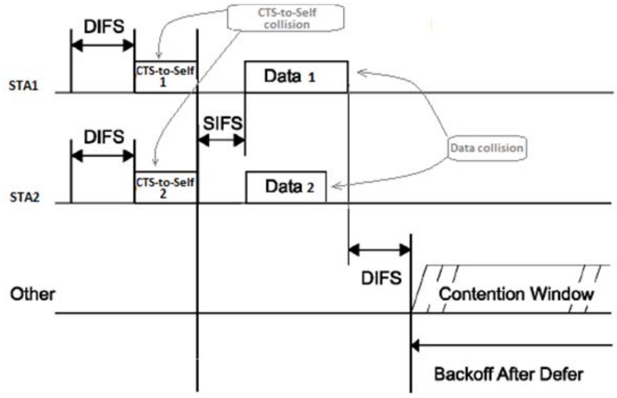

Fig 2: CTS-to-Self and data Collisions

The use of CTS-to-Self does not make any improvement in this case as collided CTS-to-Self messages cannot be identified. As we can see in figure 2, two STAs with the same backoff time (STA1,2) will transmit a CTS-to-Self simultaneously. None of the two will identify the collision because CTS-toSelf1_time=CTS-to-Self2_time. After that, they will both, sense the medium idle for a SIFS and they will transmit their data causing another collision. In addition, NAV1 and NAV2 cannot be distributed to the nearby STAs.

III. MODIFIED IEEE 802.11 MAC MECHANISM

As it mentioned earlier in this paper in order to override the inability of the 802.11 protocol in handling multiple broadcasting audio data, a modified MAC mechanism is proposed. The amendments focus on two main areas, the NAV distribution and the random backoff algorithm.

A. *The OPNET Modeler network simulation platform*

All modifications to the standard IEEE 802.11 MAC were made using OPNET Modeller network simulation environment. OPNET modeller is a powerful simulation tool which allows users to have full access to the executed code and gives the ability to create and modify complex communication protocols. It has its own C++ library and it is using state machines to design and implement processes. For our implementation the OPNET wireless station node model is used.

B. *NAV distribution using CTS-to-Self*

NAV distribution is normally used in broadcasting only in cases where legacy technologies coexist with an ERP (802.11g) or HT (802.11n) physical (mixed-mode networks). It is achieved by sending a CTS-to-Self control frame in appropriate (usually lower) data rate and modulation that all STAs can understand. CTS-to-Self frame contains in its duration field the time that all non-transmitting STAs must defer before trying to access the medium.

In our modified MAC we proposed the use of CTS-to-Self control prior to every data transmission. In order to decrease delay the MAC process is reprogrammed to transmit this control frame using the operational data rate used for data transmission. In OPNET's standard wireless station node model the *wlam_mac* process is handling the 802.11 MAC algorithms. In *function block* of this process where all frame exchange function are defined, the necessary modification has been done in the code in order for the CTS-to-Self frame to be transmitted in all cases prior to every data frame transmission.

C. Linear increase of CW

According to the IEEE 802.11 standard, in broadcasting the CW remain unchanged and always hold its minimum value. This results in busy networks for broadcasting STAs to unfairly compete for the access to the medium. In this modification, the CW dynamically change according to variation of the broadcasting STAs in the network. For this purpose a variable (*N_of_STAs*) indicating the number of broadcasting STAs is created. The number of backoff slots is a random value between 1 and a number which is never less than a minimum CW. The simulation is based on IEEE 802.11g PHY, with a bit rate of 54Mbps.The minimum value of the CW for this PHY is 15. In OPNET the '*wlan_dispatch*' process and the '*wlan_mac*' child process are modified. In the *wlan_mac* process *(BKOFF_NEED state)*, the backoff slots allocation algorithm has been changed according to the above logic.

D. Exclusive Backoff Number Allocation algorithm (EBNA)

In order to prevent STAs from choosing similar backoff numbers which leads to a collision regardless the use of NAV distribution mechanism, an EBNA algorithm is implemented. This algorithm linearly increases the size of CW according to the number of broadcasting STAs in the network. It is also designed to maintain fairness while allocating exclusive backoff values for each transmission attempt. In order to do this, the algorithm needs two external variables, the total number of STAs in the BSS (*No_of_STAs*) and the Station ID (*STID*) that every STA obtains upon joining the network. The CW is always given by:

$$CW = No\_of\_STAs * 2$$

The algorithm divides the CW in two equal groups. Values in the groups are allocated as follow:

$$group1 \leqslant No\_of\_STAs/2$$
$$group2 > No\_of\_STAs/2$$

For each transmission attempt a random value between 1 and 2 is generated in order to select one of the two groups. If group1 is selected the algorithm allocates to the STA a backoff value equal to its STID, in other case the value given by the algorithm it is a projection of the STID value to group 2 and it is given by the formula:

$$Backoff\_slots = [(No\_of\_STAs * 2) - STID] + 1$$

For a network with 10 STAs the station with STID=2 will take randomly one of the backoff values 2 or 19 while a station with STID=6 will take the backoff value 6 or 15 (fig. 4). The pseudo-code describing the above process is illustrated in figure 3.

```
No_of_STAs=10    %total no of stations
STID=2           % current station
Group=rand (1,2)
if (group=1)
   backoff_slots=STID
else
   backoff_slots=No_of_STAs*2-STID+1
end if
```

Fig 3: Exclusive Backoff Number Allocation algorithm pseudo-code

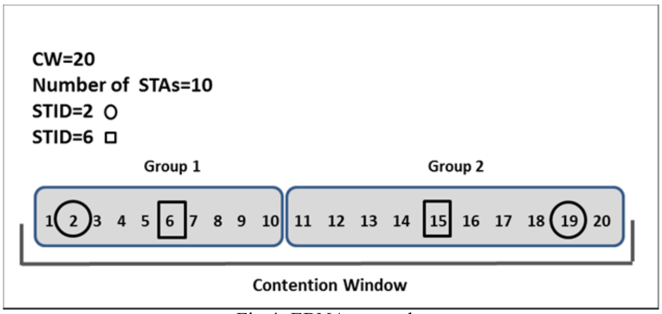

Fig 4: EBNA example

Both cases described in C and D, are implemented in OPNET by modifying the '*wlan_dispatch*' process and the '*wlan_mac*' child process. In the *wlan_mac* process (*BKOFF_NEED state*), the backoff slots allocation algorithm has been changed according to the above logic. Figure 5 shows a 3D snapshot of the backoff number allocation process while figure 6 shows the fairness of the EBNA algorithm over the time as it is illustrated for to different broadcasting STAs during the same simulation by presenting the mean average of backoff values for these STAs.

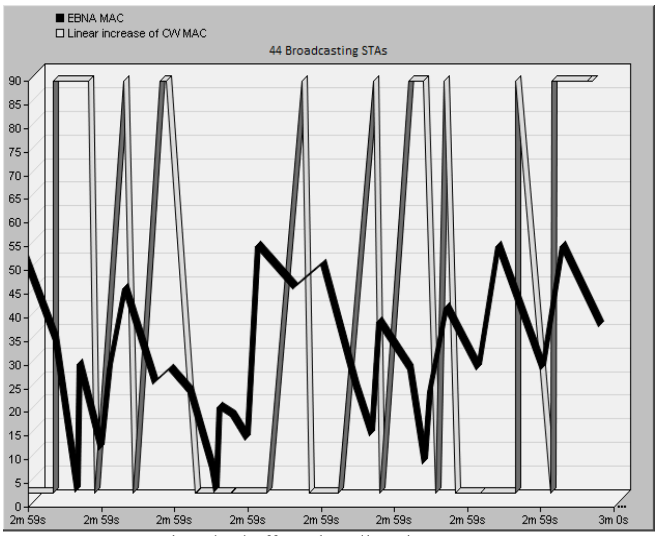

Fig 5: backoff number allocation process

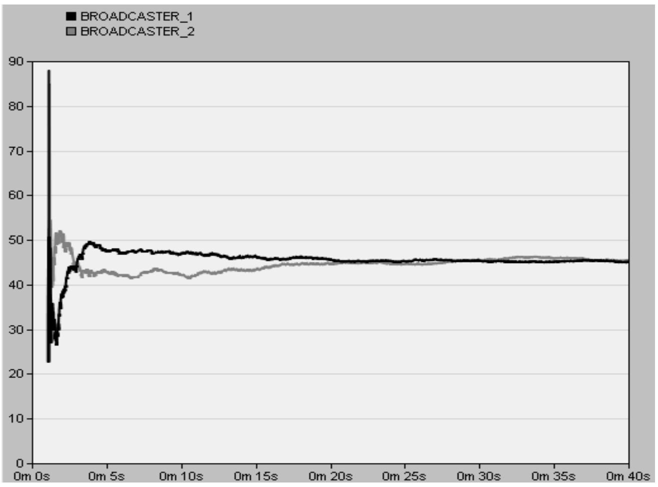

Fig 6: Mean average of backoff values

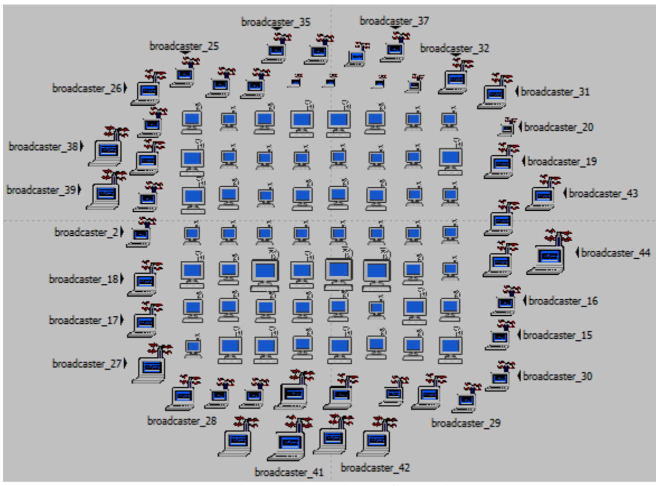
Fig 7: Network configuration

IV. SIMULATION CHARACTERISTICS AND RESULTS

A. Simulation characteristics

The network simulation platform used in this study is OPNET Modeler 17.1. The simulation is based on IEEE 802.11g PHY, with a bit rate of 54Mbps.

The topology is based on an ad-hoc network in a single BSS, with 56 unicast STAs located in the middle and broadcasting STAs randomly surrounding the unicast group in a 50x50m surface. The number of broadcasting STAs is gradually increased from 4 to 40, taking sequentially the values 4, 8, 16, 24, 34, and 44. The simulation duration is 3 min. This is enough time for the system to reach its steady state. Three separate simulations have been conducted where all stations were relocated and also a different seed number has been set during the simulation execution. The presented results are the average values, in those cases where significant differences occurred. All data traffic generation parameters for unicast and broadcast traffic are listed in table 1.

Unicast traffic	
Start Time	Normal Distribution (0.5, 0.1)
On-State	180 sec
Off-State	0 sec
Interarrival Time	Normal Distribution (0.1, 0.005)
Packet Size	2200 bytes
Broadcast traffic	
Start Time	Normal Distribution (1, 0.01)
On-State	180 sec
Off-State	0 sec
Interarrival Time	Constant (0.0243)
Packet Size	1100 bytes

Table 1: Traffic Generation Parameters

Figure 7 shows the network configuration for a population of 56 unicast and 44 broadcast STAs. The resulting load transmitted by each broadcasting STA is approximately 370Kbps while unicast STAs are transmitting with a bit rate of 77Kbps.

B. Simulation results

The statistics collected during simulations are global throughput, end-to-end delay, retransmission attempts, overall number of backoff slots and number of collisions encountered during the simulation for the entire network. For each increase of the broadcasting STAs population a separate simulation is performed. The results from all the above measurements are presented below [12].

Collisions:

This statistic describes the total number of collisions encountered in the entire network during each simulation. This is not a standard OPNET statistic. In order to obtain this measurement the OPNET *wlan_mac* process is equipped with a counter which increases every time the collision flag in OPNET is set. The accuracy of this custom statistic was validated using the OPNET collision status statistic which indicate the present of a collision but cannot describe the total number of collisions for the entire simulation. As we can see from figure 8, the number of collisions in the network are lower by using the EBNA algorithm and most important, maintain stability as the number of broadcasting STAs increases.

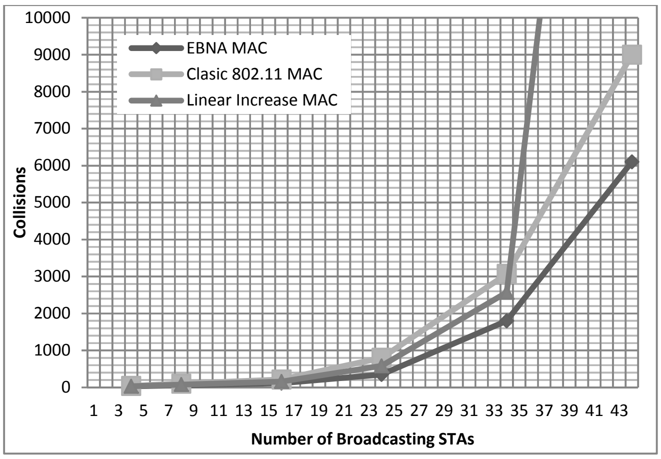

Fig 8: Total number of collisions

End-to-End Delay:
This statistic shows the overall end-to-end delay for the entire network. As it is expected, the delay increases with the use of the EBNA algorithm as the size of the CW increase. It remains however in acceptable levels. The simple linear increase leads to saturation of the network when the number of broadcasting STAs critically increases. It is however important to note that the good performance of the classic 802.11 MAC is fictitious because it is measured only for successfully transmitted packets. That means that a good performance of a network when it comes to delay does not mean necessary a good throughput. Figure 9 shows the end-to-end delay measurement for the three different MAC implementations.

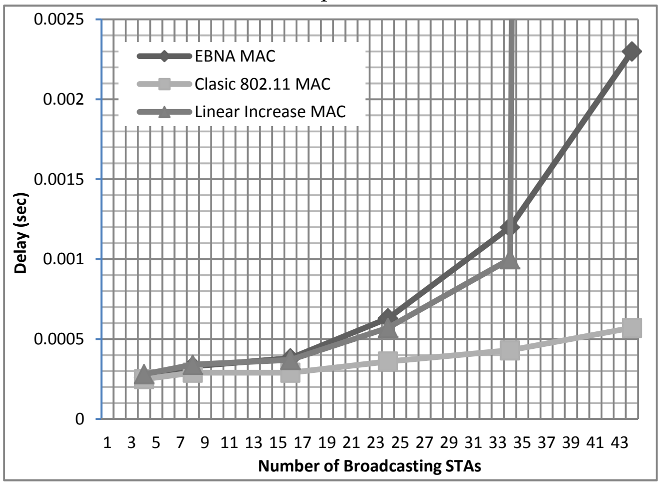

Fig 9: Overall end-to-end delay

Number of backoff slots:
The average number of backoff slots is measured in this statistic. This number is higher for the EBNA MAC because of the design of the algorithm. This also can be shown from figure 5 where both techniques are illustrated in parallel. Figure 10 shows the number of backoff slots results.

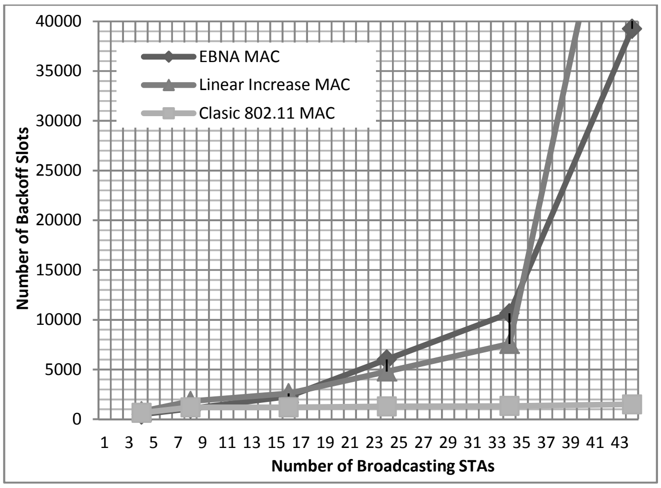

Fig 10: Number of backoff slots

Retransmission Attempts:
This statistic measures the average retransmission attempts for each packet for the entire network. It is shown from this measurement also, that the use of the EBNA approach gives better performance for this type of wireless networks.

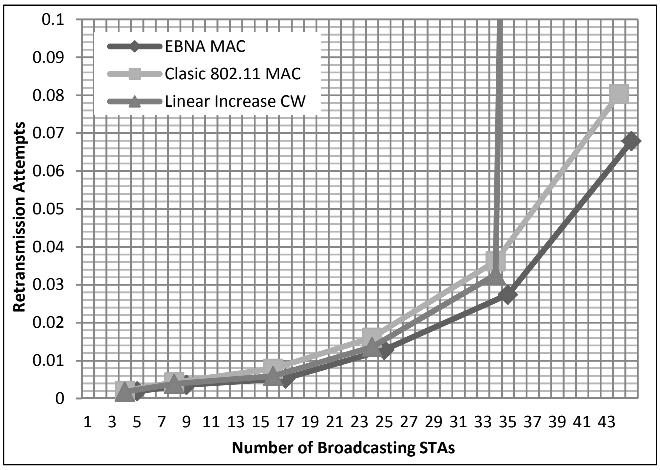

Fig 11: Retransmission Attempts

Overall Throughput:
This statistic represents the total number of bits (in bits/sec) forwarded from wireless LAN layers to higher layers in all LAN STAs of the network. As it is shown from figure 12, both modified MACs are performing better than the classic 802.11 MAC when the number of the broadcasting STAs are small. When the number of STAs critically increases, EBNA approach maintains stability while simple linear increase of CW leads to saturation of the network.

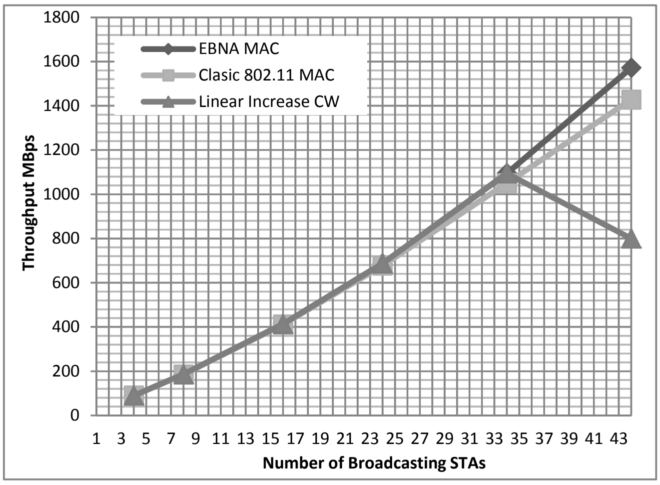

Fig 12: Throughput

V. CONCLUSIONS

In this paper we are examining the ability of the IEEE 802.11 standard to handle multiple broadcasting media type traffic in a mixed broadcast/unicast environment. We first analyse the standard and highlight its drawbacks. The problems are mainly in the way that 802.11 MAC is handling broadcasting and more specific in random backoff algorithm and also in the lack of a NAV distribution mechanism. To address these problems a modified MAC was proposed. In this amendment, the NAV distribution is achieved by using CTS-to-Self control frames which are transmitted with the operational bit rate of the network, prior to each data transmission. In addition two alternative approaches are proposed and tested, a linear increase of the CW and also random backoff Exclusive Backoff Number Allocation (EBNA) algorithm. This algorithm implements a linear increase of CW according to the number of STAs, while fairly allocates exclusive backoff values to each STA. This modified 802.11 MAC is simulated and the results shows that it drastically improves its performance in a multiple broadcasting environment. As it is expected the End-to-End delay is increased. This is caused by the additional control traffic due to CTS-to-Self transmission and also due to the increase of the CW. The classic 802.11MAC keeps the CW size at its minimum level which for ERP and HT technologies this is extremely small. That gives an impressively low delay but this is only measured for the traffic that manages to be delivered. When loss is becoming high this low delay does not have an important meaning. Using the modified 802.11 MAC proposed in this paper the delay remains in acceptable levels. In addition, the EBNA algorithm maintain fairness during the backoff values allocation process, while keeps the size of the CW in relatively low level.

REFERENCES

[1] Yamaha System Solution “white paper”, an introduction to networked audio, YamahaComersial Audio 2006, C. Bakker, H.Hamamatsu, T.Harison

[2] AES White Paper: Best Practices in Network Audio, JAES Volume 57 Issue 9 pp. 729-741; September 2009

[3] A. Floros T. Karoudakis, Delivering high-quality audio over WLANs, AES 116th Convention, 2004.

[4] Kevin Gross, Audio Networking, Application and Requirements, JAES Volume 54, No.1/2, January/February, 2006

[5] Nakjung Choi; Yongho Seok; Taekyoung Kwon; Yanghee Choi, "Leader-Based Multicast Service in IEEE 802.11v Networks," Consumer Communications and Networking Conference (CCNC), 2010 7th IEEE , vol., no., pp.1,5, 9-12 Jan. 2010

[6] Fluke networks White Paper, Ensuring 802.11n snd 802.11 a/b/g Compatibility, 2011

[7] IEEE Standard, Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, 2007M. Young, the Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.

[8] Brad Williams Tracy Camp, Comparison of Broadcasting Techniques for Mobile Ad Hoc Networks, 3rd ACM international symposium on Mobile ad hoc networking & computing, 2002

[9] Shiann-Tsong Sheuy, Yihjia Tsai and Jenhui Chen, A Highly Reliable Broadcast Scheme for IEEE 802.11 Multi-hop Ad Hoc Networks, Communications,. ICC 2002. IEEE International Conference, 2002

[10] Jenhui Chen and Muwen Huang, Broadcast Engagement ACK Mechanism to Support Reliable Broadcast Transmission in IEEE 802.11 Wireless Ad Hoc Networks, Vehicular Technology Conference, 2004

[11] Xiaomin Ma Xianbo Chen, Performance Analysis of IEEE 802.11 Broadcast Scheme in Ad Hoc Wireless LANs, IEEE Transaction on Vehicular Technology, VOL.57, NO.6, November 2008

[12] Purat, Marcus; Ritter, Tom, Comparison of Receiver-Based Concealment and Multiple-Description Coding in an 802.11-Based Wireless Multicast Audio Distribution Network, JAES Volume 59 Issue 4 pp. 225-238; April 2011