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Classified Medium Access Control Algorithm (CL-MAC) for Enhanced Operation of IEEE 802.11ah

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Abstract—We present in this apaper a high level framework of a proposed Medium Access Control Algorithm known as Classified Medium Access Control Algorithm for enhanced operation of IEEE 802.11ah. IEEE 802.11ah is an amendment for the IEEE 802.11 standard known as Wireless Local Area Network (WLAN) or Wi-Fi network standard. This amendment was mainly established to increase the number of Wi-Fi stations managed by the single Access Point. As more and more number of heterogeneous network stations emerge to also utilize this network, some techniques have been employed to ensure better management of the network but this still remains an open issue that needs to be tackled. This paper presents a hybrid TDMA and CSMA/CA scheme for the channel access in lieu of the default Enhanced Distributed Channel Access (EDCA) of the WLAN. When compared with the result of the EDCA, the proposed scheme provided a better throughput performance for the IEEE 802.11ah amendment.

Keywords— CSMA/CA, EDCA, IEEE 802.11ah, TDMA, Traffic Management.

1. Introduction

In the global world today, the presence of the sensor/actuator devices to interact with the environment has fostered the establishment of new applications and services. The development of smart grids and smart cities are made based on the existence of such sensor/actuator networks in order to achieve a more sustainable utilization of the resources in the environment and also to provide a better quality of life to citizens (Bellalta et al, 2016). IEEE 802.11 task group proposed IEEE 802.11ah to support a network communication known as Machine-to-Machine (M2M) communication as an amendment to IEEE 802.11 (Akeela & Elziq, 2017). This M2M has attracted a lot of users in the industries as well as in the academic environment for ubiquitous communication within devices. M2M which is also known as MTC (Machine Type Communication) (Yue, 2015), is a technique that involves automatic communication between two or more devices without the need for human intervention. Applications scenarios for this technology include smart cities, industrial automation, environment and agriculture monitoring as well as emergency services and intelligent utilities. This M2M has so far been one of the fastest growing technologies in wireless communication. It was employed even in mechanical automation such as Internet of Things (Borgia, 2014). In comparison with the human centric communication technologies, features peculiar to M2M communications include scalability of large number of devices and infrequent transmission of small data. Thus, in order to facilitate M2M solution by existing wireless technologies such as cellular network (known as Long Term Evolution (LTE)) and short range radio (known as the Wi-Fi), such technologies face greater challenges due to the above features. One of the challenges faced is the inability to minimize energy consumption as device batteries are drained very fast which is unsuitable for M2M use cases that take cognizance of energy management. IEEE 802.11ah was then proposed as an amendment for such applications.

IEEE 802.11ah contributes to Wi-Fi networks by extending the range and accommodating up to 8191 stations coordinated by a single AP (Leon, 2015). However, with increasing number of heterogeneous beacon-enabled Stations (Traffic Indication Map (TIM) stations) of different traffic profiles and priorities, to effectively manage the network by the AP becomes an issue. This challenge of poor traffic management results in: data loss that results in low throughput, uncontrollable packet delay and more power consumption by such battery powered stations (nodes) which shortens their lifetime. Therefore in this paper, we are designing an algorithm that will classify the numerous beacon enabled groups of stations into traffic profiles based on battery level, positions to the AP and the application priority. This paper covers the classification of stations into four profiles. It also covers the channel access for the stations in their respective transmission queue. It will also evaluate its throughput performance. With the advent of several heterogeneous stations with different traffic profile and application priorities especially in the urban areas, this research will help in ensuring better quality of life to citizens as regards security through immediate attention to real time applications as slots will be reserved for high priority stations. Details of this paper is given in the next section.

The remaining part of this paper is as follows; Section II describes the background of the network and relevant amendments on the MAC Layer of the standard. Section III analysis the proposed traffic management algorithm for the beacon enabled IEEE 802.11ah stations. In section IV, we described the result for implementing the algorithm with the hybrid MAC while section V shows the conclusion of the paper.

2. System Description

In this section, we looked at technical background of the IEEE 802.11ah starting with the IEEE 802.11 Standard (Wi-Fi) and further gave details of amendments of the IEEE 802.11ah standard in the MAC layer as well as the specific requirements considered as given by the task group.

2.1. WI-FI Network

Wi-Fi is also known as Wireless Local Area Network (WLAN). It is an IEEE 802.11 Standard that connects nodes (stations) with an access point (AP) in wireless communication. In 1997, the version of this standard was introduced to support existing wired LAN with the aid of Ethernet technology (Bellalta et al, 2016). Since then, there have been more functionalities, emerging technologies and amendments. It has been very important as internet access technology and also been very available everywhere. Among the several factors that have immensely contributed to Wi-Fi are the flexibility, ease of use and interoperability. Table I. shows the summarized Wi-Fi amendments which include their released dates and goals.

Table I. Summary of IEEE 802.11 Standard Ammendment

Amendments	Released Date	Band	Goal
IEEE 802.11aa	2012	2.4, 5Ghz	Robust streaming of Audio/video
IEEE 802.11ac	2014	5Ghz	Very High Throughput WLAN
IEEE 802.11af	2014	470-790 MHz (EU)	WLAN in TV White Space
IEEE 802.11ah	2016	902-928 MHz (US)	WLAN in Sub 1GHz license exempt band
IEEE 802.11ax	2019	2.4, 5GHz	High Efficiency WLANs

2.2. IEEE 802.11ah

IEEE802.11ah is a WLAN standard that operate at sub 1GHz ISM (Industrial, Scientific and Medical) band in the license exempt bands (Sun et al, 2013). IEEE802.11ah is employed to reduce power consumption and as well support large number of devices (Stations) by a single Access point. Unlike the conventional 2.4GHz and the 2.5GHz bands of the WLANs technology, IEEE802.11ah provides an increased transmission range with a relatively narrow bandwidth as well as a reliable use for outdoor environment for cellular traffic offloading. Its relevance is felt in reducing the saturation of the two spectra above in limiting the irregular deployment of stations and excessive utilization of channels. This made it easy to deploy 11ah sensors across basements, backyards, garages and market areas that are all connected to a single Access Point. Table II. summarizes the respective features of the IEEE 802.11ah.

Table II. Basic Features of IEEE 802.11AH

Parameters	**Values**
Number of Stations	8191
Network mode	Single hop
Transmission mode	OFDM
Channel Bandwidth	1, 2, 4,8,16 MHz
Range	1000m outdoor
Packet Length	Up to 100 byte
Data Rate	150-4000 kbps(for 1MHz BW), 65-7800KBPS (for 2MHz BW)

In 2010, a task group known as the Task Group ah (TGah) was set up in the IEEE 802.11 working group that triggered the IEEE 802.11ah to work on the Sub 1GHz standardization to ensure better performance in Internet of things (IoT) and applications that involve extended range. Below are specific requirements the group have set for any novel amendment (Adame et al, 2014):

- A numerous stations with power constraint
- Extended transmission range
- Low data rates
- Small and infrequent data messages
- Non-critical delay

The MAC layer of IEEE 802.11ah is designed to increase the number of stations supported by a single AP in the network provided that the energy consumption is minimized. In IEEE 802.11ah, stations are categorized into three based on their respective procedures and periods of time for channel access as seen in Fig 1: they are TIM (Traffic Indication Map), Non-TIM and unscheduled stations (Adame et al, 2013).

TIM Stations only need to listen to beacons from the AP in other to receive or transmit data frame and they must transmit within a RAW (Restricted Access Window) period. The Non-TIM stations need not listen to beacons in other to transmit data. They only negotiate directly during the association process with the Access Point for allocated transmission time in the PRAW (Periodic RAW). Just like the Non-TIM stations above, unscheduled stations need not listen to beacons, they rather send poll frame to the AP requesting immediate access to the channels within the RAW. There is a response frame which indicates periods (outside both RAWs) for which such stations can gain channel access. This is relevant for stations that intend to sporadically join the network.

Enhancement made by the MAC layer of the IEEE802.11ah for desired system requirements include support of numerous number of stations (about 8191 stations per AP), increased energy saving features, efficient mechanisms of medium access, and higher throughput by greater compactness of several frame formats. Some specific features of the MAC layer include hierarchical TIM (Traffic Indication Map) structure, RAW (Restricted Access Window) technique, Non-TIM operation and TWT (Target Wake Time) mechanism as well as long sleeping and waking interval to reduce energy drained by batteries. Relay operations which involve tree-based multihop network are also mechanisms included in the amendment.

3. Related Works

There are some methods that have been employed in traffic management of IEEE 802.11ah to solve the problem of contention, energy consumption, throughput, delay and other important metrics.

In the channel access for TIM stations in IEEE 802.11ah, allocation system for AP-Centralized period is combined with the DCF (Distributed Coordination Function) medium access technique within such periods. Immediately after each period, a time between successive TIMs that contains RAW (that has one downlink, one uplink, and one multicast segment) is placed. In the downlink, for a packet to be sent by AP to a station, the TIM group for such station must be included on the bitmap of the DTIM beacon. Also, the TIM group includes such station in its bitmap. DCF is used by that station for contention as it listens to beacons of its own TIM group and it then sends a Poll frame to get its corresponding data after its backoff elapses. For the uplink, In other to send an uplink message to the AP, a station must first listen to its corresponding TIM group to be aware of time for channel contention through the DCF Scheme. Request to Send RTS/Clear to Send CTS as mechanisms for both basic access and handshake could be employed (Qutab-ud-din, 2015).

EDCA is a channel access mechanism that amends for the Distributed Coordination Function (DCF) of the IEEE 802.11 standard. It is also the default channel for channel access for group of stations in IEEE 802.11 Standards. EDCA uses the CSMA/CA Mechanism and also employs backoff mechanism together with the AIFS (Jun et al, 2009).

Another scheme carried out is a technique known as Grouped Synchronized Distributed Coordination Function (GC-DCF) that uses the RAW and RAW slots to grant access to the IEEE 802.11ah groups of stations (Zheng et al, 2014). It yielded about seven times the throughput of the pure DCF scheme. In (Tian et al, 2016), the paper carried out a research to also use the RAW to distribute stations into various group but could only grant a particular group of stations medium access simultaneously without priority. In Virtual Grouping and Power Saving Techniques for IEEE 802.11ah enabled M2M networks, a random AIFSN scheme that complies with the CSMA/CA protocols was employed (Ogawa et al, 2013). parameters (randomly selected by the stations) are distributed by the AP to each station through a data frame against traffic congestion. The method provided a good throughput and delay as well as an improved power saving compared to the conventional DCF considering 6000 stations. However, it only employed the AIFS parameters without considering other important parameters in prioritized grouping. In order to reduce association delay of IEEE 802.11ah network in (Pranesh & Jae-Young, 2017), a mechanism is introduced as authentication control for classifying stations into groups and identifying the best group that allowed specific groups to communicate over the channel in a beacon interval. There was a fair medium access considering a large number of stations. The best group size ensured minimum access delay. Although the throughput of other groups were not much considered. Grouping of real-time stations in IEEE 802.11ah dynamic traffic IoT networks Parameters for Optimal RAW grouping was determined using a traffic adaptive RAW algorithm (TAROA) to enhance (Tian et al , 2017). The TAROA then assigns RAW slots to the stations with respect to their transmission frequency. TAROA performed better compared to EDCA/DCF on scalability and throughput.

the impacts of latency and throughput

So far from our researches, we have not seen a developed algorithm based on prioritized classes of stations to enhance the performance of IEEE 802.11ah networks. Thus our scheme will be compared with the EDCA based on the conclusion as shown in Table III.

Table III. Comparing te Features of both EDCA and the Proposed Hybrid MAC

Features	EDCA	Hybrid TDMA and CSMA/CA
Access Categories	AC1, AC2, AC3 and AC4	TP1, TP2, TP3 and TP4
Channel Access parameters by a queue	AIFS, (CW_{min} and CW_{max}), TXOP	SIFS, GTS, RTS, CTS, ACK
Channel Access mechanism	Enhanced CSMA	Both TDMA and CSMA/CA
Prioritized Scheduling	No	Yes
Reserved slots	No	Yes

4. Classified Management Traffic Algorithm

In line with the review of existing techniques adopted for protocol amendments in wireless sensor networks especially the Queue-MAC technique (Zhuo *et al*, 2012), an algorithm is proposed to ensure better management of traffic for prioritized scheduling of stations in order to reduce overheads and congestion and as well reduce energy consumed by the batteries. This can be achieved by employing the algorithm and then modify the Queue-MAC technique in the MAC layer. Fig. 1 shows the positions of stations in the respective class.

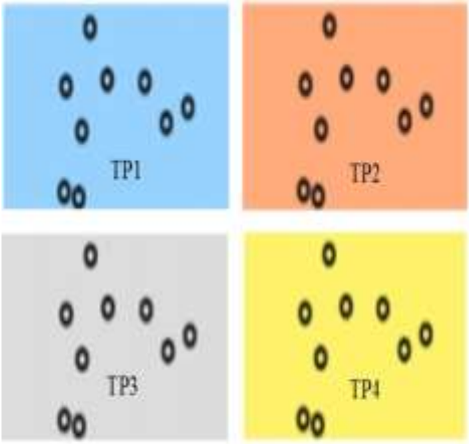

Figure 1. Scattered Positions of Deployed Stations for Respective Traffic Profiles

4.1 Classification of Stations

The classification was made with respect to the traffic profiles for access to channel. The random distribution of the stations into traffic profiles based on location to AP (which is at the centre) is as shown in Fig 2:

The terms TPs (Traffic Profiles) are described with respect to their features and further analyzed well in Table III: As the payloads of stations are available to be sent to the AP, each of the traffic profiles can have either a real time or non-real time packets, their battery levels and distance to AP can also be similar or different. AP observes from the Group Association Packet sent by the stations and then class each into any of the group as regards the information of each station as shown in Table IV.

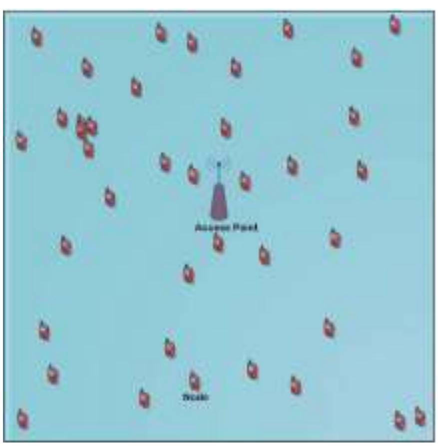

Figure 2. Random Distribution of Stations (Nodes) with ap at the centre of the Playground

Table IV. Classification of Stations

Classes of Grouped Stations (TP1, TP2, TP3 or TP4	REAL TIME PACKETS	NON-REAL TIME PACKETS	≤ 50% BATTERY LEVEL	> 50% BATTERY LEVEL	AT MOST 200m DISTANCE TO AP	ABOVE 200m DISTANCE TO AP
TP1	✓	✓	✓		✓	
TP2	✓	✓	✓			✓
TP3	✓	✓		✓	✓	
TP4	✓	✓		✓		✓
TP1	✓		✓		✓	
TP2	✓		✓			✓
TP1	✓			✓	✓	
TP2	✓			✓		✓
TP3		✓	✓		✓	
TP4		✓	✓			✓
TP3		✓		✓	✓	
TP4		✓		✓		✓

TP1: This is the class with the highest priority. It is nearer to AP (<200m to AP) and with packets that contain mostly real time applications.
TP2: This is the second category which is farther from AP (>200m to AP) and with real time applications.
TP3: This class has stations that are nearer to AP (>200m to AP) and packets contain mostly non-real time applications.
TP4: This is the traffic profile whose stations are farther from AP (>200m to AP) and packets have mostly non-real time applications

4.2 Design of the Traffic Management Algorithm

The algorithm shows the flow chart for the traffic mechanisms that will be implemented on the AP. Four different buffers are considered for scheduling which are as shown in Fig. 3.

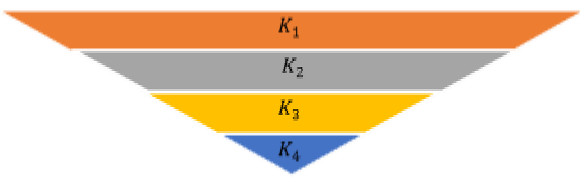

Figure 3. Diagrams showing different hierachy of buffers

From the figure, K_1 represents the buffer for the highest profile priority TP1. This is the first buffer where the packets from the stations are processed before relayed to the receivers. It has the maximum capacity in which packets can no longer be buffered. Followed the K_1 is the K_2 and other buffers in the order of priorities.

4.3 The Modified Queue-Mac Design

The Access Point broadcasts periodically beacon frames in order to split time into repeating superframes with both active and inactive periods. Activities and communications are arranged in the active period while all the stations are on sleep mode (radios are turned off) in the inactive periods for energy conservation. Fig 4 shows the packet structure of the AP MAC. The Group Association Packet (in lieu of the Queue indicator) includes the respective traffic profile (TP1, TP2, TP3 or TP4) that give the information of the load of the stations as in Fig 4.

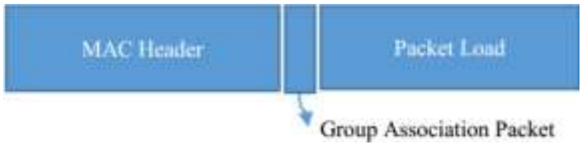

Figure 4. MAC Packet Structure

In the superframe structure of the AP in Fig. 5, there exist the variable TDMA, the CSMA/CA and the inactive period in the IEEE 802.11ah RAW period between the beacon intervals.

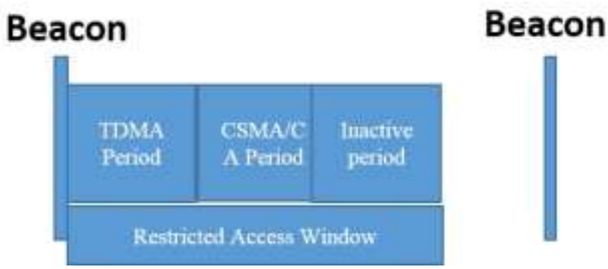

Figure 5. Superframe structure

The TDMA slots are assigned based on traffic priority and load of nodes as notified by the Group Association Packets. More TDMA Slots are granted if the capacity of the buffers are not filled. There is also an amount of Guaranteed Time Slots GTS reserved for high priority stations. Assuming request for GTS allocation by the TP1 and TP2 are piggybacked onto the packets without the need to send certain control packets in advance. A fixed CSMA period is then employed to cater for nodes that may not have access to TDMA slots. All nodes will now be in a sleep mode to conserve energy during the inactive period.

As regards the CSMA period, the stations that are yet to be granted channel access contend for the limited channel. GTS will be available for TP1 and TP2 Stations upon request. Then the other two categories contend with the four way handshake of the CSMA/CA mechanism. The four way handshakes are in the order RTS-CTS-Data-ACK.

In this mode of contention, a station first senses for free channel, sends RTS (Request to Send) to the AP and waits SIFS (Short Interframe Space) period for CTS (Clear To Send), the AP then sends CTS to the stations if the channel is idle. Then the station waits further SIFS period and then transmit after the SIFS period. The station also waits further SIFS for ACK upon successful reception of the packets and check for packets available. But if ACK is not received (as a result of collision), the station goes back to backoff counter and transmit available packets or otherwise terminate communication. If the medium is busy, the station goes to back off timer (for time when the channel will be free again) sending a back off counter, transmit immediately and thereafter receives an ACK for successful transmission. All classes of stations go on sleep mode in the inactive period until they receive another beacon from the AP before waking up to listen again.

4.4 Flow Chart For The Traffic Profile Access

From the flow chart in Fig 6, the packets to be sent to the receiving stations are first buffered in their forwarding queue. Each of the buffer has its capacity, (that is maximum number of packets in its queue). Each packet is served based on time of arrival. Thereafter, access for channels are started based on the profile and the information of the queue indicator of each node. TDMA slots are available for all the classes but priority is granted from the first categories to the last. For stations that were unable to transmit in the TDMA period, they can then contend to transmit in the CSMA period. Guaranteed Time Slots are also available for TP1 and TP2 within this period to enable real-time transmission without delay. CSMA/CA protocol is employed to cater for light traffic of nodes without TDMA slots where each node contends for channel access.

5. Simulation Results

A very reliable network simulator for discrete events known as NS3 was employed for IEEE 802.11ah (Tian *et al*, 2016). A TDMA module was added in the NS3 for periodical transmission. We then enabled a hybrid TDMA and CSMA/CA Wi-Fi network. We input the physical data rate of the Wi-Fi mode, the slots value for TDMA users, varied TDMA cycle value and other parameters. We ensured that packets to be transmitted with TDMA are sufficient. The throughput of each class is measured with increasing number of stations from 32 to 1032. Fig. 7 shows the result at the end of the work considering the required parameters. Evaluations were carried out for each class in both EDCA and the CL-MAC (the hybrid MAC proposed). When compared with the EDCA, the performance of the proposed scheme provides better output of the two most prioritize classes showing greater throughput.

Table V. Default and Assumed Parameters for Simulation

Parameters	TP1	TP2	TP3	TP4
Data rate	150kbps	512kbps	1024kbps	1024kbps
DIFS	186μs	212μs	238 μs	264μs
SIFS	160μs	160μs	160μs	160μs
CW_{min}	1	3	7	15
CW_{max}	1023	1023	1023	1023
Number of Stations	32 – 1024			
Payload size (bytes)	256			
Wi-Fi mode	MCS8, 2MHz			
Size of playground	400m by 400m			
MAC Header (bytes)	12			
Length of ACK (bytes)	14			
Length of RTS (bytes)	20			
Length of CTS (bytes)	14			
RAW Duration	500ms			
Beacon Duration	10ms			
TDMA Period	300ms			
TDMA Slots for one Packet	5ms			
TDMA Slots duration	4ms			
CSMA period	90ms			
Inactive period	100ms			
Slot time T_{slot}	52μs			
Channel Bandwidth	2MHz			
Max capacity of forwarding queue of each station	50			
Maximum Capacity of buffers (Packets)	K1- 100 K3- 50		K2- 75 K4-25	

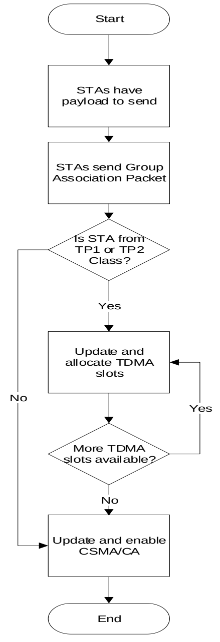

Figure 6. Flow Chart for the CL-MAC Algorithm

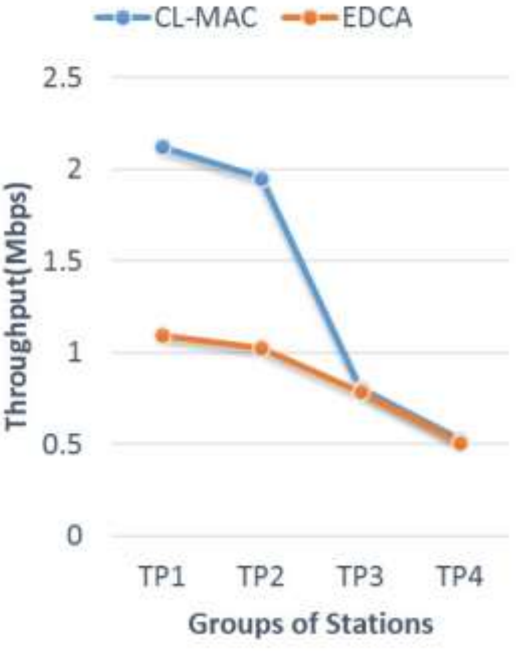

Figure 7. A Compared Result for the Proposed Alggorithm and EDCA.

6. Conclusion

We discussed in this paper, IEEE 802.11ah and its amendments with respect to traffic management. We first looked at its basis (the Wi-Fi) and then explained its features such as the MAC layer channel access mechanisms for the numerous stations. Finally, we developed a classified traffic management algorithm for beacon-enabled IEEE 802.11ah stations and showed the simulation result of its performance and then compared it with the EDCA scheme. The results show that the CL-MAC is a better scheme for the IEEE 802.11ah amendment than the EDCA in terms of throughput.

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