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Review of 802.11 based Wireless Local Area Networks and Contemporary Standards: Features, Issues and Research Objectives

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Abstract- Wireless local area network (WLAN) provides robust high quality service at a low cost and is a an essential part of everyday web browsing, file exchange, texting, e-mailing and to access live audio/video streams at homes, in public places such parks and airports, and in private places such as offices, enterprise environments, retail stores, and hotels. The adoption of the technology is also increasing in services providing emergency relief measures and in service mechanisms of public safety to ensure quick channel access for several emergency situations at the same time with critical assurances of a hard-and-fast guaranteed quality of service (QoS). The technology is being developed for guaranteed high rates of transmissions for the future of large scale wide area networks implemented at present using mostly wired networks. The advantages of wireless local area networks (WLANs) over wired local area network are many including the ease of fast network access and have at the same time several challenges in providing signal stability, issues of security provisioning, and ensuring usage based on scalable environments. In this paper we investigate in the WLANs the various existing problems, the challenges faced in solving these problems, and the direction of current research activities in providing Quality of Service.

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Abstract- Wireless local area network (WLAN) provides robust high quality service at a low cost and is a an essential part of everyday web browsing, file exchange, texting, e-mailing and to access live audio/video streams at homes, in public places such parks and airports, and in private places such as offices, enterprise environments, retail stores, and hotels. The adoption of the technology is also increasing in services providing emergency relief measures and in service mechanisms of public safety to ensure quick channel access for several emergency situations at the same time with critical assurances of a hard-and-fast guaranteed quality of service (QoS). The technology is being developed for guaranteed high rates of transmissions for the future of large scale wide area networks implemented at present using mostly wired networks. The advantages of wireless local area networks (WLANs) over wired local area network are many including the ease of fast network access and have at the same time several challenges in providing signal stability, issues of security provisioning, and ensuring usage based on scalable environments. In this paper we investigate in the WLANs the various existing problems, the challenges faced in solving these problems, and the direction of current research activities in providing Quality of Service.

I. Introduction

WLAN (Wireless Local Area Network) technology generally called WiFi is an easy and efficient alternative to the Ethernet technology based wired LANs for fast and reliable Internet access. A rapidly growing technology WLAN caters to a wide segment of audience with applications in diverse of environments including mobile wifi, transportation wifi, IoT, etc. [1]. The IEEE 802.11 standard for Wireless Local Area Networks (WLANs), was initially released in the year 1997 and has been developed continuously and standardized to include new functions and technologies. Today typically many types of devices include radio interfaces based on IEEE 802.11.

A number of elements have led to the wide acceptance of IEEE 802.11 standards, the major ones being simplicity in usage, flexible in implementation, and having several inter-operable features. The first fundamental characteristic of IEEE 802.11 standards in the beginning was developed for utilization in the unlicensed spectrum area that is generally easily available globally and called ISM (Industrial Scientific and Medical) bands in 2.4 GHz (12 cm) UHF and 5 GHz (6 cm) SHF ISM radio bands. In these bands anybody may deploy a WLAN easily by meeting specific conditions like maximum transmission power, etc. A flip-side to this is that the problems usually overlooked during WLAN deployment is the interference among the WLANs. Also to handle the ever rising demand for network access in hotspot regions the installation of base stations in huge numbers causes network densification [2]. All these problems of network speed and availability create challenges in assuring performance levels with QoS. A second important feature of IEEE 802.11 standards is that it is based on the Media Access Control (MAC) protocol known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The important factor for using this protocol is the half-duplex characteristic of systems based on IEEE 802.11, due to which a station is unable to detect a collision similar to an Ethernet based transmission as it does not carrier-sense/receive in the process of sending data. The key benefits of using CSMA/CA scheme are the easy operations involved for accessing the channels and the implementation is inexpensive since the radio interface is not inflicted with stringent time requisites. Also the CSMA/CA protocols offer scalability, simple mobility support and decentralized network architecture covering wide range of networks such as classical ad-hoc networks and the latest and evolving people-centric networks [3], [4]. However the drawback with the CSMA/CA protocols is the transmission is based on best effort that reduces the QoS offered. The research has focused on overcoming these problems by developing systems (e.g, IEEE 802.11e amendment) for enhanced QoS delivery [5].

The drawbacks in the WLAN products introduced in the beginning led to the development of IEEE 802.11 standards [6]. An important factor in this design evolution has been the focus on improving the throughput and develops high-throughput WLANs mostly due to the implementation of new physical-layer techniques. One of these techniques that is implemented initially is the OFDM (orthogonal frequency-division multiplexing) technique that attains

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maximum data rates of 36 Mb/s. The implementation of the IEEE 802.11n amendment with multiple-input multiple-output (MIMO) technologies in 2009 saw the WLANs throughput performance finally almost equaling the throughput achieved with Ethernet based wired networks [7]. Also during that time, with the introduction of newer amendments of the first IEEE 802.11 standard varied applications of WLAN products in several different domains was possible. An example is the was acceptance of the IEEE 802.11p amendment in 2010 that improvises the basic IEEE 802.11 standards to offer additional communication support for vehicle-to-vehicle (V2V) and vehicle to infrastructure (V2I) (called V2X in combination) using the 5.9 GHz band licensed for Intelligent Transportation Systems (ITS) [8]. In continuation to this amendments the IEEE 802.11s amendment that defines rules for implementing wireless mesh networks over the existing IEEE 802.11 MAC protocol [9] is accepted in 2011. In this amendment guidelines are laid out for the components of new infrastructure required for mesh networks and for the routing protocol to determine routes among these elements in the mesh. The final IEEE 802.11 standard also known as IEEE 802.11-2012 merges and organizes all the IEEE 802.11 improvements implemented between 2008 and 2011 and represents all the amendments released with a single specification [10].

This advancement in the technological specifications of WLAN standards is constantly evolving with new amendments. In finalizing the major amendment IEEE 802.11–2012 the team for developing the standards also readied themselves for devising the next generation WLANs [11]. They predicted three main driving factors: (i) communication using Machine-to-Machine technologies (ii) Communication of high-definition multimedia (iii) communication using spectrum sharing with licensed bands and cognitive radio techniques. The latest developments in Internet of Things (IoT) where internet connected smart devices using very less power connect household appliances and smaller devices powered by tiny batteries [12], have driven the development of WLAN technology [13,14]. The increasing use of various networking and multimedia technologies enabled mobile devices and simultaneous increase in the usage of advanced multimedia applications has elevated the consumption of mobile video data so much that in 2013 video data share of the total data traffic used up globally by mobile devices was more than 50 percent [15]. All this have made WLANs to be ready with capabilities to handle different multimedia based applications for multimedia that is real-time and interaction based and for lives or storage based multimedia streaming [16].

The possibilities of the using the extra spectrum available in the television allotted spectrum white spaces are further opportunities that could be beneficial for enhancing WLANs access in rural areas using cognitive radio techniques [17]. The next-generation amendments being developed after the previous 2012 amendment should have these capabilities to handle the requisites of the new age applications. Here the very important versions in terms of the latest application requisites are among others, IEEE 802.11aa accepted in 2012, IEEE 802.11ac accepted in 2013, IEEE 802.11ad accepted in 2012, IEEE 802.11af accepted in 2013, IEEE 802.11ah being developed and anticipated in 2016, and IEEE 802.11ax being developed and due by 2019.

We have in this paper surveyed the major implementation challenges of WLANs that we have determined previously in this section and those faced in utilizing new generation models of data consumption and applications. Next using these use cases a specific set of IEEE 802.11 amendments, IEEE 802.11ac, IEEE 802.11ax, IEEE 802.11aa, IEEE, 802.11ah and IEEE 802.11af, are classified and reviewed based on how they handled the described challenges and how they achieved improvement by implementing the newer techniques and functions like, group cast communications, multi-user MIMO techniques, spectrum databases and channel sensing, dynamic channel bonding, efficient small data transmissions, and enhanced power saving mechanisms. Here it is essential to realize that IEEE 802.11 specifications essentially do not describe the complete processes rather various organizations are offered essential blocks with the interfaces for constructing compatible processes. We have in this paper reviewed in detail the key research performed in different areas and have made an attempt to explain the challenges that are open technically.

Lastly we assess the evolving new technologies in the field of WLANs and focusing on Programmable WLANs and the mechanisms of LTE-WiFi internetworking. The survey comprehensively covers the WLANs features that are of maximum relevance. The subject of IEEE 802.11 standards due to their significance associated with WLANs has given many surveys however the focus of these surveys has been on describing the various classes of the MAC protocols that have been developed [18]. The research paper [1] offers a detailed summary of the contributions of various approved amendments that were prior to 2010 standardized or were in the process of being standardized. A detailed evaluation of the current 802.11 standards such as the standards of the IEEE 802.11s amendment are given in the recent surveys [19] [11], [16], [20]. However there are no surveys published that review the challenges faced in implementing the current requirements and standards of WLAN.

II. Nomenclature of Issues and Challenges in Current 802.11 based WLAN

WLANs used widely today for fast wireless network access is undergoing transformation in its applications due to the growing number of Internet users, web services, internet based applications, and mobile devices such as smart-phones, tablets, etc increasing the demand for mobile-rich multi-media content. The progress of Internet of Things (IoT) based uses that gather data ubiquitously using low-powered sensors fitted in various equipment such as home appliances, in consumer electronics, wearable devices such as smart bands and in connected cars has driven the evolution of new generation WLANs in terms of the emerging requirements and challenges.

a) High-quality multimedia content delivery

The multimedia content of high quality such as high-definition video, audio, and image content can be easily handled by the present multimedia devices such as mobiles, tablets, and other portable devices. In [21] the conditions for a few widely used real-time video applications such as maximum data rate, latency, etc. are reviewed. The web based television and streaming video content services supporting real-time video streaming, and services for sharing stored multi-media image, audio, or video files are the important changes influencing WLAN technology. To access and share multi-media content ranging daily increasing number of users simultaneously connect to a single WiFi network. This requires a high speed network to accommodate this huge traffic and to deliver qualitative service to the users. This requires huge transmission rates in the WLAN and though techniques for encoding videos like the H.264/MPEG- 4 AVC [22] technique provide very good compression efficiency for assuring quality multimedia services mechanisms particularly devised for multi-media applications based on content-awareness are needed. In this context the standardization groups of IEEE 802.11 take into account several techniques like, single and multi-user spatial multiplexing, channel bonding, group-cast communication protocols, etc. These techniques are explained in detail in Section 3. The IEEE 802.11 amendments that may be referenced for multimedia content services of high-quality are the, IEEE 802.11aa, IEEE 802.11ac, and IEEE 802.11ax amendments.

b) Machine-to-Machine (M2M) communications

The smart devices using sensors and actuators have created a new form of communication. The sensor/actuator networks have led to the development of various services, applications and concepts like smart cities and smart grids for a efficient utilization of public utilities, infrastructure, environmental resources to offer better health, safety and medical opportunities to to the people [23,24].

The Machine to Machine (M2M) technology extends the range of standard Wireless Sensor Network (WSN). The wireless sensor networks consisting of distributed sensor nodes collect and transmit data to a central sink in multiple-hops [25] are extended with devices based on wireless and/or wired networking and related services where without any definitive human interaction, information is exchanged and applications are controlled smoothly. The communication using M2M technologies is also involved with technical challenges similar to WSN technologies and a major challenge in these systems is the use of battery power to run the nodes where the network suffer from very high constraints of availability in power resources. The advantage with M2M devices and systems is that the data used is very less in a unit of time and that too only a fraction of the total time. The energy utilization has to be minimized for accessing channels and in protocols networking without incurring further complexity and extra cost . As the devices have to be idle during lengthy periods new mechanisms for sensors and actuators have to be developed to power the devices.

In M2M communications many wireless protocol standards are used however the standards most widely used are the Bluetooth, ZigBee and BT-LE [12] protocols. Also protocols are being developed optionally as mobile networks encourage linking M2M based devices to the infrastructure of cellular networks for Internet networking [26]. However as a substitute to multi-hop WSNs and cellular networks WLANs are being promoted though they currently are unable to perform the basic M2M communication fulfillments [13]. To extend the network lifetime protocols and technologies that consume very less power have to be developed for the WLANs to be implemented on a commercial scale as the network nodes in thousands have to be linked to a single AP and have to be handled with efficient power management.

c) Efficient use of the spectrum

In the utilization of the ISM bands multiple wireless communication technologies are used such as IEEE 802.11, IEEE 802.15.4 and Long Term Evolution (LTE)-Unlicensed networks, among others causing high spectrum occupancy problems and leads to mutual interference between the wireless networks functioning in the same spectrum area that could bring down all the networks performances. Also the situation is further worsened especially in urbanized areas where huge number of wireless networks is deployed in the ISM band. An example for this situation is a building with many apartment having individual WLANs where different networks functioning in overlapping channels have regular mutual interferences [27]. A solution to this problem is that the new APs would widely be integrated with the Dynamic Channel Allocation (DCA) schemes that would enable run-time handling of their channel selection and update mechanisms.

The scheme that may be optionally used to solve the occupancy problems of spectrum is moving to another section in the spectrum though the newer spectrum region belongs to a licensed holder with interference to these primary users avoided by maintaining WLANs as secondary users. Also the empty TV channels called TV white spaces created recently due to analogue TV transforming to digital TV transmissions and the VHF/UHF bands undergoing subsequent spectrum reorganization. These white spaces could be utilized particularly in rural areas for data communication [28] covering huge areas by using the properties of radio propagation in UHF band. This should be achieved by finding ways of using CSMA/CA protocols with VHF/UHF bands, and gain higher rates of transmission in case of fragmentation of the spectrum.

III. Issues, Challenges and Research Objectives

The present-day research in developing 802.11 based technologies of WLAN must incorporate two major characteristic: (1) know the performance bounds of IEEE 802.11ac to develop new platforms, simulations, and modeling solutions of IEEE 802.11 for WLANs, and (2) develop mechanisms to group STAs for DL-MU-MIMO transmissions, devise smart packet schedulers that can determine when the application of DL-MU-MIMO would exceed the performance of SU-MIMO transmissions, and implement feature for sharing TXOP among various ACs. The tests performed with both these scenarios would yield valuable results and judgments for further developing existing 802.11 technologies and the upcoming amendments.

A second challenge open technically closely related to the above factors is developing better schedulers which take into account the priorities in the traffic, the buffer state, various strategies of MIMO, policies for sharing TXOP, mechanisms to group the STAs, and ensuring fresh CSI feedbacks inclusion so that every active traffic flow achieves throughput maximization and required QoS guarantee. An update of the CSI estimates of all STAs should be available and is significant as it enables the AP to get minimal mutual interference among the spatial streams transmissions giving lesser probability of packet errors and higher rates of transmission. These advantages are good but the disadvantage is that to acquire the CSI from all STAs huge overheads are incurred that increases proportionally as the channel sounding rate and STAs number increases. To bring down the CSI overhead different schemes are being developed. The approach in [29] estimates for every user the stability in the channel to control the channel sounding in case of an available opportunity to cut back on the overhead incurred due to CSI. A closely associated problem is the approach to be followed in grouping the STAs with the intent of determining the STAs groups having compatible or orthogonal channels. The authors in the research [30] review the challenges integral to the difficult task of group assignment and develop a heuristic based solution. TXOP sharing is considered in [31] by presenting two alternative approaches to enhance the considered back-off procedure for the purpose of improving both throughput and fairness.

A third major challenge is in cases of overlapping multiple WLANs using various channel widths where achieve efficiency in spectrum utilization is the requirement. An increase in the width of the channel in theory enables WLANs individually to obtain a higher throughput. Also an opposite effect may be caused if in the region other WLANs are also present and because of inter-WLAN contention the possibilities of the frequency overlapping are also increased [27]. Also adaptive mechanisms are required to be devised for choosing channel center frequency and channel width, and for MAC protocols to select for every transmission the instantaneous channel width. An example is study in [32] of selecting channels if WLANs could utilize multiple channel widths in a game-theoretic framework. The approach in [33] is devised for performing communication among the nodes that have semi overlapping channels and could handle channel interference with greater resilience.

Apart from the above described solutions additional mechanisms much more efficient than capabilities like raw packet transmission and reception must be implemented by the existing WLANs. These functionalities are, to achieve among the APs related to the same administration domain a quick, efficient and robust handoff [34], improve the device-to-device communication (D2D) [35], and increase the multi-AP networks coordination [36]. As for the initial functionality of achieving quick, efficient and robust handoff the amendment IEEE 802.11ai known as Fast Initial Link Setup is aimed for a complete handoff within 46 ms that includes discovery of new AP, and to authenticate and configure the user. The amendment with these functionalities is anticipated to be implemented in 2016. The second functionality is of implementing D2D communication as it eliminates using AP as a relay and enhances efficiency totally due to the reduction in the number of packets to be transmitted. And the third and last functionality of coordination among the multi-AP networks is implemented by using virtual network functions that enables managing multiple APs with a new feature that may in densely populated networks enhance the user experience significantly.

The WLANs have to be densely deployed to provide seamless coverage and achieve high rates of transmission. In this context for improving co-existence with networks in the neighborhood and for the spectrum to be spatially reused, there are two ways of implementing a WLAN, (i) reduce its coverage area through a decrease of its transmitting power, and (ii) accept higher interference levels through an increase of the levels of Clear Channel Assessment (CCA). In case both mechanisms are implemented among neighboring WLANs the number of concurrent transmissions may increase and thus their capacities, and leads to a major challenge of possible effect that is opposite to the desired result because of the increased level of interference negatively impacting the achievable rates of transmissions.

In the context of high WLAN dynamics it is highly important to implement WLAN with adaptive systems even though they are many challenges associated with this implementation. The systems based on adaptability are associated with additional complexity in using the resources of computation and memory. Also the executed solutions do not assure converges as every WLAN has its functionality decentralized.

A very important research factor anticipated to influence and lead effective advancement of the IEEE 802.11aa-based products to support voice/video traffic is the development of efficient scheduling algorithms. This has been possible due to the IEEE 802.11e amendment that introduces two novel mechanisms for QoS-aware access that are, EDCA and HCCA [37] to improvise the initial IEEE 802.11 MAC. The HCCA mechanism generally using a properly designed mechanisms of admission control and scheduling offers hard guarantees of QoS to the traffic flows [38], [39], but its implementation is not often done in WLANs based on IEEE 802.11e due to the complex process and very high cost associated with it. As an alternative the EDCA approach is most used and the motivation for maximum number of literature works has been to improve the performance of EDCA. Several analytical models have been developed by various literature works for different subsets of EDCA functionalities. An example for this is in [40] that is an implementation of the saturation-based performance analysis using differentiation of the minimum back-off window size, the back-off window-increasing factor, and the retransmission limit. In literature's [41], [42] the modeling of the AIFS differentiation is shown. In [43] the model attempts traffic differentiation by capturing all the 4 parameters of EDCA in combination. In [44] the paper reviews the literature of recent times to examine the performance of EDCA in terms of non-saturated conditions and for arbitrary buffer sizes. In [45] an analytical model is presented that in WLAN predicts for a new voice or video flow the QoS levels that may be realized. In [46] a Kalman filter is introduced that estimates in EDCA for every Access Category the active number of transmission queues. The above analytical models could be used for achieving specified performance conditions by devising optimal parameters configuration in EDCA, or for preserving the QoS constraints by devising efficient admission control strategies. An example is the mechanism devised in [47] that with the assignment of contention-window values attempts to attain prior set weighted fairness objectives. In [48] for achieving minimal delay in video traffic a control-theoretic mechanism is proposed

In many of the above approaches proposed the problem is that they view the dynamics of the video traffic based on assuming factors that are mostly non-realistic. Another group of solutions for this problem view the network dynamic conditions to updates the EDCA parameters. In [49], for a WLAN with rigid and elastic traffic the proposed approach optimizes the parameters of EDCA and also performs analysis of the traffic in terms of the interactions among the two types of traffic in the WLAN. In the literature [50] for an assured QoS delivery of voice and video data traffic various mechanisms are defined for bandwidth-sharing. The paper [51] proposes mechanisms for measurement-based admission control. In [52] the approach devised is based on TXOP adaptation that considers transmission queue lengths along with size of the video frames. In these solutions the major challenge is that an optimization and guarantee of performance is not assured as they are heuristic based. A final third group of solution proposes techniques of cross-layer scheduling with the objective of performance enhancement of the video delivery. In the above proposed methods a common factor is that multi-layer video encoding is used along with the importance associated with the frames for the classification of the frames and assigning them to different access groups [53]. An example for this method is the literature [54] that proposes classifiers and waiting time priority schedulers that consider end-to-end delay measurements for dynamically modifying the priority requirements of the data packets. However a challenge in implementing the complicated interactions is the requirement to implement between the MAC layer and video coding applications a further adaptation layer.

IV. Conclusion

In the present studies the primary principles and techniques of designing multimedia streaming in IEEE 802.11 networks are provided for enhancing the performance. In the existing IEEE 802.11 standard implementation there are many new challenges that have to be fully studied in future research experiments. The open technical problems discussed require further research to find solutions for important challenges like scheduling between primary and alternate queues, and mapping of individual frames to multiple queues for achieving graceful voice/video quality degradation.

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