Servicing Delay Sensitive Pervasive Communication Through Adaptable Width Channelization for Supporting Mobile Edge Computing

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Abstract—Over the last fifteen years, wireless local area networks (WLANs) have been populated by large variety of pervasive devices hosting heterogeneous applications. Pervasive Edge computing encouraged more distributed network applications for these devices, eliminating the round-trip to help in achieving zero latency dream. However, These applications require significantly variable data rates for effective functioning, especially in pervasive computing. The static bandwidth of frequency channelization in current WLANs strictly restricts the maximum achievable data rate by a network station. This static behavior spawns two major drawbacks: under-utilization of scarce spectrum resources and less support to delay sensitive applications such as voice and video.To this point, if the computing is moved to the edge of the network WLANs to reduce the frequency of communication, the pervasive devices can be provided with better services during the communication and networking. Thus, we aim to distribute spectrum resources among pervasive resources based upon delay sensitivity of applications while simultaneously maintaining the fair channel access semantics of medium access control (MAC) layer of WLANs. Henceforth, ultra-low latency, efficiency and reliability of spectrum resources can be assured.

In this paper, two novel algorithms have been proposed for adaptive channelization to offer rational distribution of spectrum resources among pervasive Edge nodes based on their bandwidth requirement and assorted ambient conditions. The proposed algorithms have been implemented on a real test bed of commercially available universal software radio peripheral (USRP) devices. Thorough investigations have been carried out to enumerate the effect of dynamic bandwidth channelization on parameters such as medium utilization, achievable throughput, service delay, channel access fairness and bit error rates. The achieved empirical results demonstrate that we can optimally enhance the network wide throughput by almost 30% using channels of adaptable bandwidths.

Index terms— Channel Bandwidth, Adaptable Bandwidth Channelization, Pervasive Devices, Central Frequency, Ultra Efficient Spectrum, Co-Channel Interference, Edge Computing

I. Introduction

Explosive growth in 802.11 products has changed the whole paradigm of networking. A large number of users at public places such as shopping malls, airports, train stations, universities and stadiums use public hot-spots for their communications. Different network nodes associated with same access point (AP) may have variable needs of throughput based on the applications running on these nodes [1]. The wide spread use of media centric applications such as VoIP, video streaming and online gaming has substantially increased the importance of support for delay sensitive applications [2] [3]. These applications require a minimum level of user experience which is based on their throughput requirements. Maintaining said level of user experience becomes critically important when network is operating in saturation mode and network resources are limited. Traditionally, servicing delay sensitive applications [4] is accomplished by implementing quality of service (QoS) frameworks. However the priority que mechanism of various QoS implementations [5] [6] [7] [8] [9] [10] introduces a fairness problem of resource sharing among contending network nodes in saturated network conditions [11]. Moreover, the conventional static bandwidth channelization imposes a stringent upper bound on maximum achievable throughput. In many practical scenarios, this upper bound may not serve the data rate requirements of certain delay sensitive applications such as online gaming [12] requiring intelligently optimized resource utilization [13]. We have witnessed that Mobile Edge Computing has been considered as one key technology to support the collaborative resource allocation. Moving to edge computing at the side of pervasive devices will decrease the overload of communications [14]. This means that to provide sustainable connectivity and optimal distribution of spectrum resources to this large and dense user-base signifies the work on bandwidth efficient protocols.

Current 802.11 b/g/n networks operate in 2.4GHz ISM unlicensed frequency band and divide the available spectrum into 14 fixed width channels of 22 MHz each with 5 MHz guard band between adjacent channels [15]. Channels 1, 6, 11 and 14 are non-overlapping while rest of 10 channels are overlapping. Wi-Fi networks use non-overlapping channels for their communications. Each of these channels consists of 52 sub-carriers. Four out of these 52 sub-carriers are used for transmission of control signals while rest of 48 are used for data transmissions. The close packing of 52 sub-carriers in a single channel results in their overlap, both in the same channel as well as in adjacent channels. This overlapping results in co-channel interference (CCI) [16]. Table I provides the overlapping degrees of channels with respect to channel distances. The design of conventional Wi-Fi networks like 820.11g [15] and its static channelization is not flexible enough to effectively manage scarce wireless spectrum [17]. Moreover, the high density of wireless clients require more number of APs in close vicinity to provide sustainable wireless connectivity [18]. The benefit of deploying more number of APs per unit area is manifold. This includes more number of collision domains resulting in less average channel access time, higher signal strength values, higher network capacity and better network coverage. However, increasing number of APs in a small area results in frequency interference.

In this work, we propose two algorithms for channel width adaptation in wireless networks. We name these algorithms as best effort channel adaptation (BECA) and servicing delay sensitive applications (SDSA). The objective of these algorithms is to optimally manage spectrum resources and effectively servicing delay sensitive applications. Moreover, the impact of dynamic bandwidth channels on network performance measuring parameters such as, achievable throughput, medium utilization, access delay, channel access fairness and bit error rate (BER) has been measured. To test the effectiveness of the proposed algorithms, a test-bed environment of commercially available universal software radio peripheral (USRP) kits and open source GNU radio software has been deployed. As a proof of concept, we have implemented our proposed algorithms on 802.11g wireless networks by modifying transmitter implementation provided at CGRAN (Comprehensive GNU Radio Archive Network) [19] [20] and better explained in [21].

The contribution of this paper can be outlined as (1) Implementation of an adaptable bandwidth channelization for rational distribution of spectrum resources among communicating nodes; (2) Enhancing network wide throughput by optimal use of spectrum resources; and (3) Effectively servicing delay sensitive applications, while simultaneously maintaining equal long term channel access probability of contending nodes.

The rest of this paper is organized as follows: Section II presents a brief summary of related work reported in the literature. The modeling of interference and throughput for adaptable channel widths in WLANs is presented in Section III. Section III-A and III-B demonstrate the proposed algorithms. Section IV provides details of our test-bed and its operations. Achieved results are presented and discussed in Section V. Concluding remarks are made in Section VI.

II. Related Work

In conventional WLANs such as 802.11e supporting for delay sensitive applications is implemented through QoS framework. QoS in WLANs is thoroughly explored in [5] [6] [7] [8]. In [5] authors present a detailed survey of various QoS techniques incorporated at different layers of TCP/IP protocol stack with their classification. In [6] a comparison of QoS provisioning for point coordinator function (PCF), the enhanced distributed coordinator function (EDCF) of 802.11e, distributed fair scheduling (DFS), and Blackburst has been provided. Authors concluded that PCF performance is comparably low from EDCF while the best performance is achieved by Blackburst [22]. In [7] authors evaluated the performance of 802.11 for QoS and modeled the delay and packet loss rate. They concluded that controlling the total traffic rate, the original 802.11 protocol can support strict QoS requirements [23].

Tuning channel-width for better throughput is thoroughly studied in [17] [2] [24] [25]. Authors in [17] proposed SampleWidth algorithm which focuses on throughput enhancement by adjusting channel widths, and discusses the effect of different channel widths on transmission range and energy consumption. Authors in [25] implements a FLUID algorithm which analyses multi-path fading and range enhancements by using variable channel widths [26]. Authors in [27] focused their research on adaptable channel detection and choosing mechanisms. In [2] [3], authors presented an optimal spectrum sharing algorithm and proposed the channel adaptation using USRP devices. They devised the mechanism of accurate determination of channel width, based on the physical layer frame preambles. The main objective of all the proposed algorithms is to improve throughput. Many authors proposed the idea of channel width adaptability which is not fully dynamic. Channels are formulated before the actual transmission and then selected dynamically during the transmission. In [17] and [25], authors used channels of 5 MHz, 10 MHz, 20 MHz and 40 MHz for their experimentation and chose the channels of desired width on the fly.

A notable work on enhancement of network capacity is reported in [28] [29]. In [28] authors evaluated network capacity with respect to node density. This work concludes that small number of users associated with APs having high signal to noise ratio (SNR) values substantially increases network capacity. The work presented in [29] explained the benefits of deploying multiple antennas on APs for capacity enhancements for an N arbitrary nodes network with random node density. To our knowledge no capacity enhancement technique through adaptable channelization has been discussed in literature. Most of the reported work on channel width allocation is based on either fixed or partially dynamic channel width distributions [30].

III. Modeling Interference and Throughput of Adaptable Width Channelization

Assume that a network consists of J nodes (J_1,J_2,....,J_s) and Knumber of APs (K_1,K_2,.....,K_t), where J_i and K_i

TABLE I. Overlapping Degree of Channels with different Channel Distances

Channel Distance	0	1	2	3	4	5	6	7-10
Overlapping Degree	1	0.7272	0.2714	0.0375	0.0054	0.0008	0.0002	0

represent i^{th} node and i^{th} AP, respectively. Each AP uses L transmission channels (L_1,L_2,....,L_u) for communication, where L_i represents the i^{th} channel. As conventional Wi-Fi networks use 14 channels for communications, L_u ranges from 1 to 14. Let J nodes be divided into two types of nodes $O-Nodes$ and $S-Nodes$ where $O-Nodes$ consist of a group of ordinary nodes not running any rate sensitive application while $S-Nodes$ consists of all such nodes that are running delay sensitive applications. The association of any node $(J_i \in O-Nodes) \rightarrow K_i$ or $(J_i \in S-Nodes) \rightarrow K_i$ follows Poisson distribution with probability density function λ as given below,

$$\Pr\left\{(J_i \in O-Nodes) \rightarrow K_i\right\} = \frac{\lambda^{J_i} e^{-\lambda}}{J_i!} \tag{1}$$

$$\Pr\left\{(J_i \in S-Nodes) \rightarrow K_i\right\} = 1 - (\frac{\lambda^{J_i} e^{-\lambda}}{J_i!}) \tag{2}$$

where J_i denotes a node belonging to either $O-Nodes$ or $S-Nodes$ and $\rightarrow$ expresses the association of a node to an AP.

Considering that network is operating in a saturation mode and every node has data to send each time it gets access of the channel then the total time $T_{(total)}$ will be

$$T_{total} = t_{tr} + t_{over} \tag{3}$$

where t_{tr} is the time elapsed in transmission while t_{over} is the overhead time associated with the transmission, which can be computed as given in equation (4).

$$t_{over} = t_{cont} + t_{DIFS} + t_{pr} + t_{SIFS} + t_{pr} + t_{ack} \tag{4}$$

where t_{cont} is the time elapsed in contention (channel access), t_{DIFS} is the distributed interframe spacing time which is equal to 50 μS, t_{pr} is the time required for transmission of physical layer frame preamble, t_{SIFS} is short inter frame spacing time which is 10 μS, and t_{ack} is the time taken for transmission of acknowledgement. The total time taken for transmission of one packet t_{pkt} will then be

$$t_{pkt} = \frac{D}{R} + t_{over} \tag{5}$$

where D is the total payload of data and R is the transmission rate of node J_i. The transmission rate R of any node J_i can be calculated by Shannon-Hartley theorem [31] $R = B\ log_2(1 + SINR(dB))$ and $SINR(dB) = 10\ log(SINR)$ where R is the data rate and B is the bandwidth of the communication channel. The contention based distributed coordination function (DCF) mechanism of 802.11 WLANs ensures equal long term channel access probability for all network nodes. Let's assume that all the nodes are operating under ideal channel conditions with zero collision probability, the total time (T_{total}) will be divided among all nodes equally. Then the total time occupied by any node J_i is given by:

$$T(J_i) = \frac{1}{T_{total}} \tag{6}$$

and the total number of packets (η) that can be transmitted are,

$$\eta(J_i) = \frac{T(J_i)}{t_{pkt}} \tag{7}$$

It is pertinent to mention that the transmission rate of any node is a function of channel bandwidth and corresponding signal to interference plus noise ratio (SINR). Both of these quantities remain static for fixed width channels for static nodes. However if the width of channel becomes adaptable then transmission rate varies significantly. In 802.11 WLAN the SINR is a function of co-channel interference (CCI). Another contribution of this research work is to calculate signal to interference plus noise ratio (SINR) for adaptable width channels.

$$SINR(J_i) = \frac{Pd(J_i,K_i)^{-\alpha}}{N+P\sum\varphi(L_i,L_j)d(K_i,K_j)^{-\alpha}}$$
$$\begin{cases} \forall\ L_i\&L_j \in L,\ K_i\&K_j \in K\ and\ L_i \rightarrow K_i, L_j \rightarrow K_j \\ and\ i\ \neq\ j \end{cases} \tag{8}$$

where P is the transmission power, $d(J_i, K_i)$ is the distance between node J_i and access point K_i, α is the path loss factor which is an integer value ranging from 2 to 4 for a typical 802.11 network, N is the ambient noise and $\varphi\ (L_i, L_j)$ is the overlapping degree between channels L_i and L_j. The expression $L_i \rightarrow K_i$ shows that channel L_i is associated with access point K_i.

Equation (8) is true when the network operates in a saturation mode. As this is not always the case, it is generalized as shown in equation (9) below,

$$SINR(J_i) = \frac{Pd(J_i,K_i)^{-\alpha}}{N + P\beta(L_i)\sum P\varphi(L_i,L_j)d(K_i,K_j)^{-\alpha}} \tag{9}$$

where $\beta(L_i)$ is the probability of channel occupation. It is '1' when the network operates in a saturation mode showing that all available channels have been occupied by the APs. Substituting the value of $SINR(J_i)$ from equation (8)

$$R(J_i) = Blog_2\Bigg(\ 1 + 10\log\frac{Pd(J_i,K_i)^{-\alpha}}{\delta+P\beta(L_i)\sum\varphi(L_i,L_j)d(K_i,K_j)^{-\alpha}}\Bigg) \tag{10}$$

The channel bandwidth B is a sum of overlapping and non overlapping sub-carriers. Let us assume that a channel consists of Xoverlapping sub-carriers (X_1,X_2,....,X_u) and

Y non overlapping sub-carriers (Y_1,Y_2,....,Y_v) with X_i and Y_i being the i^{th} overlapping and non-overlapping sub-carrier, respectively. Then

$$B(L_i) = \sum_{i=1}^{u} X_i + \sum_{i=1}^{v} Y_i \tag{11}$$

To achieve a higher transmission rate of a node J_i for delay sensitive applications, the objective is to minimize this overlapping degree and its numerical form is given in equation (12).

$$B(L_i) = \arg \min_{i \in (1,u)} \sum X_i + \arg \max_{i \in (1,v)} \sum Y_i \tag{12}$$

Notice that first term in equation (11) is actually an overlapping degree of channels.

$$\sum_{i=1}^{u} X_i = \sum \varphi(L_i, L_j) \tag{13}$$

Then the transmission rate of a node J_i with variable channel width becomes

$$R(J_i) = Blog_2 \left(\sum \varphi(L_i,L_j) + \sum_{i=1}^{v} Y_i \right) \left(1+ 10 \log \frac{Pd(J_i,K_i)^{-\alpha}}{\delta + P\beta(L_i) \sum \varphi(L_i,L_j) d(K_i,K_j)^{-\alpha}} \right) \tag{14}$$

Servicing delay sensitive applications require adjustment in achieved throughput of a node. This tuning of throughput can be obtained by constructing channels of wider widths using maximum non-overlapping sub-carriers and subsequently modifying t_{over} parameters. We name the modified t_{over} parameters as tuned parameters $t_{(tune)}$. A thorough overview of $t_{(tune)}$ parameters is given in Table II.

Using measurements made in this Section and adjustment of tuning parameters, we have developed two algorithms. The best effort channel width adaptation (BECA) algorithm optimally adjusts the channel widths for achieving a maximum network wide throughput while servicing delay sensitive applications (SDSA) algorithm assigns channel widths based on the throughput requirements of nodes to service delay sensitive applications.

A. Servicing Delay Sensitive Applications (SDSA)

The pseudo-code of the proposed channel width adaptation algorithm for delay sensitive applications SDSA is presented in Fig.2. Let's define the nodes running delay sensitive applications as S-Nodes (Sensitive Nodes) and traditionally called QoS-enabled nodes in conventional WLAN settings and normal nodes as O-Nodes (Ordinary Nodes) connected with a resource allocation and management server (RAMS) through APs as shown in Fig.1.

SDSA is based on distributing available frequency spectrum to S-nodes to meet the user demands. At network initialization, RAMS accesses S-nodes based on their SSIDs and assigns frequency spectrum share to ensure minimum threshold transmission rate accordingly. To validate the proposed algorithm, an indoor network comprising of three APs by configuring three USRP2 kits is deployed as shown in Fig. 1.

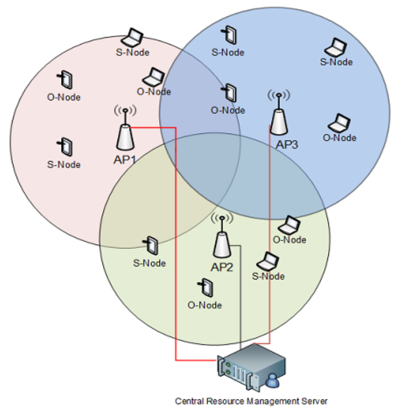

Fig. 1. Architecture of Deployed Network

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Result: Required Channel Width (CW_(req))
Transmission Paprameters (TP)
Input : R(J_i), SINR(J_i), SSID(J_i)
begin
    for J_i ∈ J_s do
        if SSID(J_i) = SSID_(S-Nodes)
        && R(J_i) ≥ R_(Min) then
            CW_(req) ← CW_(current)
        else
            if R(J_i) ≤ R_(Min) then
                do
                    CW_(new) ← CW_current + 1.875 MHz
                    && TP ← TP for CW_(new)
                while R(J_i) ≤ R_(Min)
            else
                CW_(req) ← CW_(new)
            end
        end
    end
end
```

Fig. 2. Servicing Delay Sensitive Applications (SDSA)

Each AP communicates the SSIDs of S-nodes associated with it to the RAMS. Based on the number of S-Nodes, RAMS calculates the minimum data rate required to maintain threshold user experience. This threshold user experience can be calculated based on data rate and delay sensitivity values. When an S-Node starts communication, the AP demands additional bandwidth to fulfil requirements of user experience. Based on the demand of AP, RAMS assigns a specific width channel, central frequency and modulation scheme to be followed by that AP. The process of calculating the bandwidth requirement of S-Nodes is repeated for each individual node. If RAMS finds unused frequency spectrum, it equally increases the channel widths of each AP and shifts their central frequencies accordingly to maximize the spectrum utilization . In case some nodes go off-line, APs communicate it to RAMS which decreases their channel widths accordingly.

TABLE II. 802.11g Frame Transmission Parameters

Channel Width (MHz)	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30
Symbol Duration (μS)	16	12	8	7	6	5	4	3.5	3	2.5	2
SIFS (μS)	40	30	20	17	15	13	10	8	6	5	4
DIFS (μS)	50	40	30	20	17	15	13	10	8	6	3
Slot Duration (μS)	20	20	20	20	20	20	20	20	20	20	20
Guard Interval (μS)	3.2	2.4	1.6	1.2	1	0.8	0.7	0.6	0.5	0.4	0.3

If the combined bandwidth requirement of all the APs exceeds the total available spectrum, RAMS makes the decision based on the number of S-Nodes associated to a specific AP. If any AP K_i has more number of S-Nodes than other AP K_j then channel width assigned to K_i will be wider than the channel width assigned to AP K_j. The change in channel width by an AP will be detected by the parameters communicated through physical layer frame preamble. discussed in [2].

B. Best Effort Channel Width Adaptation (BECA)

Fig.3 presents the pseudo-code of the proposed algorithm for Best Effort Channel Width Adaptation Algorithm (BECA). We explain it by considering the same setup of S-Nodes and O-Nodes connected with RAMS through APs as shown in Fig.1. At the beginning, each AP uses standard non-overlapping channels 1, 6, and 11 for AP 1, 2 and 3 respectively. BECA maintains two windows at each AP to keep record of incoming and outgoing packets naming them the receiver window (RW) and transmitter widow (TW) respectively. If the difference between RW and TW falls below the lower threshold or increases above the upper threshold values, it is communicated to RAMS. The server calculates the optimal channel width and number of sub-carriers for the spectrum allocation to AP dynamically based on the RW, TW, signal strength (SS), channel interference and the required throughput. The shrinking and expansion of channel widths, central frequency shifting and modulation scheme are based on the predefined values.

If an AP needs more bandwidth it notifies the server and the server checks the status of available sub-carriers. BECA running at RAMS directs the server to check the demand considering threshold values of both throughput and interference and decides if the increment in channel width is possible. RAMS then communicates the values of sub-carriers to the corresponding AP. After increasing the channel width AP starts spreading it signal by adding more frequencies to already in use sub-carriers.

On the other hand, if an AP has less bandwidth requirement it releases spectrum resource. This spectrum is added by the management server in its available pool of sub-carrier frequencies for its on demand dissemination to other APs in the network. If throughput requirement of an AP decreases at any given time it sends its new state of TW and RW to the management server. The management server checks the in-use sub-carriers and directs the AP to reduce its channel width by spreading its signals on less number of sub-carrier frequencies.

Result: $Required\ Channel\ Width(CW_{(req)})$
$Transmission\ Parameters\ (TP)$
Input : $R(J_i),\ SINR(J_i)$
begin
  for $J_i \in J_s$ do
    if $SINR(J_i) \le SINR_{(Max)}$ && $R(J_i) \ge R_{(Min)}$ then
      $CW_{(req)} \leftarrow CW_{(current)}$
      && $TP \leftarrow TP\ for\ CW_{(req)}$
    else
      if $SINR(J_i) > SINR_{(Max)}$ && $R(J_i) > R_{(Max)}$ then
        do
          $CW_{(new)} \leftarrow CW_{current} - 1.875MHz$
          && $TP \leftarrow TP\ for\ CW_{(new)}$
        while $R(J_i) > R_{(Max)}$
      else
        $CW_{(req)} \leftarrow CW_{(new)}$
      end
    end
    if $SINR(J_i) \ge SINR_{(Min)}$ && $R(J_i) < R_{(Min)}$ then
      do
        $CW_{(new)} \leftarrow CW_{(current)} + 1.875MHz$
        && $TP \leftarrow TP\ for\ CW_{(new)}$
      while $R(J_i) < R_{(Min)}$
    else
      $CW_{(req)} \leftarrow CW_{(new)}$
    end
  end
end

Fig. 3. Best Effort Channel Width Adaptation

In a case when the cumulative demand by all APs exceeds the available spectrum the management server assigns channel width to achieve maximum network capacity maintaining the minimal interference level. Thus an AP with better SNR and lower interference index will use a wider channel width.

The advantage of adopting this approach of frequency spectrum sharing is that it does not need profiles of wireless users in advance. The proposed model is robust and scalable. It can efficiently share the available spectrum among the associated nodes based on their requirements and the availability of spectrum.

IV. Experimental Setup

For empirical evaluation of SDSA and BECA, we deployed an indoor network of three USRP kits connected to laptops running GNU radio software on Linux operating system. A proof of concept, implementation of proposed algorithms for 802.11g wireless networks has been made by significantly modifying transceiver implementation provided at CGRAN [19] [20] and further explained in [21]. This implementation is extendable to any 802.11 standard by modifying its parameters at physical layer accordingly. A central management server constituted of Dell T-620 computer running SDSA and BECA on Linux OS has been placed for implementation of adaptable width channelization. Each USRP2 kit contained a 2400 RX/TX daughter card with omnidirectional antennas. The specifications of USRP kit and daughter cards are available at [32] [33]. The APs and the wireless nodes are located in an area of 200 X 200 square feet. There is no interference of any other Wi-Fi network operating in its close vicinity. The physical layer of each AP is customized in such a way that an AP can switch to any of narrower or wider channel widths at the end of current frame transmission.

V. Performance Results and Discussion

A series of experiments have been conducted to enumerate the effect of deploying proposed algorithms on essential network performance parameters. These parameters include medium utilization, throughput, channel access delay, channel access fairness and bit error rates. The obtained results are averaged out by collecting traces of all APs for accurate network wide measurements.

A. Medium Utilization

Fig. 4 compares the results of medium utilization of BECA and SDSA with standard 802.11g distributed coordination function (DCF), enhanced distributed coordination function (EDCF) of 802.11e and BlackBurst [6] for different combinations of number of S-Nodes and O-Nodes. It is observed that BECA and SDSA perform significantly better than contemporary techniques pertaining to the fact that adaptable channel widths utilize spectrum more efficiently. Since both the proposed algorithms do not alter channel access mechanism of standard WLANs, therefore employing adaptable channelization on standard channel access mechanism significantly enhances the spectrum utilization.

On the other hand both EDCF and BlackBurst alter contention window of standard channel access mechanism to achieve QoS guarantee with burst traffic and priority transmission ques, which results in patches of high and no medium utilization. A second factor involved in high medium utilization of BECA and SDSA is co-channel interference. Since proposed adaptable channelization ensures to maintain minimum level of interference. This minimum interference causes less number of collisions resulting in relatively low values for contention window size. Thus less time is elapsed in channel access resulting in high medium utilization.

B. Throughput Analysis

Since implementation of differential services and support for delay sensitive applications results in rapid variation of required throughput, we focused on measuring normalized throughput. In Fig. 5, we can see that both EDCF and Blackburst provide very good throughput performance to high priority nodes. However, for low priority nodes their performance is drastically low and as the number of QoS enabled nodes goes on increasing, the low priority nodes suffer complete starvation. On the other hand since both BECA and SDSA do not give priority to any node in channel access, and support of high data for delay sensitive applications is implemented by widening of channel width of S-Nodes. This mechanism does no affect the performance of low priority nodes to a great extent. Thus low priority nodes transmit data on narrower channels. Although narrower channels degrade the throughput performance of O-Nodes but avoid complete starvation.

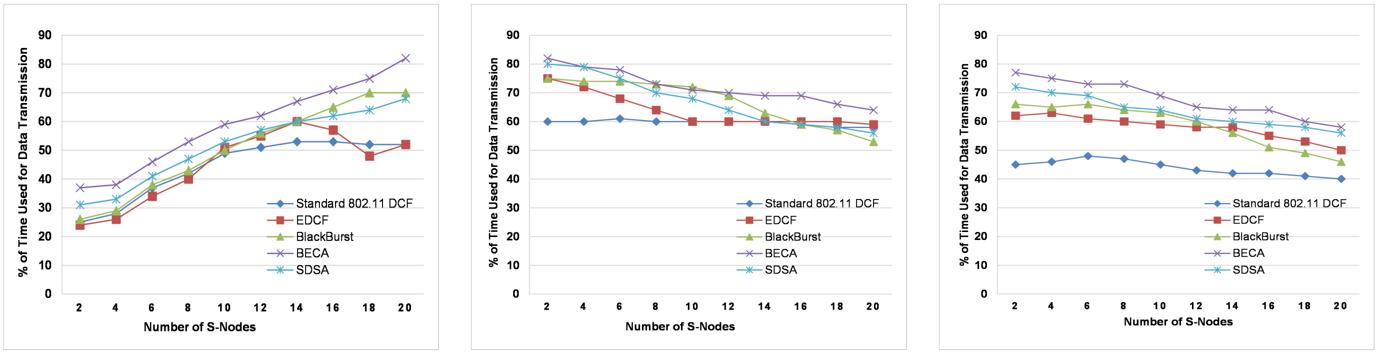
C. Analysis of Bit Error Rate (BER)

The effect of channel width on bit error rate using different modulation schemes is given in Fig. 8. No error correction or detection mechanisms are deployed and a single bit error in header, payload or checksum can cause the frame to drop. The total sent and received frames are collected at all the nodes by using Wireshark packet sniffer. An exclusive-OR operation is performed for the dropped and originally transmitted frames to calculate the bit error. As shown in Fig. 8, the wider channel widths and higher modulation schemes are more prone to errors. The reason behind the high BER is CCI and frame preamble based frequency detection as explained earlier.

D. Analysis of Delay Bounds and Jitter

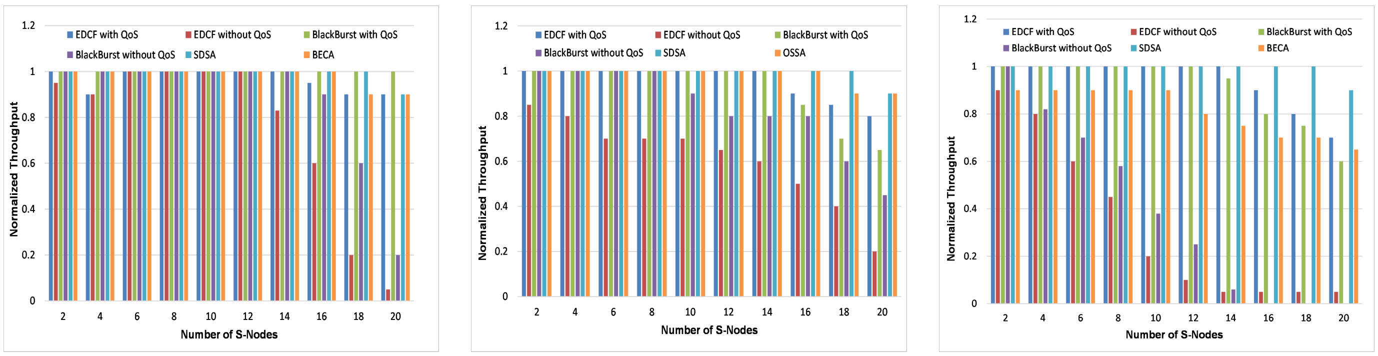
Fig. 6 shows the mean beacon delay for EDCF, BlackBurst, BECA and SDSA. It is observed that both EDCF and Blackburst have very low delays for high priority nodes. These low delay values can be explained by the burst transmission mechanism of these algorithms. Since packets in a burst are closely packed and are transmitted without encountering contention, therefore lower delay values are observed. This close packing and contention free transmission also results in low delay variations (jitter) which make it highly suitable for multimedia traffic. However these implementations increase the delay bounds and jitter of low priority node. While on the other hand the delay bounds for BECA and SDSA are substantially less for high priority nodes. This lower values of delay bounds can be explained by higher throughput capability of wider width channels. Since wider width channels can deliver more number of packets in smaller amount of time, therefore less delays is incurred. In case of O-Nodes, the delay values are relatively higher but not as high as in case of EDCF and BlackBurst.

The jitter analysis for various combinations of S-Nodes and O-Nodes for SDSA, BECA, EDCF and BlackBurst



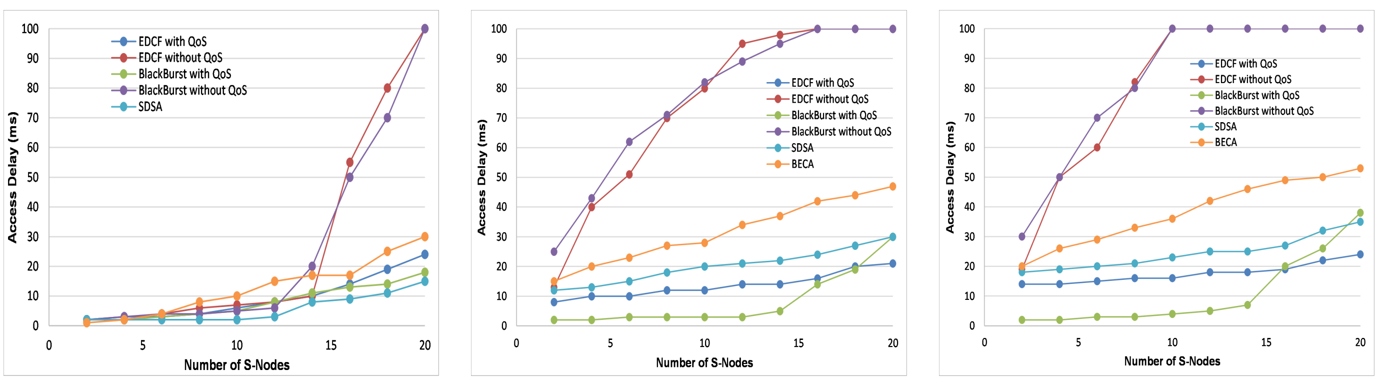
(a) Different Numbers of S-Nodes and Three O-Nodes (b) Different Numbers of S-Nodes and Six O-Nodes (c) Different Numbers of S-Nodes and Twelve O-Nodes

Fig. 4. Medium Utilization for Various Combinations of S-Nodes and O-Nodes



(a) Different Numbers of S-Nodes and Three O-Nodes (b) Different Numbers of S-Nodes and Six O-Nodes (c) Different Numbers of S-Nodes and Twelve O-Nodes

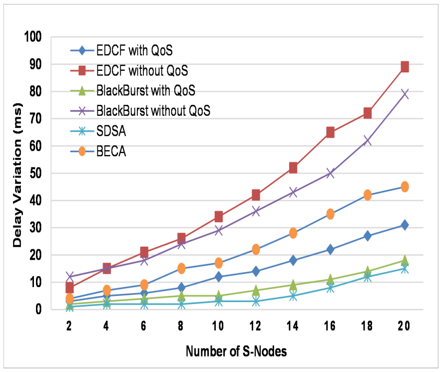
Fig. 5. Normalized Throughput for Various Combinations of S-Nodes and O-Nodes



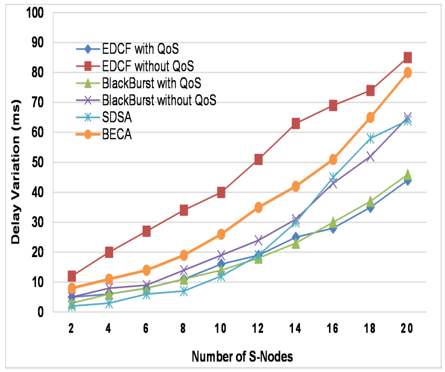
(a) Different Numbers of S-Nodes and Three O-Nodes (b) Different Numbers of S-Nodes and Six O-Nodes (c) Different Numbers of S-Nodes and Twelve O-Nodes

Fig. 6. Access Delay for Various Combinations of S-Nodes and O-Nodes

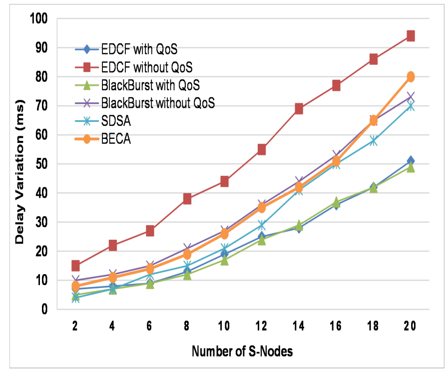
is presented in Fig 7. The obtained results show that with increased number of S-Nodes, the delay variation also increases for all deployed algorithms. The EDCF and BlackBurst have relatively low delay variations as compared to SDSA and as number of S-Nodes goes on increasing the delay variations for SDSA are substantially high. We have analysed that, if S-Nodes are dispersed across all cells, the delay variations are high. However, if we can service S-Nodes through a single AP, SDSA performs significantly better than EDCF and BlackBurst. This behavior can be explained by opportunistic sharing of spectrum resources among APs. Both EDCF and BlackBurst employ bandwidth reservation and priority ques for S-Nodes, therefore major portion of network resources are assigned to these nodes thus limiting delay variations. On the other hand, SDSA tries to maintain fair scheduling of channel access with variable spectrum resources for S-Nodes and O-Nodes. If number of S-Nodes across all APs exceeds more than a threshold, it results in huge variations of access delay.



(a) Different Numbers of S-Nodes and Three O-Nodes



(b) Different Numbers of S-Nodes and Six O-Nodes



(c) Different Numbers of S-Nodes and Twelve O-Nodes

Fig. 7. Jitter Analysis for Various Combinations of S-Nodes and O-Nodes

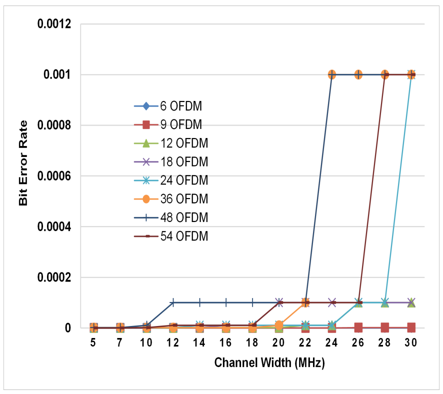


Fig. 8. Bit Error Rate of Channel Widths using different Modulation Schemes

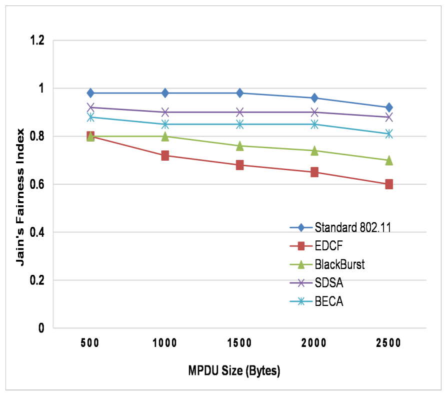


Fig. 9. Channel Access Fairness for Various MPDU Sizes

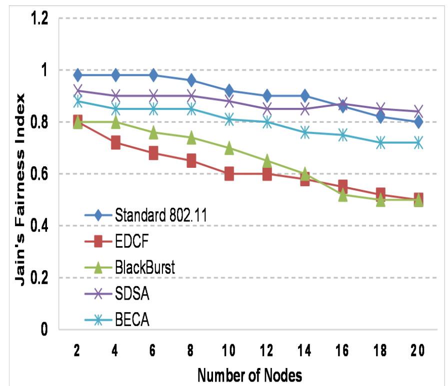


Fig. 10. Channel Access Fairness for Different Number of Nodes

E. Channel Access Fairness

Finally, Fig. 9 and 10 show channel access fairness of proposed algorithms for various sizes of MPDU and different number of nodes respectively. The achieved results depict that fairness of BECA and SDSA in granting channel access to various nodes is below the standard implementation but higher than EDCF and Blackburst. Since both EDCF and Blackburst give prioritized channel access to a set of nodes which results in degraded values for channel access fairness. BECA and SDSA assign channels of variable width to different nodes that results in different transmission time of same length of packets. Therefore the channel occupation of nodes with higher channel widths is lower than the nodes with narrower channel widths. Since BECA and SDSA are MAC layer independent mechanisms and they do not change the channel access mechanism, therefore the fairness remains similar to standard implementation of 801.11 MAC.

VI. Conclusion

In this work, we have proposed two channel width adaptation algorithms for servicing delay sensitive applications and optimal spectrum sharing among communicating nodes. The evaluation of proposed algorithms have been made by using fundamental performance defining parameters such as throughput, medium utilization, transmission delay, and channel access fairness. The focus of this research is to embed support for delay sensitive applications in conventional 802.11 WLANs while simultaneously minimizing the starvation problem of low priority nodes. It has been concluded that contemporary techniques like EDCF and BlackBurst perform fairly better for high priority nodes but results in almost complete starvation of low priority nodes. The proposed algorithms on the other hand perform significantly better in maintaining fairness of resource allocation to both types of nodes. Moreover, our results showed a significant improvement of almost 30% in achieved throughput with different combinations of delay sensitive and ordinary nodes. This improves Servicing Delay Sensitive Pervasive Communication Through Adaptable Width Channelization for Supporting Mobile Edge Computing. The proposed algorithms are also more spectrum efficient than EDCF mechanism of 802.11e and BlackBurst and can perform well under stringent network conditions. This high medium utilization ensures optimal use of scarce spectrum resource in dense network deployments. It is also concluded that if required throughput is low, switching to a narrower channel should be preferred as narrower channel widths decrease BER and increase network capacity.

Future work includes the implementation of adaptable channel widths in MIMO based wireless networks like 802.11n. Moreover distributed approaches to implement support for delay sensitive applications in WLANs using adaptable width channelization are also needed to be explored.

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