BE-OZR: AN EFFICIENT AVAILABLE BANDWIDTH ESTIMATION IN IEEE802.11e NETWORK

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Abstract

In wireless network, the support for Quality of Service (QoS) depends on the ability of a network to estimate the available bandwidth of a link effectively and efficiently. Due to the shared nature of the wireless medium, there has been challenges in achieving an accurate measurement of the available bandwidth. This paper therefore proposes an efficient available bandwidth estimation approach that improves the accuracy of previously proposed approach for accurate measurement. The approach used in this paper is to passively estimate the available bandwidth, where the maximum range of the channel idle time measurement used in the calculation is re-defined to address the outer zone range threshold (OZR). This limits the under-estimation and over-estimation of bandwidth measurement. The proposed approach used limits the network overhead and achieves accuracy and efficiency. Results obtained from the simulation shows how our proposed approach out-performs the state-of-the-art approach in terms of throughput and delay, using the IEEE802.11e. We have been able to achieve 8% improvement in accuracy and efficiency when compared with the best of the state-of-the-art available bandwidth estimation technique.

Keywords: wireless network, QoS, bandwidth estimation, IEEE802.11e

1. Introduction

The available bandwidth is quantified by estimating the throughput of a path or link without interrupting existing flows. This metric is very important for QoS achievement in areas of routing and admission control. Due to the shared nature of wireless networks, which allows for node contention, there has been challenges with the accurate estimation of the available bandwidth of a link [1]. Therefore, the focus of this paper is to estimate the available bandwidth of a multi-hop link in IEEE802.11e to guarantee QoS.

There have been various approaches proposed in the literature to estimate the available bandwidth. [2] classified the bandwidth estimation techniques into passive (i.e., Non-intrusive) estimation and active (i.e., Intrusive) probing. In [3], bandwidth estimation techniques were categorized into active probing, mathematical model based, and calculation based passive measurement techniques. In the work of [4], they classified bandwidth estimation technique into self-congestion and model-based approach, while [5] classified it into algorithm that are designed for specific networks (usually with guaranteed QoS), algorithm that uses probe packet with pre-determined spacing and algorithms targeting video streaming where a client-server is assumed. Researchers have presented different classification of bandwidth estimation technique; however, they perform the same role notwithstanding their different
nomenclatures. We therefore argue that classification of bandwidth estimation into active technique and passive technique, as categorized by [2], will simplify the readers understanding.

In active bandwidth estimation, a dummy packet, known as probe packet, is transmitted through the network at different traffic rates from the source to the destination node. The available bandwidth along a path is therefore estimated by measuring the inter-arrival times [6]. The above technique adds probing traffic and can possibly degrade the existing flow performance [7]. The main objective of the active technique is to observe the network characteristics by introducing the probe packet. According to existing research studies, it was found out that the active technique does not perform well in wireless network environment. Additionally, a research conducted by [8] shows that the active technique performance is poor as compared with passive estimation in terms of accuracy. Therefore, passive available bandwidth has been adopted for the available bandwidth estimation in this paper.

In [8], passive estimation is referred to as a calculation-based technique. Passive bandwidth estimation technique does not inject any probe packet into the network when estimating the required available bandwidth. Dispersion and delay are used to observe the acknowledgement and data flow and probe packet are not used. This form of estimation works with earlier generated information traces collected. The local information on bandwidth utilization is used for calculating the available bandwidth and exchanged via local broadcast. Despite several attempts to accurately estimate the available bandwidth, previous approaches failed to consider all the factors necessary for accurate available bandwidth estimation such as synchronization, collision probability, backoff time, maximum propagation range considered for channel idle time, etc. Therefore, in this paper, aside considering synchronization, collision probability and backoff time, we have additionally proposed a maximum range a channel is allowed to sense in order to guarantee that the channel is idle. The maximum range we proposed herein is called OZR (Outside zone range). This sensing range enables nodes that are outside the transmission range and carrier sensing range of a channel to be considered, as they may also have an impact on the availability of the channel. However, if OZR is used during the channel idle time estimation process, the only reason a channel will lead to under-estimation is during the no impact occasion. Therefore, the available channel idle time underestimated which is sensed by the OZR-threshold can be compensated by estimating the channel time occupied through the no impact occasion.

The rest of the paper is organized as follows; Section 2 presents related works, while in Section 3, the paper presents the definition of available bandwidth, as well as a novel available bandwidth estimation technique. In Section 4, the evaluation of the accuracy of our proposed available bandwidth estimation was presented and compared with BECIT, MBA-AODV and AABWM, which are the state-of-the-art available bandwidth estimation. Finally, Section 5 concludes the paper.

2. Related Works

There have been various approaches proposed in the literature to estimate the available bandwidth in wireless network. We have therefore, classified those available bandwidth estimation approaches into active technique and passive technique to ensure simplicity.

2.1. Active Available Bandwidth Estimation

Most of the previous works classified the active available bandwidth estimation into single packet/one packet and packet pair [9], while other classifications of active technique are different but with the same role. In [10], the active available bandwidth estimation technique is classified into isolated probing, direct probing, and iterative probing. [11] classified it into direct probing and iterative probing technique. In [12], the active available bandwidth estimation was classified into direct probing, iterative probing, and mixed techniques while [13] classified it into packet dispersion measurement (PDM), probe gap model (PGM) and probe rate model (PRM). In [14], the active technique was classified into variable packet size (VPS) probing, packet pair/train dispersion model (PPTD), self-loading periodic streams (SLoPS) and train of packet pairs (TOPP).

It was observed in [10] that isolated probing and probe delay model are the same as single-packet probing technique. In [15], the authors regard PRM and iterative to be a self-loading technique. Also, [15], regard PGM and direct probing to be a packet-pair dispersion technique.
We therefore argue that classification of active bandwidth estimation into single packet/one packet and packet pair, as categorized by [9], will simplify the reader's understanding of the active bandwidth estimation process.

2.1.1. Single Packet Active Technique: In this active technique, one probe packet at a predefined time interval is injected into the network in order to measure the delay. Link capacity is measured instead of end-to-end path capacity by using the time difference between the round-trip times of the probe packet from one end of the link to the other. The packet transmission time \( t = (P/b) + 1 \), where \( P \) = packet size, \( b \) = link bandwidth, and 1 is the fixed latency. If the round-trip time and the size of the probe packet is known, the bandwidth can be calculated for a given fixed latency of a link. Tools that have been developed using single packet active probing are as follows: Clink [16], Pathchar [17], Tailgating [18] and Pchar [19]. The only protocol implemented for the estimation of bandwidth using single probe packet is variable packet size probing [20].

2.1.2. Packet Pair Active Technique: In this active technique, two probe packets known as packet pair are sent back-to-back towards the target and this echoes the packet back to the sending node. The space between the two packets as shown in the figure 1 below is always determined by the bottleneck link which is preserved by a higher bandwidth link [21]. A packet within the packet pair that arrives at the target node have a specific time separation between each packet which is specified by \( \Delta in \). Having interacted with the cross traffic, from various sources, packets exit the output queue with changed time separation which is stored as \( \Delta out \). Researchers have tried to formulate models based on the variation between \( \Delta in \) and \( \Delta out \). The packet-pair active probing techniques that have been published differ in the way the packet sequence rate increases and in the metrics measurement of the probe packet flow. The packet-pair active probing technique can therefore be further classified into self-loading packet-pair active probing, packet pair/train dispersion active probing, reactive packet-pair active probing, and hybrid packet-pair active probing.

![Figure 1: Effect of Probing Packets at Node with Time Separation](image)

2.2. Passive Available Bandwidth Estimation

Passive technique is non-intrusive because there is no frequent exchange of HELLO packet. The available bandwidth is used for the selection of network in heterogeneous network environment. Parts of the protocols that comes under passive technique are: Distributed LaGrange interpolation based available bandwidth estimation (DLI-ABE) [23], available bandwidth estimation method for IEEE 802.11 ad-hoc network with concurrent transmissions (ABCT) [24], measured based bandwidth estimation technique and flow admission control (BandEst) [25], cognitive agent based available bandwidth estimation using collision probability, idle period synchronization and random waiting time (BECIT) [26], MBA-AODV [27], analytical available bandwidth estimation including mobility (AABWM) [8].

[23] proposed distributed LaGrange interpolation based available bandwidth estimation (DLI-ABE). In this protocol, the channel idle time synchronisation uses the actual channel utilization and collision rate.
Also, the collision probability model uses a separate Lagrange interpolation polynomial at each node, depending on the behaviour of node.

Available bandwidth estimation method for IEEE 802.11 ad-hoc network with concurrent transmissions (ABCT) was proposed by [24]. This protocol focused on estimating the available bandwidth of a medium using the control-gap based concurrent transmission.

Measured based bandwidth estimation technique and flow admission control (BandEst) was proposed by [25]. This protocol proactively considers the complete wireless 802.15.4’s unslotted CSMA-CA MAC layer overhead and considers the future load. It also considers the estimation of intra-flow contention and estimates contention on non-relaying nodes. Additional MAC layer overhead that is associated with increased data traffic load was considered and an algorithm that deals with concurrent admission request in FIFO was implemented.

Cognitive agent based available bandwidth estimation using collision probability, idle period synchronization and random waiting time (BECIT) was proposed by [26]. In BECIT, the author adopted an intelligent software agent known as cognitive agent (CA) to estimate the available bandwidth. The author stated that the intelligence is provided similar to the logical human being thinking ability for cognitive agent decision making. The technique uses CA at each node to create mobile agents for the collection and distribution of statistics. The collected statistics are then used by the CA for bandwidth estimation using the distributed LaGrange interpolation estimation.

(MBA-AODV) was proposed by [27]. In MBA-AODV, the author proposed an approach for estimating bandwidth by considering node mobility. They stated that node mobility usually results in frequent link failures as well as retransmissions. To tackle this, reactive route discovery process, which discovers end-to-end path from the source to the destination node as well as intermediate node route discovery to provide for QoS, was used.

Analytical available bandwidth estimation including mobility (AABWM) was proposed by [8]. The author stated that node mobility results in link instability which leads to loss of data and delay that have an impact on the available bandwidth. However, they proposed an analytical approach for the estimation of the available bandwidth on a link. The contribution of AABWM includes its use of mathematical model based on renewal theory to estimate the collision probability of packets to enhance simplicity and the, mobility consideration under 3-D space for predicting link failure and for admission control purpose.

Having reviewed the state-of-the-art passive available bandwidth, it has been observed that the channel idle time detection for available bandwidth estimation has operated on a limited range, which however can lead to the underestimation/overestimation of the available bandwidth on a channel.

3. Available Bandwidth Estimation (BE-OZR)

This section begins by defining the available bandwidth of a channel. Thereafter, the proposed approach used in this paper to estimate the available bandwidth is presented.

In a wireless medium, the available bandwidth is a network characteristic that is dependent on both the link and the link direction. The available bandwidth that is associated with different link directions with the same node will have different values. This is mainly because the available bandwidth of different links or directions will generate different interference.

The available bandwidth of a network is therefore defined as the maximum transmission throughput between two neighbour nodes in a given transmission direction, having a condition that the QoS of any ongoing packet within that medium is not disrupted. From the transmission point of view, the bandwidth used by any ongoing transmission and the transmission QoS requirements should be considered during the available bandwidth estimation. From the channels point of view, the available bandwidth is associated with the effective channel capacity on the available idle time of the channel at a given period of time.
Therefore, it is important to note that the standard available bandwidth estimation formula of a wireless channel is majorly based on the effective channel capacity and the available channel idle period.

The channel capacity in the available bandwidth estimation does not only depend on the data rate set by the physical interface card, but also on other random factors in the network. For the available channel idle period to be accurately determined, the meaning of *availability* in IEEE 802.11e will be clarified.

Before defining the concept of *availability*, it is essential to be familiar with the following three fundamental terms with respect to the available bandwidth range distance. These are carrier sensing range (*CSR*), transmission range (*TR*), and outside zone range (*OZR*). The carrier sensing range, which covers a double distance circularly around the node, is the distance through which a node can sense the transmission of another node based on carrier sensing threshold. The transmission range gives information about the node activities through the clear channel assessment (*CCA*) provided by the MAC layer and it is the distance through which a node can receive and decode a signal correctly, given that there is no interference around. The outside zone range covers the distance from the sending node to any node beyond the carrier sensing node, i.e., any transmission occurring outside the transmission range and the carrier sensing range.

The *availability* channel period between the source and the destination link of a wireless channel is hereby achieved given that the following nine conditions are satisfied.

i. No node within the *CSR* of the source node *S* is sending packets. This condition, however, meets the wireless channel requirement, i.e., the wireless channel should be idle before transmitting a packet.

ii. No node within the *CSR* of the source node *S* is receiving packets. For example, within the *CSR* of *S*, if *S* sends data, and other nodes simultaneously receive data, which will result in collision. Therefore, the channel occupied by the receiving nodes within the *CSR* of the *S* is not available for *S*.

iii. No node within the *CSR* of the destination *D* is sending packets. This condition guarantees that the packet sent by *S* will be received by *D* without collision.

iv. No node within the *CSR* of the destination *D* is receiving packet.

v. No node within the *CSR* of the source/destination (*S/D*) has a non-empty queue.

vi. No node within the *TR* of the source node *S* is sending packet.

vii. No node within the *TR* of the source node *S* is receiving packet.

viii. No node within the *TR* of the destination node *D* is sending packet.

ix. No node within the *TR* of the destination node *D* is receiving packet.

Once all the above nine conditions are met, then it is guaranteed that there is channel *availability* for a given link. However, the throughput of this channel *availability* is said to be the available bandwidth that can be used without obstructing any existing flow. The *link carrier sensing area* is defined as the union between the carrier sensing area of two ends of the link. Giving the topology below as in Figure 2, the dashes round about the circular lines represents the *link carrier sensing area* of link *S* and *D*. Therefore, any frame sent within the *link carrier sensing area* of *S* and *D* will make the channel *S* and *D* to be unavailable, thereby violating the above stated condition of i and iii. Given that the outer area (*OZR*) of the *link carrier sensing area* of *S* and *D* sends a packet to the destination located within the dashes round about the circular lines (*CSR*), the available bandwidth will be affected, thus violating the condition stated in ii and iv. For example, the data received by *S*(2) from *6*(3) may collide with the data sent by *S* (*D*). Also, giving that any of the nodes within the *CSR* of *S/D* has a queue of packet within it, this may cause the channel to be unavailable in-case there is a trigger which may cause a shift to enhance the node in the *CSR* to start sending packet. This, therefore, will tend to violate the condition stated in v. All these complications however make it more difficult to accurately estimate the available bandwidth on a network.
As previously highlighted in this section, it is important to note that the standard formula for the available bandwidth estimation in a wireless channel is majorly based on the effective channel capacity and the available channel idle period. Therefore, the available bandwidth of link \( l_{sd} \) (denoted as \( AB_{sd} \)) is originally computed using equation 1 below,

\[
AB_{sd} = \frac{T_{idle(s,d)}}{T} \times C
\]

Where \( T_{idle(s,d)} \) is the available channel idle time period and \( C \) is the maximum effective channel capacity.

Below is the proposed algorithm used to accurately estimate the available channel idle time period and the effective channel capacity of a link.

3.1. Estimating the Maximum Sensing Range of the Available Channel Idle Time Period

In BE-OZR, the sending node, the destination node and the transmission of other neighbouring node will contend for the channel. It is therefore necessary to take note of the maximum range a node can sense. We therefore propose and use a new sensing threshold called OZR, that not only monitor the transmission range or the carrier sensing range, but will monitor any neighbouring transmission outside the carrier sensing range that may possibly affect the estimation of the channel idle time.

With reference to section 3, i, ii, iii, iv, v, vi, vii, viii, and ix will have an impact on the channel availability, however, their impact may vary. There is therefore a need to properly choose the range a node can sense, in order to prevent improper network estimation of the channel idle time. For a source to detect any nearby transmission, any of the three ranges are to be monitored, namely, the source/destination to the Transmission range, Carrier Sensing range, or Outside zone range (check the diagram in Figure 2). Therefore, since the outside zone range tends to be the maximum distance range
amongst the three ranges, our proposed BE-OZR selects the outside zone range to be the peak a node can sense to check that the channel is idle. The outside zone range is denoted as OZR, hence, the corresponding sensing threshold is represented as OZR-threshold. However, just like the carrier sensing range threshold (CSR-threshold), OZR-threshold has an additional feature to sense the medium range of nodes that are beyond the carrier sensing range. Hence, using the OZR-threshold, the source of the target link can sense the transmission and determine whether the medium is available for the transmission to be granted.

At a given time period $T_p$, let $T_{bus}^{OZR}$ denote the channel busy time that is sensed by a sender when an OZR-threshold is used and let $T_{bus}^{CSR}$ denote the channel busy time that is sensed by a sender when CSR-threshold is used. However, since we are making use of a larger sensing range, the channel can claim to be too busy and the channel busy time sense by the OZR-threshold may under-estimate the available idle channel time. A typical example of this is as follows; considering the diagram in Figure 2, when the transmission is located outside the dashes round about the circular lines, this means that the transmitting nodes (e.g. transmission from node 7 to node 6 or transmission from node 4 to node 3) are not within the channel link of $S$ and $D$. In BE-OZR, this kind of transmission is denoted as no-impact occasion. Since it is not possible for the passive sensing to detect the no-impact occasion, the OZR-threshold approach will therefore cause the channel idle time to under-estimate. In Figure 2, let us denote the outside of the dashes round about the circular lines as a special area (SA) of link $S$ and $D$. Therefore, if a node in the SA of link $S$ and $D$ sends a packet, and the destination is located outside the link carrier sensing area of $S$ and $D$, the transmission will not affect the available channel. However, the two cases given below will have an effect on the channel availability:

- If the destination of a transmitting frame is located in the carrier sensing range of node $S$ (e.g., if node 6 is transmitting to node 5), the receiving frame (node 5) may interfere with the packet sent by node $S$.
- If the destination of a transmitting frame is not located in the carrier sensing range of node $S$, but it is located in the carrier sensing range of node $D$ (e.g., if node 3 is transmitting to node 2), the receiving frame (node 2) may interfere with the acknowledgement frame sent by node $D$.

Therefore, based on the above analysis, the no impact occasion happens to be the only reason in which a channel will lead to under-estimation if an OZR-threshold is used for monitoring the idle channel time. By using the OZR-threshold to monitor the channel idle time, we assume that the channel time used for transmission in the SA at a given time period $T_p$ is $T_{SA}$. We therefore define Standard probability of a given link (denoted by $P_c$) as the probability that the destination of a transmission in the SA is not situated within the link carrier sensing of $S$ and $D$. Therefore, the available channel idle time underestimated which is sensed by the OZR-threshold can be compensated by estimating the channel time occupied through the no impact occasion. Therefore, the range of the channel idle time when node $S$ is transmitting a packet to node $D$ is finally computed as;

$$R_{S,D} = \frac{P_c(T_{OZR} - T_{SA})}{T_p}$$  \hspace{1cm} (2)

$$T_{SA} = \left(\frac{T_{OZR} - T_{CS}}{\pi R_{OZR}^2 - \pi R_{CS}^2}\right) A_C$$  \hspace{1cm} (3)

Where $A_C$ denotes the area of SA. Therefore, the range of the channel idle time when node $S$ is transmitting a packet to node $D$ is finally computed as;
Therefore, the channel idle time with respect to the range propagation is expressed as:

\[
\frac{T_{\text{idle(s)}}}{T} \approx \frac{T_{\text{idle(s)}}}{T} \times R_{S,D} \times C
\]  

(5)

3.2. Effective Channel Capacity

As previously highlighted in section 3, the available bandwidth estimation in a wireless channel is also dependent on the effective channel capacity. It is therefore important to note that the value of the channel capacity will not be the total/raw value of the medium capacity as given by the standard (IEEE802.11e), but some fixed overheads that are introduced by the MAC protocol need to be accounted for.

A typical example of this is as follows; given that the total capacity assigned by a wireless standard to a medium is 54-Mbps, the throughput delivered by this capacity is not expected to be higher than 33.2Mbps.

It is also very important to note that the available bandwidth estimation is dependent on some other factors by the reason of its standards aside the channel idle time and the capacity, for proper functionality and estimation to be carried out. These factors are, collision and back-off. For the purpose of clarity, let us consider the frame exchange sequence for each attempt of packet transmission in wireless 802.11e EDCA as in Figure 3. For a transmission to occur between station 1 and station 2, there are various factors that will automatically have an impact (i.e., consume the bandwidth) on the available bandwidth of both stations, these are AIF and back-off.

The AIF will be included in the calculation of the collision probability and back-off duration will also be addressed as the other major factor that have an impact in the available bandwidth estimation process.

Figure 3: IEEE802.11e EDCA frame exchange sequence [28]

3.3. Other Factors Affecting Available Bandwidth Estimation

As previously mentioned in section 3.2, the available bandwidth estimation is dependent on some other factors by the reason of its standards aside the channel idle time and the capacity for proper
functionality and estimation to be carried out. These factors are collision and back-off. It is important to note that the reason for considering collision in our estimated available bandwidth is that due to the nature of wireless, there may still be some slight level of inaccuracy during the available bandwidth measurement which may sometimes result in collision. Therefore, it is wise to include the collision probability in our estimated available bandwidth process in case it occurs. Once there is a collision this will eventually lead to a backoff. To calculate the collision probability and the back-off duration, the formula in the work of [27] is used.

Finally, the available bandwidth \( AB_{sd} \) between link s and d \( (l_{sd}) \) proposed in this paper with respect to the channel idle time maximum range propagation and channel capacity is expressed as:

\[
AB_{SD} = (1 - Cl) \times (1 - Bo) \times \frac{T_{idle(sd)}}{T} \times R_{S,D} \times C
\]  

(6)

Where \( Cl \) denotes the collision probability, \( Bo \) denotes the Back-off duration of bandwidth consumed and \( C \) denotes the capacity of the link, \( R_{S,D} \) is the maximum propagation range.

4. Performance Analysis

This section presents the result analysis, validation, and evaluation of our proposed BE-OZR available bandwidth estimation. For comparison, we have integrated it into AODV routing protocol and implemented using OPNET simulation tool. This simulation tool has been selected because it can best simulate our proposed technique. Thus, we study the impact of our bandwidth estimation technique and compare our proposed BE-OZR technique with those that closely exist in the literature.

4.1. Simulation Parameters

In this section, OPNET modeler 17.5 was used to simulate the design to evaluate the performance of BE-OZR. 100 nodes have been deployed in a 1200x1200m area. Furthermore, other network parameters have been set accordingly (i.e., data rate of 11Mbps). \( T \) is set to 1 second while 8 sender and receiver nodes, which are dependent on one another, are selected among the 100 nodes to transmit traffic. The other nodes are either acting as relay nodes or idle. Simulation was carried out for 60 seconds and each simulation was repeated 10 times. Table 1 and 2 presents the parameters used for the simulation.

| Parameter                           | Value                                      |
|-------------------------------------|--------------------------------------------|
| Number of nodes                     | 100                                        |
| Total network area                  | 1200 X1200m                               |
| Wireless Standard                   | IEEE802.11e                                |
| Physical Characteristics            | Direct Sequencing                          |
| Data rate                           | 11Mbps                                     |
| Packet size                         | 1000bytes                                  |
| Number of sender-receiver           | 8                                          |
| T                                   | 1sec                                       |
| Number of simulation (repetition)   | 10 times                                   |
| Simulation time                     | 60s                                        |
| SIFS                                | 10μs (microsecond)                         |
| Slot time                           | 20μs                                       |
| CWmin                               | 31                                         |
| CWmax                               | 1023                                       |
| Traffic type of service             | Best effort, Voice and Video               |
| Transport Protocol                  | UDP                                        |
| Traffic Bit Rate                    | CBR                                        |

Table 1: Simulation Parameter of the Physical Characteristics
4.2. Simulation Model, Validation and Evaluation of BE-OZR

The performance of our proposed BE-OZR estimation technique was simulated and compared with three other protocols, namely, BECIT, MBA-AODV and AABWM. The simulation was carried out using OPNET 17.5. The simulation parameters used, which depicts the average results obtained over 10 simulation trials are shown in table 1 and 2. Different estimation parameters such as WLAN throughput and delay are used to evaluate the performance.

Note that BECIT, MBA-AODV and AABWM have been modified to function in IEEE802.11e QoS setting, since they were previously configured for IEEE802.11. AODV routing protocol has also been used for simulation for the purpose of comparison.

4.2.1 Performance Evaluation

In order to demonstrate the performance of BE-OZR, we transmitted three different traffic flows simultaneously and viewed their behaviour. Note that all the three traffic flows use the same priority level. For each flow, the source and destination node are selected, and dependent on each other. Each of the flow is made up of 1000 bytes frames with a data rate of 11Mbps. The duration for the simulation is 1 hour. Figure 4 depicts the throughput of three different network traffic types. The throughput results obtained using the Best-Effort, Voice and, Video traffic are almost the same because all the traffic are assigned the same priority. The results of BE-OZR shows an efficient throughput transmission.

![BE-OZR Throughput for all the traffic](image)

4.2.2 WLAN Throughput Analysis and Comparison

Figure 5a shows the comparison of WLAN Best effort throughput analysis of our proposed BE-OZR technique with other state-of-the-art estimation technique. Result from the graph shows that the average best effort throughput of our proposed technique tends to be more than BECIT, MBA-AODV, and

| EDCA Parameter | CWmin       | CWmax       | AIFSN |
|----------------|-------------|-------------|-------|
| AC_VO          | (CWmin +1)/4-1 | (CWmin +1)/2-1 | 2     |
| AC_VI          | (CWmin +1)/2-1 | CWmin       | 2     |
| AC_BE          | CWmin       | CWmax       | 3     |

Table 2: EDCA QoS Parameter
AABWM. Table 3 shows the raw values of the average throughput analysis of best effort traffic and how BE-OZR best effort throughput traffic result surpasses the rest of the bandwidth estimation technique used for comparison. This analysis makes our proposed BE-OZR more efficient and accurate, as the higher average value realised by BE-OZR best effort traffic shows that it is more reliable and has a faster and higher best effort throughput, when compared to the rest of the protocol considered.

Figure 5b shows the comparison of WLAN voice throughput analysis of our proposed BE-OZR technique with other state-of-the-art estimation technique. Result from the graph shows that the average voice throughput of BE-OZR tends to be more than BECIT, MBA-AODV, and AABWM. Table 3 shows the raw values of the average throughput analysis of voice traffic and how BE-OZR voice throughput traffic result surpasses the rest of the bandwidth estimation technique used for comparison. This analysis makes our proposed BE-OZR more efficient and accurate, as the higher average value realised by BE-OZR voice traffic shows that it is more reliable and has a faster and higher voice throughput, when compared to the rest of the protocol considered.

Figure 5c shows the comparison of the WLAN video throughput analysis of our proposed available bandwidth estimation technique BE-OZR with BECIT, MBA-AODV, and AABWM. Results from the graph shows that AABWM and BECIT has the highest throughput results in term of video traffic. The result from AABWM and BECIT video throughput may appear to be more than BE-OZR, but the realistic aspect of it is that AABWM and BECIT is operating as a greedy protocol during the video traffic transmission as it allows a lot of video traffic to gain access to the network channel and does not bother about giving equal access to the voice traffic which is of more importance. The average video throughput of MBA-AODV is less as compared with BE-OZR. Table 3 gives the average data analysis of the video throughput realised.

In summary, based on the analysis in Figure 5a, b, c and Table 3, the average throughput of BE-OZR for best effort and voice traffic tends to be more than BECIT, MBA-AODV and AABWM, while the average throughput of video traffic for AABWM tends to be more compared to BE-OZR, BECIT, and MBA-AODV. This analysis makes our proposed BE-OZR more functional, as the higher average value realised by BE-OZR best effort and voice traffic shows that it is more reliable and has a faster and higher best effort and voice throughput, when compared to the rest of the protocol considered. We have also ensured that the voice is prioritized for transmission by disallowing the video traffic to get hold of a very high portion of the network. Therefore, in terms of performance, the accuracy and efficiency of BE-OZR is 8% better than the state-of-the-art available bandwidth estimation technique.
Table 3: WLAN HCF Access Category Average Throughput Report Protocol Comparison

| Protocol  | Average Best Effort Throughput (bit/sec) | Average Video Throughput (bit/sec) | Average Voice Throughput (bit/sec) |
|-----------|------------------------------------------|-----------------------------------|-----------------------------------|
| BE-OZR    | 94,149                                   | 82,186                            | 81,221                            |
| BECIT     | 61,364                                   | 272,161                           | 54,261                            |
| MBA-AODV  | 40,067                                   | 36,464                            | 36,812                            |
| AABWM     | 60,615                                   | 270,317                           | 53,925                            |

Table 4: WLAN Average Delay Table Comparison of all protocols

| Protocol  | Average Delay (Sec) |
|-----------|---------------------|
| BE-OZR    | 0.0038              |
| BECIT     | 0.0044              |
| MBA-AODV  | 0.0037              |
| AABWM     | 0.0053              |

4.2.3 WLAN HCF Delay

Figures 5 show the delay comparison of the bandwidth estimation for all the traffic (best effort, voice and video). Table 4 presents the data collected from the graphs in Figure 5.

Figure 5: Comparison of BE-OZR against the state-of-the-art Wireless LAN Delay.

From Table 4, it is seen that BE-OZR has the least amount of delay compared with other protocols. This, therefore, shows the efficiency and accuracy of BE-OZR.

5. Conclusion

In this paper, we proposed a new available bandwidth estimation technique (BE-OZR), that aims to provide an efficient, effective, and accurate estimation of available bandwidth in a IEEE802.11e QoS environment. By redefining the channel idle time used for the estimation of available bandwidth, consideration has been given to achieve an appropriate estimation that will limit the underestimation.
and overestimation of the available bandwidth of a channel. In BE-OZR, the available bandwidth is estimated by considering the outer zone range, which is the maximum sensing threshold a node in a channel is allowed to sense in order to guarantee the idleness of a channel. Other factors considered in the available bandwidth estimation are, synchronization, collision probability, backoff time, and capacity estimation. Evaluation and validation of BE-OZR was carried out and the result obtained show the accuracy and effectiveness of our proposed BE-OZR. BE-OZR was also compared with the state-of-the-art available bandwidth based on the throughput and delay performance and the results obtained show that BE-OZR is 8% more accurate and efficient than the state-of-the-art bandwidth estimation. In future, we plan to integrate our proposed BE-OZR into a developed admission control mechanism and observe its result.

Declaration

Funding: Not Applicable

Conflicts of Interest/Competing Interest: The authors declare that they have no conflict of interest

Availability of data and material: Not applicable

Code of availability: Not applicable

Authors Contributions: The contribution distribution of the authors are as follows: Conceptualization, F. Aina and O. Osanaiye; methodology, F. Aina; Software, F. Aina and S. Yousef; Formal Analysis, O. Osanaiye, F. Aina and S. Yousef; Investigation, F. Aina and O. Osanaiye; Resources, S. Yousef and O. Osanaiye; Data Curation, F. Aina; Writing Original Draft Preparation, F. Aina; Writing- Review & Editing, F. Aina and O. Osanaiye; Visualization, F. Aina., S. Yousef and O. Osanaiye; Supervision, S. Yousef and O. Osanaiye, Project Administration, S. Yousef and O. Osanaiye.

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