Cognitive Estimation of the Available Bandwidth in Home/Office Network Considering Hidden/Exposed Terminals

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Abstract — Most of consumer electronic devices, including HDTV/IPTV, multimedia teleconference systems, on-line game stations, and HiFi-audio systems, are expected to be connected through WiFi WLANs in home/office networks. Especially, the realtime multimedia applications are requiring guaranteed bandwidth to provide guaranteed QoS/QoE. As a consequence, correct estimation of the available bandwidth in overlapped WiFi WLANs in home/office network environments is one of the essential functions for efficient provisioning of QoS-guaranteed realtime multimedia applications and optimized network resource utilizations in future Internet. In this paper, we propose a cognitive passive estimation of the available bandwidth (cPEAB) by correct measurements of i) the proportion of waiting and backoff delay, ii) packet collision and packet error probability, iii) acknowledgement delay, iv) channel idle time compared to measurement period, and v) traffic from hidden/exposed terminals. Using a series of experiments, we found that the proposed scheme estimates the available bandwidth more accurately compared with other schemes.

Index Terms — available bandwidth estimation, passive estimation, home/office network, network management

I. INTRODUCTION

In near future, most of consumer electronic devices, such as HDTV/IPTV, multimedia teleconference systems, on-line game stations, and HiFi-audio systems, are expected to be connected through WiFi WLANs in home/office networks. Especially, the realtime multimedia applications on these consumer electronic devices are requiring guaranteed bandwidth to provide guaranteed QoS/QoE. The WiFi WLANs, however, is operating in contention-based resource sharing scheme, and guaranteed bandwidth allocation is not possible without any additional management functions. As a consequence, correct estimation of the available bandwidth in overlapped WiFi WLANs in home/office network environments is one of the essential functions for efficient provisioning of QoS-guaranteed realtime multimedia applications and optimized network resource utilizations in future Internet.

Several approaches have been proposed and implemented for the estimation of available bandwidth in IEEE 802.11 WiFi WLAN: i) active probing, ii) calculation with passive measurements, and iii) mathematical model. The early approaches (i.e., pathChirp [2], Wireless Bandwidth estimation tool (WBest)[3], pathload[4], and Initial Gap Increase (IGI)/Packet Transmission Rate (PTR) [5]) are using active probing where probe packets are sent through the network at multiple traffic rates, and the available bandwidth is estimated based on the changes of packet inter-arrival delays at destination. The main disadvantage of these active probing approaches is that they add extra traffic load to the network which may cause performance degradation of existing time critical realtime multimedia traffic.

The bandwidth estimation schemes based on calculation with passive measurement (i.e., Adaptive Admission Control (AAC) [6], Available Bandwidth Estimation (ABE) [9], and Improved Available Bandwidth estimation (IAB) [10]) observe the channel over a given period of time, and obtain the channel usage ratio. Then by calculation, such as smoothing or calibrating the observed results, the available bandwidth is obtained. Based on the collected data, the available bandwidth is calculated without any impact to other existing flows, and this information may be exchanged among neighbor nodes to compute the available bandwidth at each WiFi BSS (basic service set). The shortcoming of currently existing schemes of bandwidth calculation with passive measurements is that most of them are not considering the overhead of control messages and impact from hidden/exposed nodes. Moreover, most of them are analyzed only by simulation environment (e.g, NS-2), not in real environment.

In our previous work [11] we have used basic concepts of the passive available bandwidth estimation technique with the consideration of hidden/exposed terminals. Furthermore in [12] we include possible overhead by control messages, which significantly improved the performance of cPEAB. Those previous work, however, did not consider packet delivery failure due to collision or error that will decrease the throughput. In this paper, we propose an enhanced scheme that provides solutions to the above mentioned shortcomings.

The estimation of the available bandwidth through mathematical models, such as Markov model [13] and Effective Link Model [14], performs accurate results in WLAN, but they are highly dependent on the network topology which is very difficult to obtain in real wireless network environment with multiple mobile nodes.

In this paper, we propose an enhanced cognitive passive estimation of the available bandwidth (cPEAB) by correct measurements of i) the proportion of waiting and backoff delay, ii) packet collision and packet error probability, iii) acknowledgement delay or acknowledgement collision, iv) channel idle time compared to measurement period, and v)
traffic from hidden/exposed terminals. For more accurate estimation of the available bandwidth, the information of the hidden nodes and exposed nodes are provided by the cognitive network management system [1]. Also, the proposed scheme is using passive measurements, instead of active probe packet exchange which affects directly the available bandwidth of other mobile nodes. The proposed cPEAB scheme has been implemented on Multiband Atheros Driver for WiFi (MadWiFi) [20], and the performance has been analyzed and compared with existing schemes, such as active bandwidth measurements with probes, adaptive admission control protocol (AAC), available bandwidth estimation (ABE), and improved available bandwidth estimation (IAB). From the experimental measurements on real WiFi environment, we found that the proposed cPEAB provides the most accurate estimation of available bandwidth on the overlapped WiFi WLAN environment where the hidden/exposed nodes are dynamically affecting the available bandwidth.

The major contribution of this paper is an enhanced scheme for correct estimation of available bandwidth in home/office WiFi WLANs with passive measurements and cognitive network management systems. The proposed scheme provided the most accurate estimations of available bandwidth with increased impacts by hidden/exposed terminals.

The rest of this paper is organized as follows. In section II, related work are briefly introduced. In section III, the enhanced cognitive passive estimation of available bandwidth is proposed. The enhancement from our previous work is explained. In section IV, the implementation details of the proposed scheme, cPEAB, are explained, and the performance analysis of the bandwidth estimations with various conditions are explained and compared with other approaches. Finally, section V concludes this paper.

II. RELATED WORK

Correct bandwidth estimation is one of the challenge issues in WLAN due to the resource sharing and fluctuating nature of wireless network and MAC layer mechanism. Therefore, many researches have been done and three major bandwidth estimation approaches have been proposed: i) active probing-based approaches, ii) calculation based approaches with passive measurements, and iii) estimation of available bandwidth through mathematical models. List of variables which are used in our analysis is given in Table I.

A. Active probing-based approaches

Most of the early approaches rely on the active probing mechanism where probe packets are sent through network using multiple traffic rates. Packet interarrival delay increases at the receiver when the probing rate exceeds the available bandwidth. By analyzing the packet interarrival delay, the available bandwidth is calculated from the probing rate that can be managed in different ways. For example, pathChirp [2] uses an exponentially increasing probing rate, whereas pathload [4] is based on binary search to adjust the probing rate. Probe gap models, such as Initial Gap Increase/Packet Transmission Rate (IGI/PTR) [5], monitor the gap changes after packet pass through the link.

One of the recent works on measurement based approaches is Wireless Bandwidth estimation tool (WBest) [3], which is designed to accurately estimate the available bandwidth in IEEE 802.11 network and to statistically measure the relative available fraction of the effective capacity, mitigating the estimation delay and the effects of wireless channel errors.

The main advantage of these approaches is that they can provide additional traffic information such as delay, jitter and packet loss of the link. However, in such scheme probing packets generate additional extra traffic load to the network which may cause performance degradations of existing flows. Besides, they take long convergence time for the measurements, and produce low accuracy comparing with other bandwidth estimation techniques.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{idle}$</td>
<td>Channel idle time sensed by sender and receiver</td>
</tr>
<tr>
<td>$T$</td>
<td>Measurement period</td>
</tr>
<tr>
<td>$N$</td>
<td>Number of neighbor nodes</td>
</tr>
<tr>
<td>$K$</td>
<td>Proportion of bandwidth consumed by the waiting</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Safe coefficient to prevent the node overusing</td>
</tr>
<tr>
<td>$L$</td>
<td>Packet length</td>
</tr>
<tr>
<td>$C$</td>
<td>Maximum channel capacity</td>
</tr>
<tr>
<td>$C_u$</td>
<td>Channel utilization</td>
</tr>
<tr>
<td>$CW_{min}$</td>
<td>Minimum value of contention window</td>
</tr>
<tr>
<td>$CW_{max}$</td>
<td>Maximum value of contention window</td>
</tr>
<tr>
<td>$W$</td>
<td>Maximum window size is $CW_{max} = 2CW_{min}$</td>
</tr>
<tr>
<td>$W_{backoff}$</td>
<td>Average backoff window size</td>
</tr>
<tr>
<td>$R$</td>
<td>Maximum number of retransmissions</td>
</tr>
<tr>
<td>$DIFS$</td>
<td>Time duration for distributed interframe space</td>
</tr>
<tr>
<td>$SIFS$</td>
<td>Time duration for short interframe space</td>
</tr>
<tr>
<td>$ACK_{timeout}$</td>
<td>Timeout value for the lost acknowledgement packet</td>
</tr>
<tr>
<td>$X$</td>
<td>Random variable representing the number of retransmission suffered by a given frame</td>
</tr>
<tr>
<td>$p_{success}$</td>
<td>Probability of successful packet delivery</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Channel bit-error probability</td>
</tr>
<tr>
<td>$p_{err}$</td>
<td>Packet error probability</td>
</tr>
<tr>
<td>$p_{coll}$</td>
<td>Probability of packet collision due to neighbor nodes</td>
</tr>
<tr>
<td>$p_{s,e}$</td>
<td>Probability of packet collision due to hidden/exposed nodes</td>
</tr>
<tr>
<td>$f$</td>
<td>Total data flow from hidden and exposed nodes</td>
</tr>
</tbody>
</table>

B. Calculation based approaches with passive measurements

Calculation based approaches with passive measurement, also known as passive estimation, observe the channel over a given period of time and obtain the channel usage ratio. Then by smoothing or calibrating the results, the available bandwidth is obtained. Several researches have been proposed to calculate the available bandwidth using observation. One of the recent approaches is Adaptive Admission Control (AAC) protocol [6], where each node measures its activity period length independently. In this approach the available bandwidth of the link is calculated by following equation:
Based on the gathered data, the available bandwidth can be evaluated and this information is exchanged with neighbor nodes in order to compute the bandwidth of each link. Furthermore, in AAC protocol the control messaging overhead, packet error/collision probability and impact from hidden/exposed nodes were not considered.

Authors of [9] proposed an enhanced Available Bandwidth Estimation (ABE) by considering the overlap probability of two ends’ idle time. Their assumption is that the medium occupancy by the sender and receivers is independent to each other, and the available bandwidth is calculated according to following equation:

\[
AB_{\text{ABE}} = (1 - K) \times (1 - p_{\text{coll}}) \times \frac{T_{\text{idle}}}{T} \times \frac{T_{\text{idle}}}{T} \times C
\]  

(2)

where, \( K \) is a proportion of bandwidth consumed by the waiting and backoff process that can be expressed by:

\[
K = \frac{\text{DIFS + backoff}}{T}
\]  

(3)

In addition, the authors give an equation to calculate the impact of packet size, \( m \) to the packet collision rate, \( p(m) \):

\[
p(m) = f(m) \times p_{\text{Hello}}
\]  

(4)

where, \( f(m) \) is a Lagrange interpolating polynomial which fits with the data obtained by simulations with NS-2:

\[
f(m) = -5.65 \times 10^{-9} \times m^3 + 11.27 \times 10^{-6} \times m^2
\]

\[ -5.58 \times 10^{-3} \times m + 2.19
\]

(5)

Packet collision probability for Hello packets, \( p_{\text{Hello}} \), is calculated by:

\[
p_{\text{Hello}} = \frac{\text{number of lost Hello packets}}{\text{number of expected Hello packets}}
\]  

(6)

The ABE calculates the probability of overlapping as the product of both idle time periods (for example, if \( T_{\text{idle}} \) in both sender and receiver is equal to 0.5, the overlapping probability becomes \( 0.5 \times 0.5 = 0.25 \)), and does not considers the control messages (like SIFS and ACK time after the data frame transmission). Moreover, in ABE authors give that packet collision probability depends on a packet length. But, in [8] it was shown that the packet collision probability does not depend on the packet length; it depends only on average backoff window size and number of neighbor nodes. Consequently the ABE produces inaccurate bandwidth estimation.

More recent work on the passive available bandwidth estimation is proposed in Improved Available Bandwidth estimation (IAB) [10]. The IAB considers synchronization between sender and receiver, and differentiates the nodes’ BUSY and SENSE_BUSY states. The available bandwidth is calculated using following equation:

\[
AB_{\text{IAB}} = (1 - K) \times \left[ \frac{T_{\text{idle}} \times (1 - p_{\text{coll}}) \times T_{\text{idle}}}{T} - \mu \right] \times C
\]

(7)

where, \( \mu = 1 - C_u \times (1 - p_c) \) is the safe coefficient to prevent the node overusing the bandwidth.

Even though the synchronization between the nodes and the differentiation of states improves the accuracy of the estimation, still IAB does not take into account the time taken for control messages, and impact from hidden/exposed nodes is not considered.

Moreover, reported passive estimation tools have been implemented and tested on NS-2 simulator. In real environment with fading, packet loss, and additional source of the noise, the performance of the passive estimation tools may not be feasible. For example, on network simulators (NS-2, OPNET) the change of received signal strength level (RSS) is handled according to a simple packet loss model, which is a function of the distance between the nodes and transceiver antenna gain. But, in real environment even at some positions with the same distance, the measured RSS values can vary within 20-30 dBm.

The authors of [15] have made simple experiments in real wireless mesh environment using the passive estimation of channel busy time. They implemented a measurement framework in the Linux kernel, using the MadWiFi-ng WLAN driver; they have modified the device driver to report certain IEEE 802.11 events, from which they derived the information about the wireless channel. Even though, they implemented estimation tool for passive available bandwidth, and produced more accurate results comparing with existing active probing based bandwidth estimation tools, in the calculations, however, they didn’t consider the possible overhead by control messaging and the impact of the hidden/exposed nodes is not analyzed in detail.

In our previous work [11], we have used basic concepts of the passive available bandwidth estimation technique with the consideration of hidden/exposed terminals. However, during the analysis i) successful packet delivery probability (which includes probability of packet collision and packet error), and ii) time taken by control messages, such as Layer 2 acknowledgements for transmitted data, have not been considered. Furthermore, in [12] we include possible overhead by control messages, which significantly improved the performance of cPEAB. Those previous work, however, did not consider packet delivery failure due to collision or error that will decrease the throughput. In this paper we propose the solution to overcome this shortcoming by including probability of successful packet delivery.
C. Mathematical models for the estimation of available bandwidth

Estimation of the available bandwidth through mathematical models, such as an effective link model [14] or a Markov model [13] also performs accurate results in WLAN, but they are highly dependent on topology. Moreover, those models require detailed operational data which are difficult to be collected by each node dynamically, in a distributed real network environment.

III. COGNITIVE PASSIVE ESTIMATION OF AVAILABLE BANDWIDTH

In our proposed enhanced cognitive passive estimation of available bandwidth, we are focusing on passive estimation; but in addition to the channel usage ratio, following issues are also considered:

- probability of successful packet delivery:
  - packet collision probability due to neighbor nodes;
  - packet collision probability due to hidden/exposed nodes;
  - packet error probability.
- possible overhead by control messaging which may occur in future;

A. Probability of successful packet delivery

The general IEEE 802.11 frame exchange sequence is depicted in Fig. 1 [17]. The medium is sensed as busy in "Interval I". This interval can be interrupted; and, if it is interrupted during the DIFS (Distributed coordination function Inter-Frame Space) or Backoff, the transmission process is restarted completely when the medium is sensed idle again. After data transmission and SIFS (Short Inter-Frame Space), the sender waits for an ACK packet in order to be sure that packet has been correctly received by a receiver. Therefore, the available bandwidth can be calculated as:

\[ A_{B,PEAB} = p_{success} \times \frac{T_{idle}}{T} \times C \]  

1) Packet collision probability due to neighbor nodes

Now consider the probability that when the station \( A \) begins its transmission, and collides with another station \( B \). If we assume that there are sufficiently many other stations so that \( A \) and \( B \)'s transmissions are not synchronized (for e.g., EDCA), then \( A \) could begin transmission any time, and its probability of colliding with \( B \) station is \( 1/W_{Backoff} \). If the system consists of \( n \) number of stations which are neighboring \( A \), or are connected to the same AP, then the probability that \( A \) collides with any of them can be approximated to (9) according to [7]-[8]:

\[ p_{coll} = 1 - \left(1 - \frac{1}{W_{Backoff}}\right)^{n-1} \]  

(9)

In equation (9), the backoff time is a changing variable, and is defined as:

\[ W_{Backoff} = \sum_{k=0}^{R} P(X = k) \times \frac{\min(CW_{max}, 2^k CW_{min}) - 1}{2} \]  

(10)

With probability \( (1-p) \), the transmission is successful at the first try, and with probability \( p(1-p) \) the first transmission fails. Continuing along these lines, after \( k \) number of fails or retransmissions, the \( X \)'s probability can be expressed by:

\[ P(X = k) = \begin{cases} p^k(1-p), & 0 \leq k \leq R - 1 \\ p^k, & k = R \\ 0, & k > R \end{cases} \]  

(11)

Equations (9) and (10) establish a fixed point formulation, and it can be solved using numerical technique [6].

2) Packet collision probability due to hidden/exposed nodes

According to [19], the packet collision probability due to traffic flow from the hidden or exposed node is calculated using following equation:

\[ P_{h+e} = \begin{cases} \frac{f - h}{(C - f + e)}, & \text{if } \frac{f - h}{C - f + e} \leq 1 \\ 1, & \text{otherwise} \end{cases} \]  

(12)

Data flow information of the hidden and exposed nodes are provided by the cognitive network management system, which continuously updates its database based on network status, based on the IEEE 802.21 Media Independent Handover (MIH) [18] and IEEE P1900.4 architecture. Detailed architecture of cognitive network management system can be found in our previous work [1].

3) Packet error probability

In [9] authors assume that packet length has an impact to the packet collision probability. However, packet collision probability does not depend on the packet length since packets collide at the sender or receiver; at the sender side packets collide when two or more nodes try to access medium at the same time, while at the receiver side when packets from different sources arrive at the same time. According to this statement the packet collision probability depends only on...
average backoff window size (controls access to the medium) and number of neighbor nodes (how many nodes are trying to access the same medium). Furthermore, if the length of packet is getting longer, the probability of bit error also increases. With the channel random bit error rate, $\rho$, and packet length, $L$, packet error probability, $p_{err}$ of a given link is calculated by following equation [19]:

$$p_{err} = 1 - (1 - \rho)^L$$

(13)

From equations (9), (12) and (13), the probability of successful data delivery can be given by:

$$p_{success} = (1 - p_{coll}) \times (1 - p_{h_e}) \times (1 - p_{err})$$

(14)

### B. Possible overhead by control messaging

In the Fig. 1 the proportion of bandwidth consumed by DIFS and Backoff time is an overhead for the throughput. It can be depicted as a coefficient $K$ as it is done in [9]-[10] and calculated according to (3). Therefore, now the available bandwidth is calculated as:

$$AB_{cPEAB} = (1 - K) \times p_{success} \times \frac{T_{idle}}{T} \times C$$

(15)

Furthermore, there exists “Interval III” in Fig.1, which consists of Short Interframe Space (SIFS) time and the time taken for acknowledgement frame. Even they are not so big, still they have impact to the bandwidth estimation, because IEEE 802.11 WLAN is based on Stop-and-Wait ARQ mechanism, every transmitted frame requires its acknowledgement [17]. In order to calculate the proportion of the bandwidth consumed by “Interval III”, in [12] we introduce a coefficient $A$ that can be expressed by following equation:

$$A = \frac{ACK_{Timeout} + SIFS}{T}$$

(16)

Thus, we will get final equation for the available bandwidth estimation:

$$AB_{cPEAB} = (1 - K) \times (1 - A) \times p_{success} \times \frac{T_{idle}}{T} \times C$$

(17)

### IV. IMPLEMENTATION AND PERFORMANCE ANALYSIS OF cPEAB

#### A. Evaluation of bandwidth estimation approaches & testbed

For the experiments we use PCs equipped with IEEE 802.11 a/b/g Atheros 5212 chipset based wireless NICs which run on Linux OS with the open source MadWiFi WLAN driver [20]. Moreover, we also implemented the calculation based approaches of AAC [6], ABE [9], and IAB [10] on real environment, in order to make correct comparisons with our proposed cPEAB technique. Through out probing based available bandwidth estimation tools we used WBEST [3]. Real available bandwidth is measured by sending saturating amount of data using UDP protocol and received data is checked at the receiver including packet losses. RTS/CTS message exchanging is disabled in our experiments as configured in usual WiFi nodes due to their negative impact to the throughput. The required information, such as channel idle time, current transmission rate are obtained by reading the specific information registers of Atheros hardware abstraction layer (HAL). The detailed analysis of register reading can be found in [12]. In the experiments, we use the testbed and the protocol parameters as specified in Table II.

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of medium</td>
<td>802.11g</td>
</tr>
<tr>
<td>Transmission rate</td>
<td>54 Mbps</td>
</tr>
<tr>
<td>Slot time</td>
<td>9 usec</td>
</tr>
<tr>
<td>SIFS</td>
<td>10 usec</td>
</tr>
<tr>
<td>DIFS</td>
<td>28 usec</td>
</tr>
<tr>
<td>Probing traffic type</td>
<td>CBR</td>
</tr>
<tr>
<td>Traffic protocol</td>
<td>UDP</td>
</tr>
</tbody>
</table>

#### B. Performance analysis

1) Effect of Different Measurement Period on the Correctness of the Bandwidth Estimation

Since the available bandwidth is estimated in every measurement period, $T$, the value of $T$ directly affects the correctness of the estimated available bandwidth; if the measurement period is short enough (0.1-1sec), any changes in the network can be reflected much faster with lots of fluctuations, while with a longer measurement period more stable results are obtained. For the comparison we have run a series of experiments with different measurement period for 40 seconds, and during 20-30 seconds of experiment time, we send 5 Mbps UDP traffic from one node, while estimating the available bandwidth by the second node as shown in Fig. 2. This variation of transmission rate is configured to see how the measurement period impacts on the correctness of the estimated available bandwidth. For the comparison we have run experiments with $T=0.2$, 0.5, 1, 5 and 10 seconds, respectively. The results are as shown in Fig. 3. From the results it is obviously shown that with the smaller sample duration the available bandwidth estimation approach can easily detect any changes in the network, although with the slight fluctuations.
In Fig. 3 the estimated available bandwidths with T = 0.2, 0.5, 1, 5, and 10 seconds, respectively, are plotted. When T = 5 or 10 seconds, the estimated values are not reflecting the bandwidth changes rapidly. When T = 0.2 or 0.5, however, we observe lots of fluctuations in the estimated value.

For fair comparison with other work, we have chosen the sampling time as 1 s in the rest of analysis, as it has been done in other work [6]-[8].

2) Comparison of performances of the available bandwidth estimation

For the comparison of proposed cPEAB and other tools we configure testbed topology as depicted in Fig. 4. All nodes are located to each others’ transmission range, and the distance between nodes and the AP is equal. Node 1 estimates the available bandwidth, while other nodes are sending data traffic (UDP with 1500B packet size) load to the AP.

The average estimated bandwidth by cPEAB, IAB, ABE, AAC and WBest are plotted in Fig. 6. Since AAC does not consider on any kind of time consumption due to control signaling (nor DIFS and Backoff, neither ACK) it performs worst result. ABE and IAB with consideration of DIFS and Backoff times give more accurate result comparing with AAC. However, without consideration of overall bandwidth utilization, μ and by calculating the probability of overlapping as the product of both idle time periods, ABE estimates the AB with high estimation error than IAB. Even IAB considers on bandwidth utilization, it does not take into account time taken by ACKs, which has still small impact to the AB calculation.

In addition to passive available bandwidth estimation tools we made this experiment for one of the active probing bandwidth estimation tool – WBBest that estimates the available bandwidth by sending packet pairs and trains. In our experiments, WBBest and cPEAB performed quite similar results, because in WBBest the available bandwidth of the link is estimated by sending probing packet through the link and analyzing the performance of those probes, while cPEAB makes a passive estimation by considering all possible overhead by control messaging.

In order to estimate the real available bandwidth we sent UDP traffic load from the current investigating node (in the Fig. 4 it is a Node_1) while the configuration of other nodes are same as previous scenario (sending 5Mbps traffic load to the AP). We check the packet loss ratio of the system at the different traffic load from the investigating node at the different packet size.
In Fig. 7 the relationship between traffic load from the investigating node with throughput and packet loss ratio of the system are given. For the comparison, we include the estimated bandwidth using cPEAB and WBest. The results in Fig. 7 clearly show that when traffic load from current node is near to the estimated bandwidth by cPEAB and WBest, the packet loss ratio of the system is rapidly increasing. Moreover, the aggregated traffic from neighbor nodes also decreasing since system cannot support such big traffic (Fig. 7-a). When the generated traffic load is higher than the available bandwidth of the system, current node can not send upcoming data from upper layer, hence it remains the amount of generated traffic.

Fig. 7. Testbed topology for the experiment with hidden/exposed nodes

3) Scenarios with hidden/exposed nodes

In order to check performance of the available bandwidth estimation tools testbed topology is configured as it is depicted in Fig. 7. Transmission range of nodes is reduced by configuring their transmission power. From several experiments we get that with 2dBm transmission power the data transmission range becomes around 6 m. In the topology MN 1 with AP 2 and MN 3 with AP 1 are hidden to each other; from to the traffic flow direction it can be found whether nodes are exposed with each other or not. Here four different scenarios can be differentiated according to the traffic flow direction, and they are depicted in Fig. 8.

In all scenarios the available bandwidth of the link is calculated between AP 1 and MN 1, while hidden/exposed traffic is sent between AP 2 and MN 2. When MN 2 becomes hidden to AP 1, and traffic flow direction is going from the MN 2 to AP 2, collision may occur at MN 1, and it decreases the amount of the bandwidth between AP 1 and MN 1. When MN 2 acts as a receiver, this traffic (traffic flow from the MN 2 to AP 2) will not affect to the available bandwidth estimation, because MN 2 needs to send only acknowledgements that makes medium as a busy for a small amount of time and which have less impact to the other data transmission due to their small packet size.

Fig. 6. Comparison of the available bandwidth estimation tools (cPEAB and WBest) at different packet size: (a) 500B, (b) 1500B, (c) 2500B, and (d) 3500B
The result of experiments that are depicted in Fig. 9, show that almost half of the available bandwidth is affected by the hidden/exposed nodes, when the network configuration is similar as described in scenario 2 and 4. Along our experiments we made simple comparison of the available bandwidth estimation tools with the scenario 2.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we proposed a new cognitive passive estimation of available bandwidth (cPEAB), which is designed to provide more accurate estimation in overlapped IEEE 802.11 WiFi WLANs. The accuracy of the estimation is obtained by correct measurements of i) the proportion of waiting and backoff delay, ii) packet collision probability, iii) acknowledgement delay, iv) channel idle time compared to the measurement period, and v) traffic from hidden/exposed terminals. For the collection of the traffic information of the hidden and exposed nodes, we are using a cognitive network management system. Moreover, the information of the hidden and exposed nodes is considered which is provided by the cognitive network management system. The proposed approach (cPEAB) is using passive measurement, which does not affect the available bandwidth of the existing flows.

The performance of the proposed cPEAB is evaluated on open source MadWiFi WLAN driver. Results are analyzed and compared with existing schemes, such as AAC, ABE, IAB, and the packet probing based tool WBest. Experimental results show that the proposed cPEAB provides the most accurate estimation of available bandwidth on the overlapped WiFi WLAN environment where the hidden/exposed nodes are directly affecting to the available bandwidth.

Especially when the impacts from the hidden/exposed terminals are increased the correctness of the available bandwidth estimations was deteriorated in most approaches, but the proposed scheme produced the most correct results.

As a conclusion, the proposed scheme can be used in the correct estimation of available bandwidth in the WiFi WLAN-based home/office networks, where most of consumer electronics devices for realtime applications and QoS-guaranteed multimedia communications are provided. Our future research work include dynamic load balancing among multiple overlapped WiFi BSSs (base service sets), and efficient differentiated QoS-aware service provisioning with IEEE 802.11e HCCA and EDCA.

VI. REFERENCES


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