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RAAC: A BANDWIDTH ESTIMATION TECHNIQUE FOR ADMISSION CONTROL IN MANET

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Abstract. *The widespread of wireless mobile network have increased the demand for its applications. Providing a reliable QoS in wireless medium, especially mobile ad-hoc network (MANET), is quite challenging and remains an ongoing research trend. One of the key issues of MANET is its inability to accurately predict the needed and available resources to avoid interference with already transmitting traffic flow. In this work, we propose a resource allocation and admission control (RAAC) solution. RAAC is an admission control scheme that estimates the available bandwidth needed within a network, using a robust and accurate resource estimation technique. Simulation results obtained show that our proposed scheme for MANET can efficiently estimate the available bandwidth and outperforms other existing approaches for admission control with bandwidth estimation.*

Key words: *Admission control, Bandwidth, Channel idle time, MANET*

1. INTRODUCTION

In recent times, the need to support QoS in MANET is rapidly increasing. Tasks, especially real-time applications, require QoS to enhance its communication (i.e. multimedia data). Solutions have been proposed to support QoS in wired network, however, these solutions are not directly adaptable to the wireless communication networks, as the latter requires novel solution for MANET. Nodes must therefore cooperate with one another to guarantee effective routing as well as QoS. This cooperation includes endpoint flow policing as well as admission control implementation along the route to prevent network violation of the initially configured policy. The aim of deploying QoS support is to provide guaranteed application support in terms of delay, jitter, throughput, bandwidth, etc. To ensure this, the MAC layer takes the responsibility of allocating resources at individual nodes, while the network layer must consider resources along the entire communication route. The support for

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QoS in MANET when compared with its wired counterpart is not trivial, due to its lack of infrastructure and sharing of resources and medium [1] [2]. A mechanism that provides QoS assurance is known as admission control. The aim of an admission control is to decide whether to admit data sessions that can satisfy a given QoS requirement without violating any previously made rules or reject sessions. The main issue encoun/during the implementation of admission control mechanism revolves around retrieving information on the available network resources. The admission control protocol must be able to determine if there are nodes that have the available resources to accommodate the intended traffic flow [3] [4].

In this work, we propose RAAC which is used to estimate the available bandwidth in a network for admission control purpose. RAAC combines and improves the existing algorithms of measurement-based available bandwidth estimation and flow admission control (BandEst) and cognitive passive estimation of available bandwidth (cPEAB). We identify the key metrics that must be considered for our protocol to have a better performance A mechanism that determines the measurement of all these metrics to improve the network performance has been implemented using OPNET modeler simulation tool.

The rest of the paper is organized as follows; Section 2 presents related works while Section 3 describes bandwidth estimation and admission control. In Section 4, we present our proposed resource allocation and admission control (RAAC) while Section 5 presents the experimental simulation. Finally, Section 6 concludes the paper.

2. RELATED WORKS

MANETs in recent times have become the choice wireless network due to the numerous advantages it proffers. In wired network, the available bandwidth measurement is done using an active estimation technique [5]. This technique is not suitable for MANET because it makes use of probe packets when measuring the available bandwidth between source and destination. If the number of source to destination pair is large, it will result in the sending of many probe packets which in turn consumes a large amount of bandwidth.

Yang and Kravets [6] proposed a contention aware flow admission control for ad-hoc network (CACP). In CACP, flow admission control is performed based on estimating the available bandwidth. The estimation is done using the wireless channel sensing mechanism by considering the back-off period. It is assumed that the back-off period is negligible even at saturation. CACP considered both intra-flow and inter-flow contention count in a distributed manner. The drawbacks of CACP is its non-consideration of the effect of MAC layer on the available bandwidth, and its failure to consider the impact of MAC layer overhead when data traffic load is increased within a network.

Sarr et al. [7] propose an available bandwidth-based flow admission control (ABE) algorithm for wireless network. Estimation of the available bandwidth is done by using the wireless channel sensing mechanism. To achieve this, they considered the virtual, physical carrier sensing, and different types of wireless CSMA/CA MAC layer interframe spacing. The authors argued that measuring the channel activities, considering the amount of time spent in the physical and virtual carrier sensing with different interframe space, results in over-estimating the available bandwidth. This is due to the non-synchronization between the sender and the receiver within an ad-hoc network (note that synchronization between the sender and receiver as used in the context of this work means that for communication to occur, the medium availability on the sender and the receiver must synchronise). The authors thereafter propose a mathematical model that considers the collision probability to estimate the actual available bandwidth and the future back-off overhead. The collision probability is derived from the amount of HELLO messages received by a node over the amount of HELLO packets expected to be received by the node at the previous interval measurement. The admission control flow algorithm makes use of one-hop neighbour and two-hop neighbour information to calculate the intra-flow contention and the authors used 4 as the maximum intra-flow contention. To calculate the inter-flow contention, the minimum available bandwidth within the interference range is determined to decide on the flows admission request. The drawbacks of this technique are: (i) If there is an increase in the data traffic load within a network, the only factor considered is the additional back-off overhead. Other important factors, such as additional retransmission and contention window overheads are ignored. (ii) The intra-flow contention count calculation does not always provide a right contention count and appears as been too simple, since it only considers the minimum available bandwidth within the interference range of a node. (iii) Collision probability is calculated without considering the hidden and exposed node causing unnecessary delay.

An improved available bandwidth (IAB) has been proposed by Zhao et al. [8]. This protocol estimates the available bandwidth of a giving link for QoS support in wireless ad-hoc network. It considers the synchronization between the source and the destination node by differentiating the busyness caused by the transmitting and receiving node from those caused by the sensing node. Furthermore, the work also improved the accuracy of estimating the overlapping probability of the idle time of two adjacent nodes. The drawback of this technique is similar to (i) and (ii) mentioned in [7].

Cognitive passive estimation of available bandwidth (cPEAB) was proposed by [9]. This protocol estimates the available bandwidth of a network in an overlapped WiFi environment. It considers the additional overhead caused by acknowledgement frames, which was not considered in both AAC and ABE, therefore estimating the available bandwidth by measuring the proportion of waiting and back off delay, packet collision probability, acknowledgment delay, and channel idle time. Furthermore, cPEAB considered the hidden and exposed node to have a more accurate available bandwidth measurement. The drawback of this proposed algorithm is that the intra-flow contention count calculation does not always provide a right contention count. Additionally, retransmission and contention window overheads were also ignored in the proposed algorithm. To retrieve the available bandwidth on a carrier sensing, HELLO packet is broadcasted to two hop neighbour which floods the network to increase the network overhead. Lastly, the dependency of the channel idle time ratio only differentiates between the *bus*y and *sensed busy* and did not regard an empty queue to be an idle channel time period. We define the *BUSY* state as a situation whereby a node is in the state of transmission or receiving while the *SENSE BUSY* state is defined as a situation whereby a node is in the state of sensing. Any other time outside the sensing time means the node is in an *IDLE* state. The *IDLE* state means that the node is neither transmitting, receiving nor sensing any packet. For a channel to be idle, the channel does not necessarily have to be sensed idle by both the physical and virtual wireless carrier sensing mechanism, however, the interface queue must be empty.

Nam et al. [10] improved on the work of [7] by enhancing its algorithm to include retransmission mechanism and back-off overhead. The drawback of this technique is that the contention window overhead was not considered with increase in data traffic load inside the network. Also, the assumptions made in the mathematical model may not hold through in the actual network.

Farooq et al. [11] propose a proactive bandwidth estimation (PABE) for IEEE 802.15.1-based network. PABE is a measurement based enhancement for available bandwidth estimation method and flow control admission control algorithm. Instead of deploying a model to predict the collision and back-off, empirical method for gathering data was used to predict any additional back-off overhead. Besides, it uses the value of the expected future data traffic load to predict additional overhead instead of using the existing one. The drawback of this algorithm is the increase in data traffic load within a network, as additional retransmission and contention window overheads are ignored. Also, the computation of the intra-flow and inter-flow contention count was inaccurate. Lastly, to retrieve the available bandwidth on a carrier sensing, HELLO packet is broadcasted to two hop neighbour which tends to flood the network, which in turn increase the network overhead.

BandEst, another algorithm proposed by Farooq et al. [12], proactively considers the complete wireless 802.15.4 unslotted CSMA-CA MAC layer overhead and considers the future load. Additionally, it considers the estimation of intra-flow contention and estimates contention on non-relaying nodes. Additional MAC layer overhead that is associated with the increase in data traffic load was considered and an algorithm that deals with concurrent admission request in a FIFO was implemented. The drawback of BandEst is that it has a higher overhead because it broadcast to two-hops. Furthermore, BandEst did not consider the channel idle time dependency together with the effect of hidden/exposed node on the accuracy of bandwidth estimation.

From the reviewed literature, the channel idle time dependency sensed by both the sender and receiver has not been properly addressed as most previous works in the literature did not factor it in their design.

This work therefore proposes a resource allocation and admission control (RAAC) mechanism that estimate the bandwidth for admission control based on some key factors.

3. Factors to be Considered for Admission Control Implementation

In this section, we identify the key factors that are essential to implement admission control within a network. This will help to create a background work to evaluate the related works.

3.1. Channel idle time dependency

Channel idle time dependency sensed by the sender and the receiver ensures an accurate estimation of the available bandwidth. This is achieved by differentiating the nodes BUSY state from SENSE state and differentiating the channel idleness that may be caused by an empty queue.

3.2. Intra-flow interference

Transmitted packets interfere with all nodes within the carrier sensing range of the transmitting host. By considering a multi-hop path, some forwarding nodes are located within the sensing range of one another, therefore, the same flow are transmitted several times in the same sensing region, thereby using the same shared channel. This circumstance is known as intra-flow contention. In [13], the contention count is defined as the number of nodes on the multi-hop path located within the carrier sensing range of the contending host.

3.3. Collision with respect to hidden node and unnecessary delay from exposed nodes

In wireless network, there is no possibility of detecting if a collision will happen, therefore, once it happens, both colliding frames are emitted completely, thereby maximizing the loss in bandwidth. Therefore, when estimating collision and unnecessary delay within the available bandwidth, consideration must be given to check the impact of both the hidden and the exposed terminal nodes [9].

3.4. Increased data traffic

Increased data traffic inside the network leads to an increase in CSMA/CA which is based on MAC overhead with respect to back-off interval, retransmission number, acknowledgement packet and contention size. When a data traffic load of a network is increased, it in turn increase the CSMA/CA based MAC layer overhead; therefore, the available bandwidth estimation of the admission control algorithm needs to take note of the consumed bandwidth such as the MAC layer overhead corresponding to different values of the offered data load inside a network [14].

4. RESOURCE ALLOCATION AND ADMISSION CONTROL (RAAC)

Our proposed algorithm, RAAC, has adopted bandwidth estimation, where channel idle time dependency, intra-flow interference, collision with respect to hidden nodes and unnecessary delay impact due to exposed nodes, and lastly, increased data traffic inside a network leading to an increase in CSMA/CA based on MAC overhead was considered. RAAC is a novel, efficient and accurate resource allocation and admission control technique that estimates the available bandwidth for the admission controller to either accept or reject a session when an admission is requested. The process to achieve this can be divided into three, namely; measuring the channel idle time dependency, measuring the intra-flow contention, and resolving issues of hidden node causing collision and exposed nodes leading to unnecessary delay.

4.1. Measuring the Channel Idle Time Dependency

Figure 1 depicts a wireless state transition diagram. A node in this transmission diagram is said to be in a state of transmission, only if it is currently emitting signals through its antenna. A node is said to be in a receiving state if there are nodes transmitting within its transmission range. A node is said to be in its sensing state if the medium is sensed busy but there is no receiving frame because the energy is below the receiving threshold. A node is said to be in an idle state if it is not transmitting, receiving, or sensing any packet.

By differentiating SENSE busy state from the BUSY state and redefining the idle channel time of a station to include a time that the MAC queue is empty, allows for the synchronization of the sender and the receiver as well as proper available bandwidth estimation.

The available bandwidth with respect to the channel idle time dependency is therefore;

$$AB = \frac{T_i}{T} \times C = \frac{T - T_B - T_S - T_E}{T} \times C \tag{1}$$

Where T_i, $T_{B,}$ $T_{S,}$ $T_{E,}$ denotes the time duration of the IDLE, BUSY, SENSE BUSY and EMPTY QUEUE states respectively at a measured period T. C is the maximum link capacity.

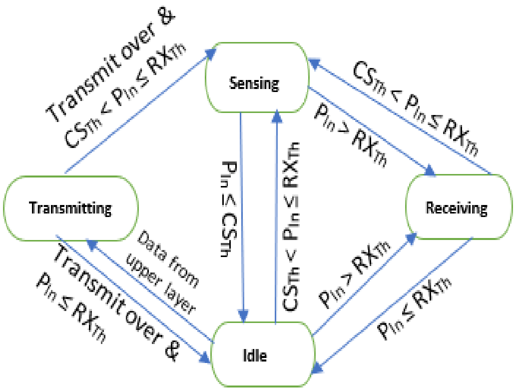

Fig. 1 Wireless radio transition diagram [15]

To further clarify this, the scenario in Figure 2a was considered, where N1 is transmitting to N2. Figure 2b shows the basic IEEE 802.11 exchange of frame sequence (at the top) and the channel state sensed by all the nodes. All the nodes that falls into the transmission range of node1 can successfully decode any packet from it. Furthermore, information about the time it finished transmitting the packet can also be determined. At this time, they are in the receiving state, which is BUSY state. Even though N1 is defined as idle in "interval a", during this period, the medium must be sensed idle by N1 and cannot be used by nodes within the carrier sensing range. To eliminate this inaccuracy, the coefficient K was adopted as used in [13], where:

$$K = \frac{DIFS + \overline{Backoff}}{T} \tag{2}$$

K represents the proportion of the bandwidth consumed during the waiting and the back-off period. Note that the back-off varies, therefore, we use its average value, which is written as, $\overline{Backoff}$.

The number of back-off slot that decrements for a single frame on an average can be represented as:

$$\overline{backoff} = \sum_{k=0}^{M} P(X = k) \times \frac{\min(CW_{max,} 2^{k} CW_{min}) - 1}{2} \tag{3}$$

Where CW_{min} represents the initial (or minimal) value of the contention window and CW_{max} represents the maximum value of the contention window, with $CW_{max} = 2^N$. M denotes the maximum number of retransmissions attempted ($M \geq N$); X denotes the number of retransmissions suffered by a given frame, therefore:

$$P(X = k) = \begin{cases} P^{k}\,(1 - P), & 0 \leq K \leq M - 1 \\ P^{M}, & K = M \\ 0, & K > M \end{cases}$$

P represents the conditional collision probability [16], which is the probability that a transmitting packet will collide. The following expression can be used to derive the $\overline{Backoff}$:

$$\overline{backoff} = \frac{1 - P - 2^{N} P^{N+1}}{2 - 4P} \times CW_{min} - \frac{1}{2} \tag{4}$$

Note that the packet collision probability effect (P) was included in the calculation of *K*.

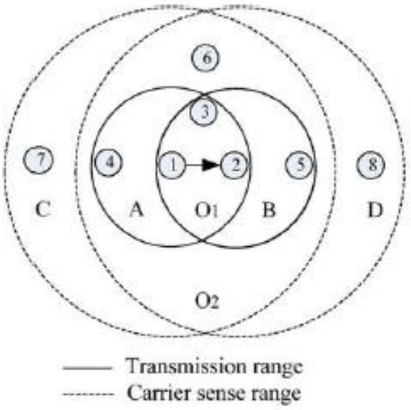

Fig. 2a Wireless transmission scenario showing transmission range and carrier sensing range [15]

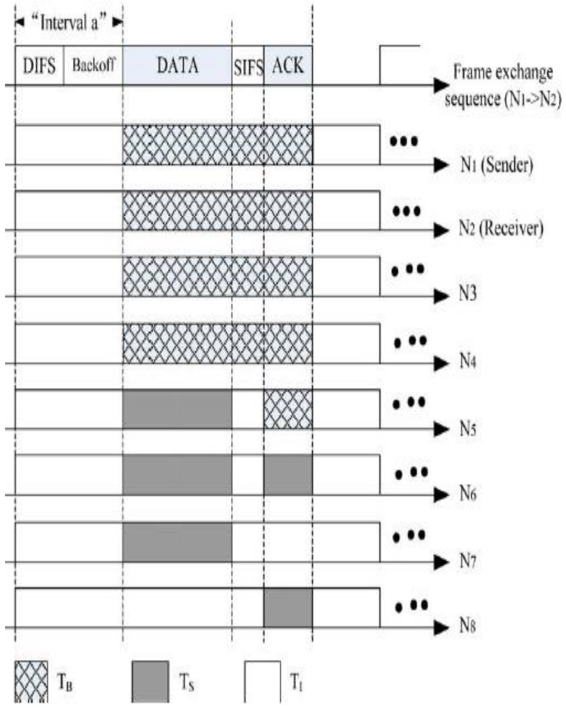

Fig. 2b Channel states sensed by nodes in scenario 2a [15]

4.2. Measuring the Intra-Flow Contention

Determining the correct value of the intra-flow contention depends on the interference range of the node in a network. Let us assume that the nodes within the two-hop distance can cause interference, therefore, the interference count on any node along the path forwarding the data majorly depends on the distance of the node from the source and the nodes destination. For a new admission control request to be granted, RAAC determines the actual intra-flow contention count along the source node, intermediate node, and the destination node.

4.3. Resolving Issues of Hidden and Exposed Nodes

Looking at the IEEE 802.11 frame exchange sequence in Figure 3, interval III is used for transmitting data frame which is dependent on the frame size. Moreover, according to [7], the size of a frame has a direct impact on the packet collision rate, where the impact of hidden and exposed node was not considered by the author.

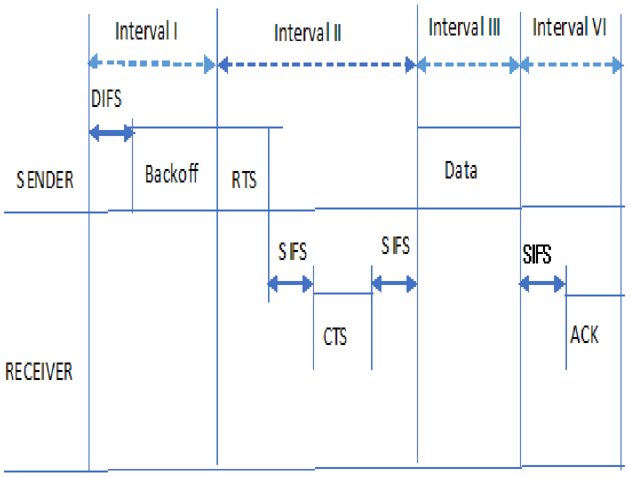

Fig 3 Frame exchange sequence in RTS/CTS mechanism [17]

Therefore, using [18], the impact of a flows hidden/exposed terminals can be calculated as:

$$P_c = \begin{cases} \frac{f\_h}{(C - f_e)}, & if (0 \leq \frac{f_h}{(C - f_e)} \leq 1) \\ 1, & otherwise \end{cases} \tag{5}$$

Where, f_h denotes the total data flow of hidden nodes and f_e denotes the total data flow of the exposed node.

To solve the issue of hidden nodes and exposed nodes which may cause collision and unnecessary delay, the request to send and clear to send (RTS/CTS) mechanism is activated. In figure 3, interval II shows the frame exchange sequence when the RTS and CTS mechanism is activated. Interval II, therefore consist of RTS and CTS messages with two SIFS (short interframe space) in between them. The overhead incurred by RTS and CTS is calculated as:

$$R/C = \begin{cases} \frac{(RTS+CTS)+2\times SIFS}{T}, & if\ RTS/CTS\ is\ used \\ 0, & Otherwise \end{cases} \tag{6}$$

By considering the extra overhead that may be added when the RTS/CTS is used, the available bandwidth estimation can be more precise.

Scenario without Hidden/Exposed Node: Figure 4 depicts a topology without hidden/exposed node. The two nodes involved are located within each other's transmission range. One of the nodes is sending traffic to the access point while the other node is estimating the available bandwidth.

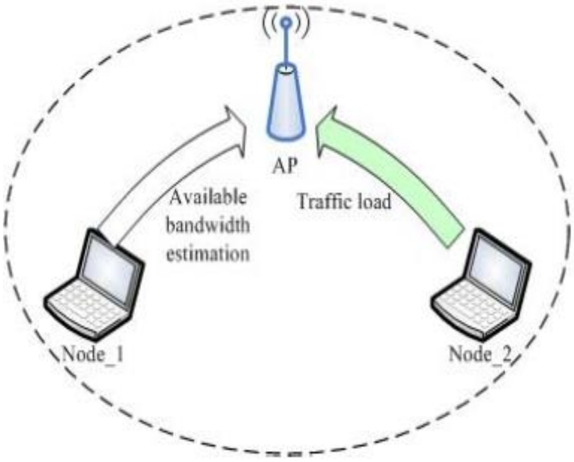

Fig. 4 Scenario without hidden/exposed node [9]

Scenario with Hidden/Exposed Nodes: In figure 5 and 6, we consider a topology which is configured to have 1 hidden node and 1 exposed node.

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/---------------------\
|           /---------+------------\
|           |         |            |
|   a<------+--b   c--+--------->d |
|           |         |            |
\-----------+---------/            |
            \----------------------/
```

Fig. 5 Exposed nodes [18]

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/---------------------\
|           /---------+------------\
|           |         |            |
|   a-------+->b   c--+--------->d |
|           |         |            |
\-----------+---------/            |
            \----------------------/
```

Fig. 6 Hidden node [18]

Figure 5 shows that node *b* and node *c*, are in the same transmission range. When node *b* sends data to node *a*, node *c* will detect that the channel is busy and node *c* will not make any attempt to send data to node *d* to avoid collision. The same process applies vice-versa. Note that node *b* and node *c* are each other's *exposed node*.

In figure 6, node *a* is not in the transmission range of node *c*. Whenever node *a* sends packets, node *c* detects that the channel is idle, if node *c* sends data at the same time, it will result in packet collision, i.e. packet *a* and *c* will collide with node *b,* which will eventually result in transmission failure. Note that node *c* is the *hidden node* of node *a.*

4.4. Increased Data Traffic Lead to an Increase in CSMA/CA MAC Overhead

Farooq and Kunz [11] in their work observed that an increase in data traffic in the network results in an increase in the CSMA/CA MAC overhead, due to the number of retransmission and back-off duration. Therefore, for an available bandwidth estimation to be effective, there is need to take note of the bandwidth consumed by the MAC layer overhead corresponding to the different values of the data load offered inside a network. In [11], an experimental study was carried out to determine the IEEE802.15.4 unslotted CSMA/CA MAC layer overhead (retransmission and back-off) with increased data load in the network. It was observed that an increase in data load will lead to an increase in the average back-off as well as the retransmission overhead. Therefore, it is essential to consider the back-off and retransmission overhead by taking note of the additional data load inside the network. If there is an excess of 60kbps of the anticipated data load within the interference range of a network, the extrapolation technique can be used to determine the additional back-off and retransmission overhead.

In order to estimate the additional MAC layer overhead leading to an increased data traffic load, the author in [11] presented a method in section 2.1 of their work. Here, the MAC layer overhead is considered after determining the future data load (i.e., the current data traffic load at the interference range of a node is added to the contention count and then multiplied by the new flow's required bandwidth). The overhead associated with the method presented in [11] is that a lookup table is stored on nodes that returns estimated MAC overhead corresponding to a given value of the data load inside a network. It is not possible to store the MAC layer overhead in terms of bps corresponding to each possible offered data load, but an algorithm can estimate the MAC layer overheads for an offered data load not present in the lookup table by linear interpolation, using the two closest available data points.

By applying equation (1) through to (6), we derived an estimation of available bandwidth for RAAC, which is:

$$AB_{RAAC} = (1 - K) \times (1 - R/C) \times (1 - ACK) \times (1 - P_C) \times \frac{T_i}{T} \times C \times \frac{1}{L} \tag{7}$$

Where:
K= bandwidth consumed as per waiting time and back-off
Pc= packet collision probability
Ack= acknowledgement
C= maximum link capacity
L= traffic load
R/C= RTS/CTS
T_i = idle time of the wireless in a measured period T

5. SIMULATION PARAMETERS

In this section, we use OPNET modeler to simulate our design to evaluate the performance of RAAC. We have deployed 100 nodes which was randomly distributed in a 1200x1200m area. Furthermore, we set other network parameters accordingly, i.e. link capacity of 54Mbps, transmission range of 250m and carrier sensing range of 550m was used. T is set to 1s and 6 sender and receiver nodes were randomly selected among the 100 nodes to carry out the background traffic while the rest of the nodes are either acting as relay node or idle. Simulation was carried out for 60 seconds and each simulation was repeated 10 times. Table 1 depicts the parameters used for our simulation.

Table 1 Simulation Parameter

Parameter	Value
Number of nodes	100
Total network area	1200 X1200m
Link capacity	54Mbps
Packet size	127bytes
Transmission range	250m
Carrier sensing range	550m
Number of sender-receiver	6
T	1sec
Number of simulation (repetition)	10 times
Simulation time	60s
DIFS	28ms
SIFS	10ms
Slot time	9ms
MAC header size	34byte
Acknowledgement	33bytes
RTS size	20byte
CTS size	14byte
CWmin	15
CWmax	1023
Traffic type	CBR

5.1. Simulation Model and Evaluation of RAAC

Similar to the work of [17], a scenario in figure 7 is used in evaluating RAAC. Flow 1 (f1) on link (5,6) has a variable bandwidth and flow 2 (f2) on link (1,2) has a constant bandwidth of 600kbps. The available bandwidth estimation on link (3,4) for RAAC is calculated using equation 7. The link capacity is 54Mbps and the source nodes which are nodes 1 and 5 generates 1Kbyte traffic. The distance between each node is 200m.

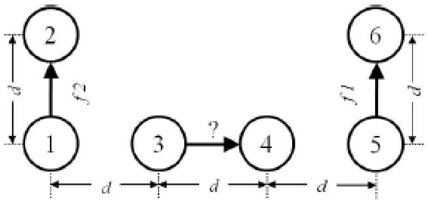

Fig. 7 Simulated Network Topology [17].

As we will be estimating the available bandwidth every T (sample period) seconds, the choice of T will have an impact on the available bandwidth estimation. We show the impact of this in the next section. To have a fair comparison, T has been chosen to be 1 second, just as in the work of [9], [12] and [11].

5.2. Measuring the Available Bandwidth

To measure the available bandwidth on a given link (*s, r*) during simulation, we transmitted a flow *f* on the link (*s, r*). For each value obtained, the rate of the flow is increased incrementally. If one of the other existing flows in the network sees its rate decrease by more than 5%, the increase in the rate of the flow *f* (*s, r*) is stopped. The achieved rate *f* (*s, r*) is considered as the available bandwidth on the link (*s, r*), i.e. the real bandwidth that can be achieved without degrading close flows.

5.3. Simulation Results

Assessing RAAC: We compared the available bandwidth estimated by RAAC with the real available bandwidth, as shown in figure 8. Our bandwidth estimation approach, RAAC, has been able to predict the available bandwidth notwithstanding the type of traffic flow. Even though some little estimation variations were recorded in some instances (see Figure 8), the results obtained by our proposed RAAC is very close to the actual available bandwidth. For clarity purpose, we present the average value of the real available bandwidth and the value obtained from our proposed RAAC (see Table 2). The results obtained from the measured and estimated bandwidth show how well RAAC has been able to estimate the measured available bandwidth.

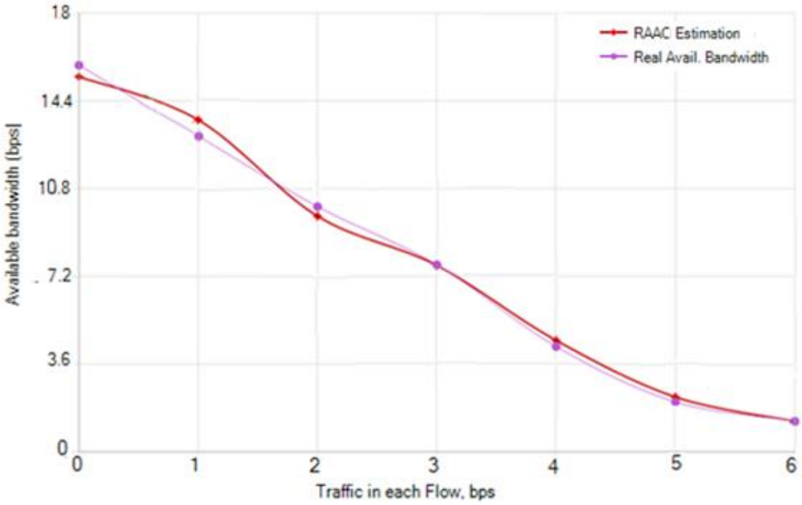

Fig. 8 Available bandwidth estimation between RAAC and Real available bandwidth

Table 2 Average Available bandwidth measurement per traffic flow

Bandwidth Estimation method	Average value of traffic flow (bps)
Real Available bandwidth	15757.12
RAAC	15844.42

Assessing RAAC against cPEAB, PABE, and BandEst: Here, we evaluate our proposed approach, RAAC, with related past works, cPEAB, PABE and BandEst using the same scenario in section 4. The available bandwidth estimation on link (3,4) for cPEAB [9], PABE [12] and BandEst [11] is calculated using equation 8, 9, and 10. Our implementation of PABE and BandEst adopted the mathematical model of estimation as against the proactive method used by the authors. The mathematical method was used to ensure a fair comparison. The estimation of cPEAB, on the other hand, was presented by the authors using mathematical model.

$$AB_{CPEAB} = (1-K)\times(1-ACK)\times(1-P_C)\times\frac{T_i}{T}\times C \tag{8}$$

$$AB_{PABE} = (1-K)\times(1-P_C)\times\frac{T_i}{T}\times C\times\frac{1}{L} \tag{9}$$

$$AB_{BandEst} = (1-K)\times(1-P_C)\times\frac{T_s}{T}\times\frac{T_r}{T}\times C\times\frac{1}{L} \tag{10}$$

Where Tr and Ts are the idle time of the sender and receiver in the wireless medium. All other parameter definition can be found in section II.

The result presented in figure 9 shows how RAAC outperforms other protocols when estimating the available bandwidth between a sender and a receiver pair of wireless node. This can be attributed to BandEst assumption on the overlap idle channel period, which resulted in an over estimation of the available bandwidth. Also, PABE and cPEAB assumed that the idle channel is independent, therefore resulting in the underestimation of the available bandwidth. RAAC considers the dependency of two adjacent node idle channel occupancy by differentiating the *BUSY* state from the *SENSE* BUSY state and the *IDLE* state caused by an empty queue to ensure a better and accurate estimation. RAAC use the current estimated available bandwidth to predict the next period, just like in the case of other calculation-based approaches.

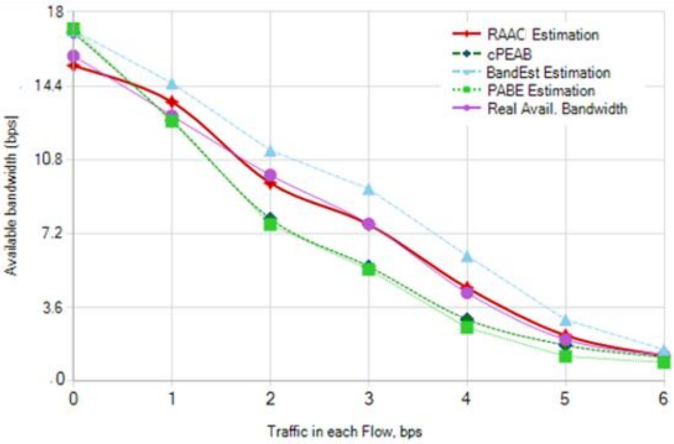

Fig. 9 Available bandwidth estimation

We have also plotted the estimated error statistics for each simulation as computed by [17] and [9] as shown in equation 11:

$$Error\ [\%] = \frac{Difference\ between\ the\ real\ bandwidth\ and\ estimated\ bandwith}{Real\ bandwidth} \times 100\% \quad (11)$$

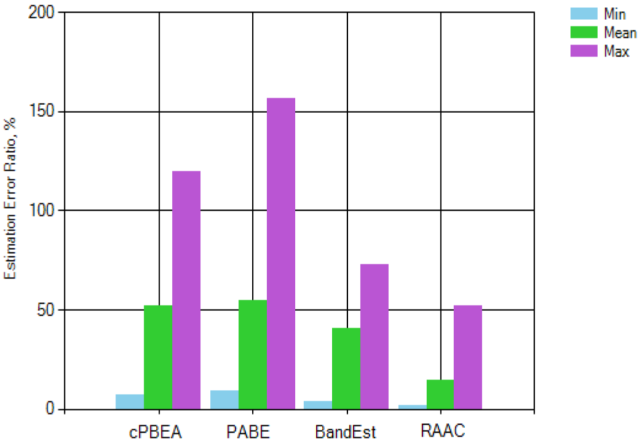

Fig. 10 Error estimation ratio (percentage)

The results shown in figure 10 further buttress the graph presented in figure 9. This shows that our proposed technique, RAAC, gives a better estimate of the available bandwidth when compared with cPEAB, BandEst and RABE.

Effectiveness of the Estimated Bandwidth: Suppose the source node of a flow transmits admission request message at 10, 20, 30, and 40 seconds, we consider that a flow makes a wrong admission decision if it accepts a new flow that degrades the throughput of an already existing flow and/or the newly admitted throughput by more than 5%. Also, an admission control algorithm of a flow makes a wrong decision if it unnecessarily rejects a flow. Both PABE and cPEAB techniques did not consider cases of wrong rejection of a flow; therefore, according to [11], the effectiveness (ɳ) is more comprehensive. One may argue that an unnecessary rejection of admission request flow will not degrade the performance of a flow that has already been admitted. Therefore, wrong acceptance of flows is worse as compared with unnecessary flow rejection, hence, wrong admission should only be considered as a bad admission decision. An alternative argument is that the available resources must be efficiently used, otherwise, there may be deployment of sufficient resources for QoS requirement flow to be satisfied during peak network utilization. However, in most cases, network resources are always underutilized, therefore, for a comprehensive evaluation to be achieved, equal importance is given to both types of wrong decision, such that:

ɳ= number of correct admission decision/total number of admission requests; where ɳ represent the effectiveness.

Figure 11 shows the mean effectiveness and evaluation over 10 repetitions, along with 95% confidence interval. It shows that the mean effectiveness of RAAC is higher than cPBEA, PABE and BandEst, and the difference is statistically significant. RAAC may also give a wrong admission accepts at some point due to factors such as corruption of bandwidth increment, broadcast messages due to interference, and lost admission reject message in response to a bandwidth increment message. Therefore, figure 11 shows that the mean effectiveness of RAAC is higher than the other techniques while also showing the mean effectiveness when an admission control is not implemented. Non-implementation of admission control means there is no control message overhead outside the routing message, however, the flow is lower than all other admission control protocol implemented in the work. If we are considering few flows, we do not need to implement admission control scheme, as all flows can be accommodated. This however is a rare case, especially when shared and low bandwidth characterizes wireless network. In conclusion, RAAC is more effective because of its low chance of false rejection. In PABE and cPEAB, correct contention factors were not considered (see section 2.3 for correct contention count estimation), hence their effectiveness is very low.

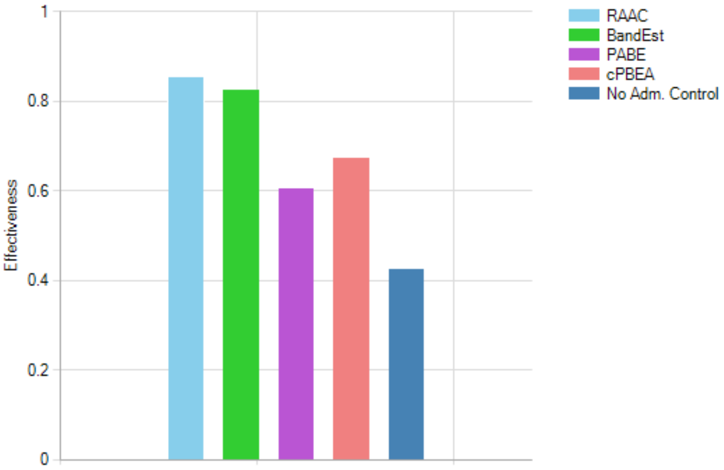

Fig. 11 Different Bandwidth Effectiveness

Table 3 shows the number of times the different schemes considered makes an incorrect admission decision. It is observed that RAAC makes fewer wrong decisions as compared with cPEAB, PABE and BandEst. Therefore, RAAC is effective because it has a lower chance of falsefully rejecting an admission request, since the algorithm is designed to account for all overhead generated by the network.

Table 3 Number of wrong admission decisions comparison (100 nodes)

Method	Wrong accepts	Wrong rejects
BandEst	18	3
Cpeab	25	7
PABE	30	5
No Admission Control	58	0
RAAC	**16**	**1**

6. CONCLUSION

In this work, we present a new approach to improve the accuracy of estimating the available bandwidth for admission control. Factors that must be considered for a flow admission control algorithm has also been highlighted. We have proposed RAAC, a novel algorithm for MANET that considers factors such as channel idle time dependency, intra-flow interference, collision with respect to hidden nodes and unnecessary delay impact due to exposed nodes, and lastly, the effect of increase in data traffic inside a network. Results obtained through simulation demonstrates that by considering the factors highlighted, an effective available bandwidth-based admission control can be guaranteed. A comprehensive comparison has shown that RAAC provides a significant improvement as compared to other related previous research work.

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