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RAACM: Resource Allocation for Admission Control in MANET

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Abstract

As wireless mobile network becomes widespread, the demand for user application is higher and the services provided by the wired application is expected to be available in the wireless medium. Therefore, the users of these applications will expect the same quality of service (QoS) obtained in wired network. Providing a reliable QoS in wireless medium, especially mobile ad-hoc network (MANET), is quite challenging and remains an ongoing research trend. The key issue of MANET lies around the ability to accurately predict the needed and available resources to avoid interference with ongoing traffic. An essential solution to the issues posed by MANET is the introduction of an admission control component for a guaranteed QoS. Admission control helps to control the usage of resources when an additional service is requested. For an admission decision to be made for a new flow, the expected bandwidth consumption must be correctly predicted prior to admission, notwithstanding the fact that wireless medium is shared and nodes contends among themselves to access the medium. The novelty of this research work is the proposed resource allocation for admission control in MANET (RAACM) solution which is an admission control scheme that estimates the available bandwidth needed within a network using a robust and accurate resource estimation technique. Furthermore, the various factors that must be considered for an effective estimation were highlighted and simulations were carried out. Results obtained show that our proposed scheme for MANET outperforms existing state-of-the-art approaches for admission control with bandwidth estimation. Part of this success is associated with its assumption about the idle channel period, which prevents the overestimation and underestimation of the existing bandwidth measurement. RAACM considers the dependency of two adjacent node idle channel occupancy by differentiating the networks *BUSY* state from the *SENSE* BUSY state and the *IDLE* state caused by an empty queue to give a better estimation.

Keywords Admission control · Bandwidth · Channel idle time · MANET · QoS

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. The cooperation must include the endpoint flow policing as well as admission control implementation along the route, to prevent network violation of initially made policy. The aim of deployed 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 wireless network support for QoS 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 satisfies a given QoS requirement without violating any previously made rules or reject sessions. The main issue encountered during the implementation of admission control mechanism lies around retrieving information on the available network resources. The admission control protocol must

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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 RAACM that is used to estimate the available bandwidth on a network for admission control purpose. We identify the key metrics that needs to be addressed for our protocol to have a better performance, namely: (1) channel idle time dependency (2) collision with respect to hidden nodes and unnecessary delay impact due to exposed nodes, (3) intra-flow interference, and (4) considering that, increased data traffic inside a network will lead to an increase in CSMA/CA based on MAC overhead with respect to back-off interval, retransmission number, acknowledgement packet and contention size. 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 organised as follows; Sect. 2 presents related works while Sect. 3 describes bandwidth estimation and admission control. In Sect. 4, we present our proposed resource allocation for admission control in MANET (RAACM) while Sect. 5 presents the simulation parameters used for the experiment. Section 6 concludes the paper.

2 Related Works

This section reviews the common bandwidth estimation technique for admission control in MANET and categorize it into active bandwidth estimation technique and passive bandwidth estimation technique. A more detailed survey that covers available bandwidth measurement and admission control can be found in [5, 6].

In wired network, the available bandwidth measurement is done using the active estimation technique; an example of this estimation technique is found in [7]. The active available bandwidth estimation approach is not suitable for MANET because it makes use of probe packet when measuring the available bandwidth between a source and destination. If the number of source to destination pair is large, this will result in the sending many probe packets which in turn will consume a large amount of bandwidth, therefore our approach in this research work is directed towards the passive bandwidth estimation technique which will briefly reviewed.

Authors in [8] 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 [9]. This protocol focused on estimating available bandwidth for admission control using the control-gap based concurrent transmission. Authors in [10] proposed 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 using model to predict the collision and back-off, empirical gathering data is used for predicting 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. BandEst has been proposed by [11]. 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 the increased data traffic load was considered and an algorithm that deals with concurrent admission request in a FIFO was implemented.

The drawbacks common to DLI-ABE, ABCT, PABE, and BandEst, as shown in the literature, is that the channel idle time dependency sensed by the sender and receiver has not been properly addressed as most previous work did not factor it in their design.

This research work therefore proposes a resource allocation for admission control in MANET (RAACM) mechanism that estimate the bandwidth for admission control based on some key factors outlined in Sect. 3 (Table 1).

3 Key Factors to be for Considered Bandwidth Estimation and Admission Control

In this section, we identify the key factors essential for a proper 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 as a result of an empty queue.

3.2 Intra-flow Interference

Due to the carrier sensing range, 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

Table 1 Evaluation of DLI-ABE, PABE, and BandEst admission control protocol against RAACM

Algorithm	MAC layer effect on available bandwidth	Hello propagation	Channel idle time dependency	Intra-flow contention calculation	Hidden/exposed node consideration	Adds MAC layer overhead
DLI-ABE [8]	Yes	2 hops (packet broadcast)	Yes (w.r.t. differentiating between busy and sense busy)	Partially correct	No	Yes
ABCT [9]	Yes	2 hops (packet broadcast)	No	Partially correct	No	Yes
PABE [10]	Yes	2 hops (packet broadcast)	No	Partially Correct	No	Yes
BandEst [11]	Yes	2 hops (packet broadcast)	No	Correct	No	Yes
RAACM (proposed algorithm)	Yes	1 hop (packet aggregation)	Yes (w.r.t differentiating busy from sense busy and idleness due to empty queue	Correct	Yes (RTS/CTS approach)	Partially

shared channel. This circumstance is known as intra-flow contention. In [12], 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 [13].

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 there is an increase in the data traffic load of a network, it in turn increases 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 for Admission Control in MANET (RAACM)

Our proposed algorithm, RAACM, has adopted

1. 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.
2. A novel, efficient and accurate resource allocation for admission control in MANET that estimates the available bandwidth for the admission controller to either accept or reject a session when an admission is requested.

4.1 Measuring the Channel Idle Time Dependency

As mentioned previously in the literature, the idle time of a channel considers the dependency of the channel time sensed by the sender and that of the receiver by differentiating the nodes *BUSY* state from the *SENSE* BUSY state and *IDLE* state caused by an empty queue to ensure accurate available bandwidth estimation.

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

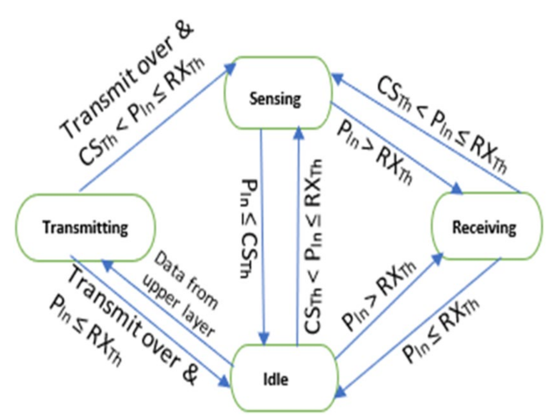

Fig. 1 Wireless radio transition diagram [16]

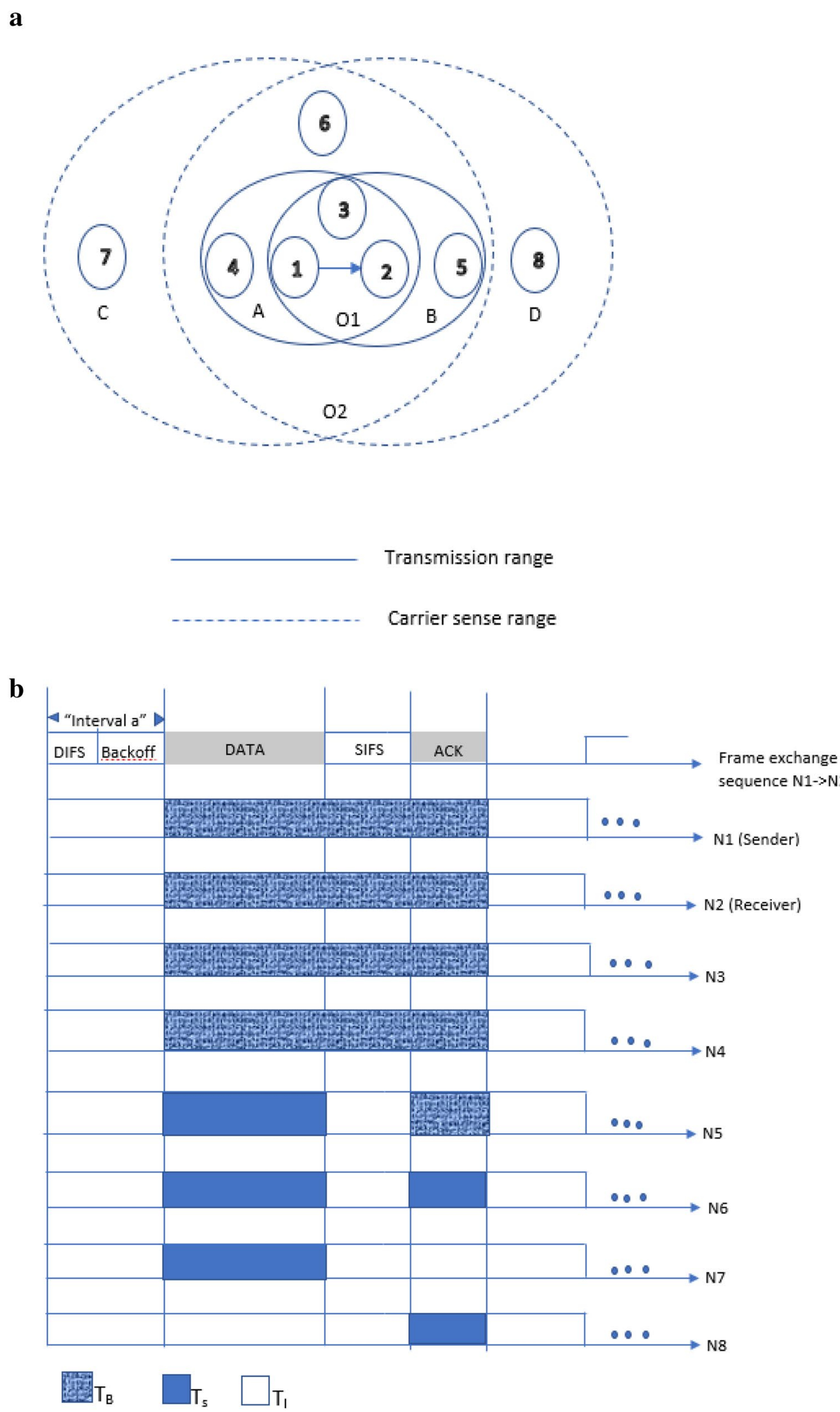

Fig. 2 **a** Wireless transmission scenario showing transmission range and carrier sensing range [16], **b** channel states sensed by nodes in scenario 2a [16]

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.

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 apart from the sensing time, the node will be in an IDLE state. The *IDLE* state means that the node is neither transmitting, receiving or sensing any packet. For a channel to be idle, the channel does not necessarily have to be sensed idle by both physical and virtual wireless carrier sensing mechanism, the interface queue must also be empty.

Note that differentiating the *SENSE BUSY* state from the *BUSY* state and *IDLE* state caused by an empty queue has not been researched in the literature. Past works, such as [15], have always viewed the SENSE busy state and the BUSY state as the same. While [16] addressed the differences between the *SENSE BUSY* state and the *BUSY* state, the authors did not consider situations where empty queue on a channel were regarded as an idle channel time. However, 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.

To further clarify this, the scenario in Fig. 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. 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 [12], 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:

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

where CW_{min} represents the initial (or minimal) value of the contention window, $CW_{max} = 2^N$. CW_{max} represents the maximum value of the contention window. 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 [17], which is the probability that a transmitting packet will collide. The following expression can be used to further derive the $\overline{Backoff}$:

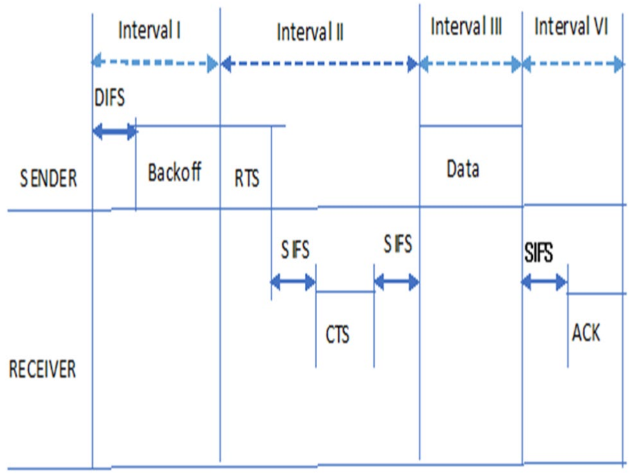

Fig. 3 Frame exchange sequence in RTS/CTS mechanism [18]

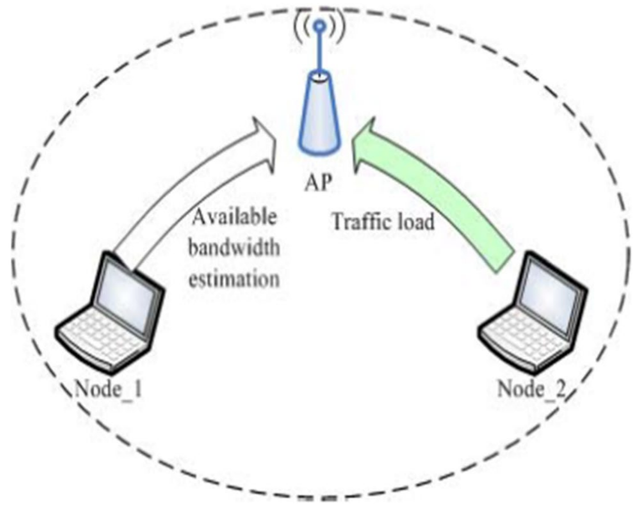

Fig. 4 Scenario without hidden/exposed node [13]

$$
\begin{aligned}
\overline{backoff} &= \sum_{k=0}^{M} P(X=k) \times \frac{\min\left(CW_{\max,} 2^k CW_{\min}\right) - 1}{2} \\
&= \sum_{k=0}^{N} P^k(1-P) \times \frac{2^k CW_{\min} - 1}{2} \\
&\quad + \sum_{k=N+1}^{M-1} P^k(1-P) \times \frac{2^N CW_{\min} - 1}{2} + P^M \times \frac{2^N CW_{\min} - 1}{2} \\
&= \frac{(1-P)\times CW_{\min}}{2} \sum_{k=0} N(2p)^k - \frac{(1-p)}{2} \sum_{k-0}^{N} P^k \\
&\quad + \frac{(1-P)\times\left(2^N CW_{\min} - 1\right)}{2} \sum_{K-N+1}^{M-1} p^N + p^M \times \frac{\left(2^N CW_{\min} - 1\right)}{2} \\
&= \frac{(1-P)\left[1-(2p)^{N+1}\right]}{2-4P} \times CW_{\min} - \frac{1-P^{N+1}}{2} \\
&\quad + \frac{(P^{N+1}-P^M)\times\left(2^N CW_{\min} - 1\right)}{2} + \frac{p^M \times \left(2^N CW_{\min} - 1\right)}{2} \\
&= \frac{(1-P)\left[1-(2p)^{N+1}\right]}{2-4P} \times CW_{\min} = \frac{1}{2} + \frac{2^N P^{N+1}}{2} \times CW_{\min} \\
&= \frac{1-P-2^N P^{N+1}}{2-4P} \times CW_{\min} - \frac{1}{2}
\end{aligned} \tag{4}
$$

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

4.2 Measuring the Intra-flow Contention

Determining the correct value of the intra-flow contention depends on the interference range of a 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,

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

Fig. 5 Exposed node [19]

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

Fig. 6 Hidden node [19]

RAACM determines the actual intra-flow contention count along the source node, intermediate node, and the destination node.

4.3 Resolving Issues of Hidden Node Causing Collision and Exposed Nodes Leading to Unnecessary Delay

By looking at the IEEE 802.11 frame exchange sequence in Fig. 3, interval III is used for transmitting data frame which is dependent on the frame size. Moreover, according to [15], 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.

Therefore, using [19], the impact of a flows hidden/exposed terminals can be calculated as:

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

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 Fig. 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:

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

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

(i) Scenario without Hidden/Exposed Node
Figure 4 depicts a topology without a 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.

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

Table 2 Simulation parameter

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

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 Fig. 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

The authors of [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

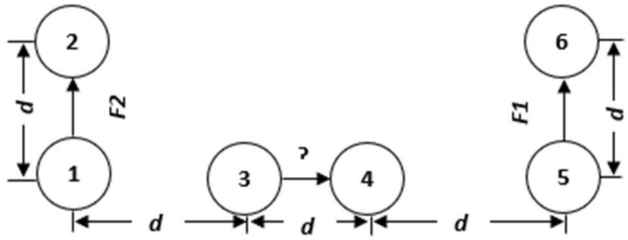

Fig. 7 Simulated network topology [18]

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 a network [20, 21]. If there is an excess of 60 kbps 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.

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

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

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 RAACM. We have deployed 100 nodes which was randomly distributed in a 1200 × 1200 m area. Furthermore, we set other network parameters accordingly, i.e. link capacity of 54 Mbps, transmission range of 250 m and carrier sensing range of 550 m was used. T is set to 1 s 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 s and each simulation was repeated 10 times. Table 2 depicts the parameters used for our simulation.

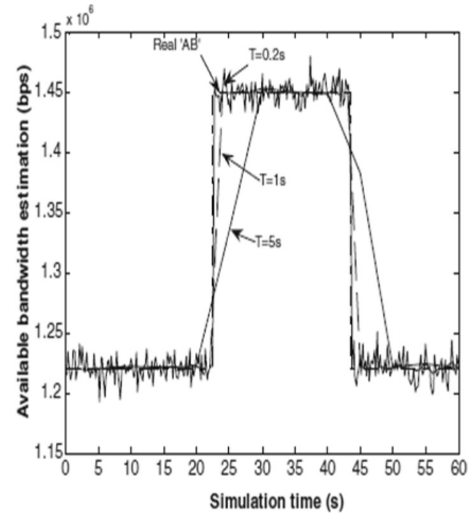

Fig. 8 The effect of sample time (T) [15]

5.1 Simulation Model and Evaluation of RAACM

Similar to the work of [18], a scenario in Fig. 7 is used in evaluating RAACM. Flow 1 (f1) on link (5, 6) has a variable bandwidth and flow 2 (f2) on link (1, 2) has a constant bandwidth of 600 kbps. The available bandwidth estimation on link (3, 4) for RAACM is calculated using Eq. 10. The link capacity is 54 Mbps and the source node which are nodes 1 and 5 generates 1 Kbyte traffic. The distance between each node is 200 m.

Since 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 s, just as in the work of [10, 11, 13].

5.2 Choosing the Sample Period

We consider T to be the sample period used in evaluating the available bandwidth. If we have a larger T, it will result in a more stable measurement, and hides fast variation in the medium load. At the same time, T should also be small enough to allow fast reaction to node mobility and long-term load variation. Therefore, T can be changed according to the scenario involved. For example, we can have a larger T when we have a more stable network, but when the network has a lot of variations, T must be a smaller value. To evaluate the effect of T on the available bandwidth estimation, an experiment was designed using two nodes, *s* and *r* respectively. In between these nodes is a flow *f*. We allow

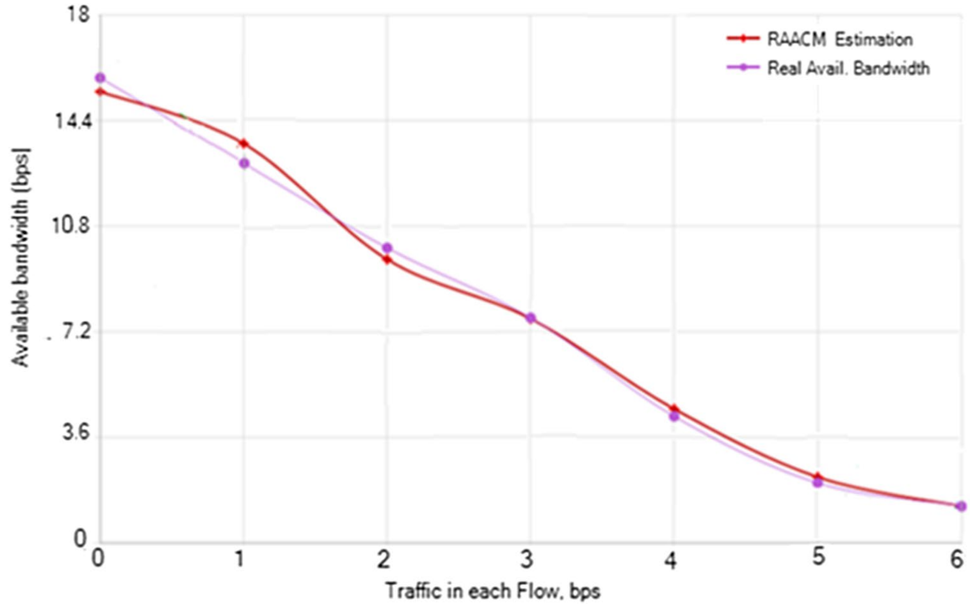

Fig. 9 Available bandwidth estimation between RAACM and real available bandwidth

Table 3 Average available bandwidth measurement per traffic flow

Bandwidth estimation method	Average value of traffic flow (bps)
Real available bandwidth	15,757.12
RAACM	15,844.42

s and *r* to evaluate the available bandwidth on the one hop link (*s, r*). The estimated available bandwidth of s and r with T = 0.2, 0.5 and 1 as seen in [11, 15, 16] is shown in Fig. 8 below. With smaller sample time, the available bandwidth estimation approach can easily follow the variation of network load, although it will bring slight fluctuation over the real available bandwidth.

5.3 Measuring the Real Available Bandwidth

To measure the real available bandwidth on a given link (*s, r*) during simulation, we transmitted a flow *f* (*s, r*) 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.

5.4 Simulation Results

1. Assessing RAACM.

We compared the available bandwidth estimated by RAACM with the real available bandwidth, as shown in Fig. 9. Our bandwidth estimation approach, RAACM, 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, as seen in the graph in Fig. 9, the results obtained by our proposed RAACM 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 RAACM (see Table 3). The results obtained from the measured and estimated bandwidth show how well RAACM has been able to estimate the measured available bandwidth.

2. Assessing RAACM against DLI-ABE, PABE, and BandEst

Here, we evaluate our proposed approach, RAACM, with related past works, DLI-ABE, PABE and BandEst using the same scenario as in section IV. The available bandwidth estimation on link (3,4) for DLI-ABE [8], PABE [10] and BandEst [11] is calculated using Eqs. 8, 9, and 10. Our implementation of PABE and BandEst adopted the mathematical

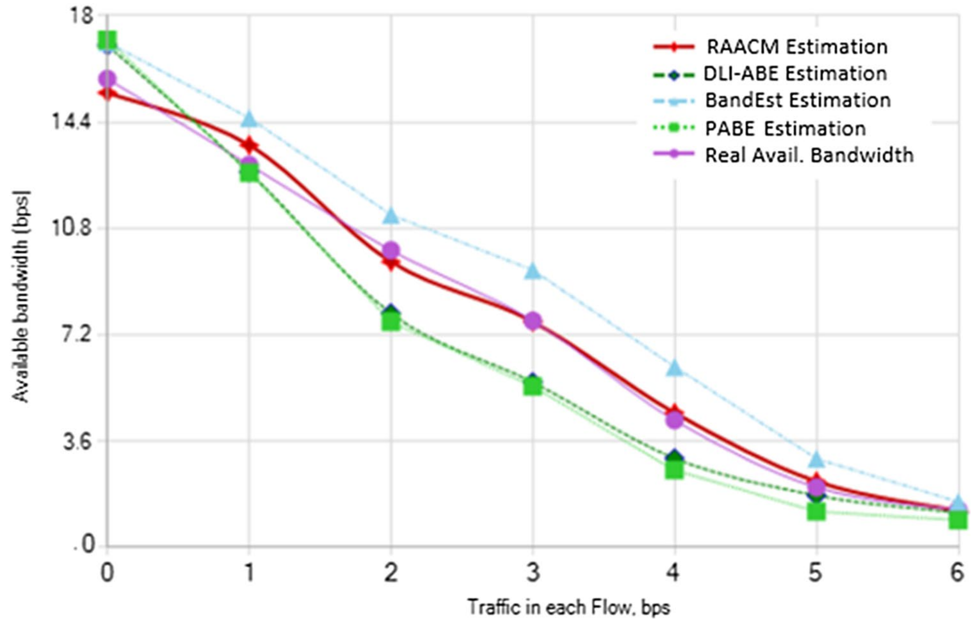

Fig. 10 Available bandwidth estimation

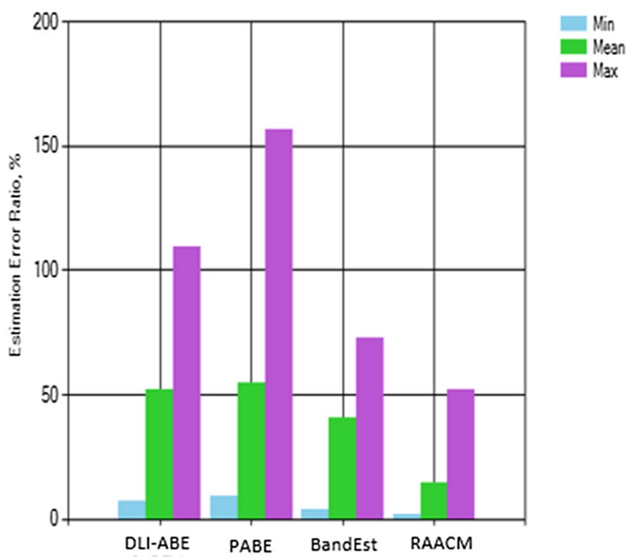

Fig. 11 Error estimation ratio (percentage)

model of estimation as against the proactive method used by the author. The mathematical method was used to enable us to have a fair comparison. The estimation of DLI-ABE, on the other hand, was presented by the authors using Eq. 8.

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

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

T_r and T_s are the idle time of the sender and receiver in the wireless medium. P_m is the collision probability of packet size m. P_1 represent the probability that s is in the state of SENSE BUSY and r is in an IDLE state. P_2 represent the probability that r is in a SENSE BUSY state and s is in an IDLE state. All other parameter definition can be found in section II.

5.5 Performance Analysis

The result presented in Fig. 10 clearly shows how RAACM 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 results in an overestimation of the existing bandwidth. Also, PABE and DLI-ABE assumes that the idle channel is independent, therefore resulting in underestimation. RAACM considers the dependency of two adjacent node idle channel occupancy

$$AB_{DLI-ABE} = (1-K)\left(1-P_m\right)\left(\min\left(\left[\frac{T_i^s\left(1-P_2\left(T_s^r/T\right)\right)}{T}\right]C,\left[\frac{T_i^r\left(1-P_1\left(T_s^s/T\right)\right)}{T}\right]C\right)\right) \tag{8}$$

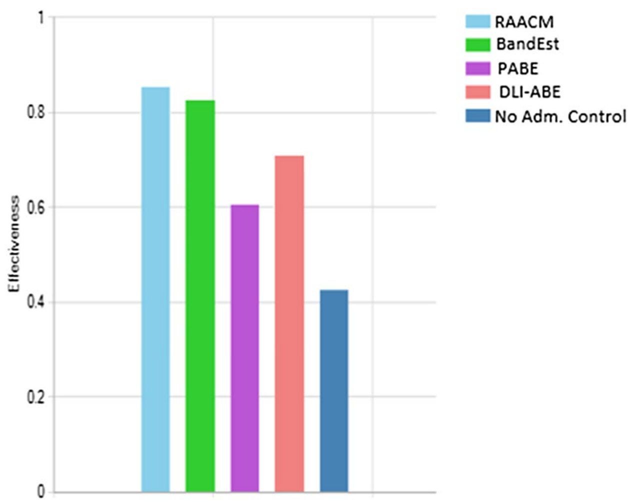

Fig. 12 Different bandwidth effectiveness

Table 4 Number of wrong admission decisions comparison (100 nodes)

Method	Wrong accepts	Wrong rejects
BandEst	18	3
DLI-ABE	23	6
PABE	30	5
No admission control	58	0
RAACM	16	1

by differentiating the *BUSY* state from the *SENSE* BUSY state and the *IDLE* state caused by an empty queue. This helps to give a better estimation. RAACM will always use the current estimated available bandwidth as an estimate for the next period, just like in the case of other calculation based approaches.

We have also plotted the estimated error statistics for each simulation as computed by [13, 18] as shown in Eq. 11:

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

The result shown in Fig. 11 further buttress the graph presented in Fig. 10. This shows that our proposed technique, RAACM, can better estimate the available bandwidth when compared with DLI-ABE, BandEst and RABE.

1. Effectiveness of the estimated bandwidth

Suppose the source node of a flow transmits admission request message at 10, 20, 30, and 40 s, 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 DLI-ABE techniques did not consider cases of wrong rejection of a flow; therefore, according to [11], the effectiveness (η) 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:

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

Figure 12 shows the mean effectiveness and evaluation over 10 repetitions, along with 95% confidence interval. It shows that the mean effectiveness of RAACM is higher than DLI-ABE, PABE and BandEst, and the difference is statistically significant. RAACM may also give a wrong admission accepts at some point, due to the following factors, namely: corruption of bandwidth increments, broadcast message due to interference and lost admission reject message in response to a bandwidth increment message. Therefore, Fig. 12 shows that the mean effectiveness of RAACM is higher than the other techniques. Figure 12 also shows the mean effectiveness when we do not have an admission control implemented. Without the implementation of admission control, the flow is lower than all other admission control protocol observed in this work. No admission control means there is no control message overhead apart from the routing message. 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. It pays off to consider the overhead within the network. In conclusion, RAACM is more effective because of the low chance of false rejection. In PABE and DLI-ABE, correct contention factors were not considered (see Sect. 2.3 for

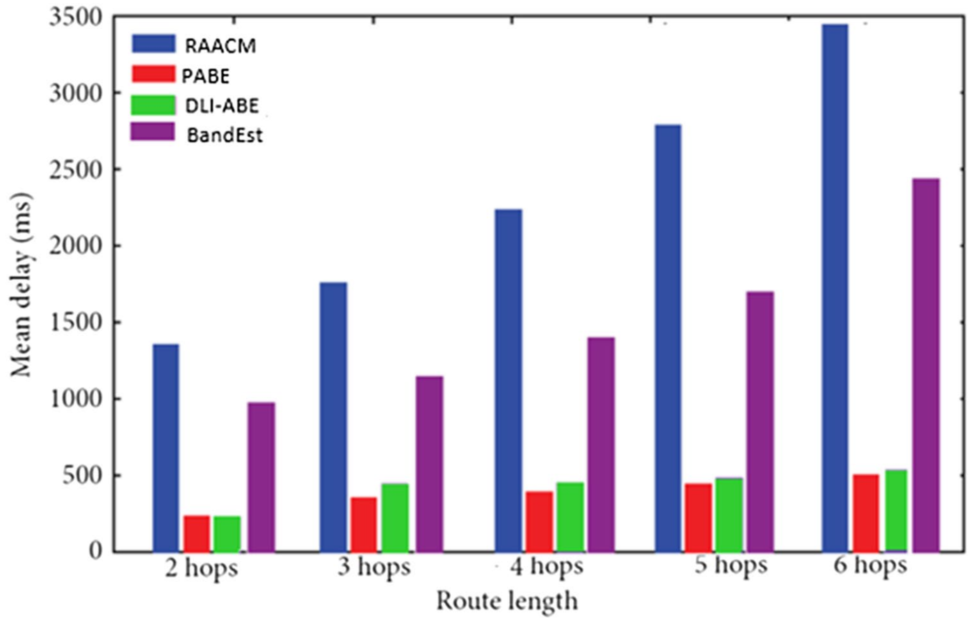

Fig. 13 Route length versus mean admission request response delay

correct contention count estimation), hence their effectiveness is very low.

Table 4 shows the number of times the different schemes considered makes an incorrect admission decision. It is observed that RAACM makes fewer wrong decisions as compared with DLI-ABE, PABE and BandEst. This further indicate that RAACM does not unnecessarily rejects a single flow. Therefore, RAACM 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.

Figure 13 shows the mean admission response delay with respect to the length of the route for the case where admission is granted. The admission response delay is measured by taking note of the time the admission request message was sent and the time the admission response was received. The average admission response delay for RAACM is higher than PABE, DLI-ABE, and BandEst because RAACM uses a distributed admission control flow (i.e. before a flow's admission request is accepted, the RAACM admission control flow algorithm sends the bandwidth increment message within the interference range of the node). The process is used in order to check if all the nodes that are within the interference range of the node can accommodate the existence of a new flow. Therefore, in RAACM admission control flow, once the bandwidth increment message has been sent, the node waits for a specific amount of time, and if any node within the interference range of the node cannot accommodate the flow, an admission reject message is unicasted to the originator of the bandwidth increment message. Having performed an additional experiment, we observed that after sending the bandwidth increment message, the node receives an admission reject message (if required) within 400 ms. Therefore, the bandwidth increment message originating node waits for at least 400 ms before attempting to forward the admission request message. In our simulation, a node waits for 500 ms before forwarding an admission request message. Figure 13 shows this with the admission response delay increasing by around 500 ms for each of the additional hop. Therefore, the per-node overhead relating to RAACM is reduced to less than 1 kbps, while the additional overhead in RAACM is only 6% when compared with DLI-ABE, PABE, and BandEst.

6 Conclusion

In this research 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 been highlighted. We have proposed RAACM, 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 RAACM provides a significant improvement as compared to other related previous research work.

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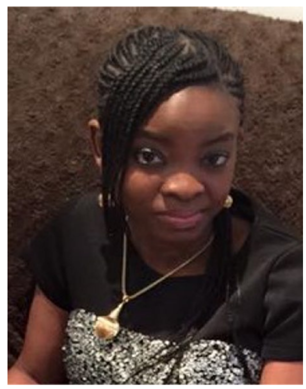

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