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# A Survey on Available Bandwidth Estimation in Mobile Ad hoc Networks

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***Abstract**: Available bandwidth estimation is one of the major issues in multimedia and real time communications which significantly reduces the throughput of MANETs. Calculating the bandwidth available is challenging task in 802.11 based mobile ad hoc networks due to its shared and dynamic environment. For managing and sharing the bandwidth effectively among the users in the resource constrained network, it is essential to have prior knowledge about the available resources. Estimating this available bandwidth is also essential to ensure the Quality of service and to enhance the system performance. There are several techniques and tools exist for available* bandwidth *estimation in MANETs. This paper consists of detailed study about the various techniques that carried out for estimating the bandwidth available and the factors that affects to reach accuracy in estimating the available bandwidth.*

***Keywords:** Ad hoc networks, Quality of Service, network utilization.*

## 1. INTRODUCTION

A MANET is a distributed wireless network in which each node involved in the network is independent to one another. There is no centralized control in this network and every host works not only as a source and destination but also as a router. The nodes in ad hoc mode should cooperate and communicate among themselves to transfer the data. Thus when a node needs to communicate to the nodes which are away from its communication area, the information should be transmitted through one or more intervening nodes. The network topology may change randomly and it seems unpredictable as the nodes can able to move readily in any direction with different speeds. This type of dynamic network is especially useful where an infrastructure cannot be supported such as military communications or emergency search, rescue operations etc. Furthermore, the dynamic architecture of an ad hoc network enables sharing data conveniently in inhospitable terrain, conference or a meeting. Enabling multimedia applications such as video and audio communication in these networks requires QoS support.

The parameters that affect QoS in wireless communications are bandwidth, delay transmission, jitter, throughput etc. The solution to ensure the quality is based on these parameters. Bandwidth is one of the fundamental resources in ad hoc networks; hence optimal management of this resource is essential due to its limited and shared nature among neighbor nodes in the network. The QoS support of resource allocation in any network is based on the ability to calculate the bandwidth remaining in the network. Estimating the availability of this bandwidth is an open issue to research in MANETs. The available bandwidth of a link can be defined as the maximal throughput that can be sent out with no affects to any current flow in the network. Capacity of the link is the maximum throughput that the flow can achieve in one idle link on an idle network. As compared to wired network, wireless networks have significantly lower capacity. The realized data transfer rate of wireless network link is usually lower than the transmission rate. This difference can be accounted for reasons like congestion, hidden terminal problem, effect of neighbor interference and noise in the channel. Since the channel is shared among various nodes, it is necessary to keep track of the number of potential emitters on the sender side and number of potential scramblers on the receiver side. The collection of such information helps in determining the resource utilization before admitting any new flow.

Progress in terms of accuracy in available bandwidth estimation to provide QoS solutions in ad hoc networks becomes real while the nodes are static. The solution becomes complex in case when the nodes are in mobile environment. The mobility issue leads to change of links between the nodes and hence the utilization of resource changes dynamically. Thus calculating the bandwidth available becomes a difficult operation in a mobile environment since the links among the nodes may fade away at any moment which has frequent detachment of paths. To effectively utilize the bandwidth available in the dynamic topology an ideal management of bandwidth is focused in wireless 802.11 based ad hoc networks. It is essential to have prior knowledge of the availability of the link between the nodes, for an accurate estimation of available bandwidth.

IEEE 802.11 DCF which uses CSMA/CA is the broadly used MAC protocol used to estimate the bandwidth available in ad hoc networks and hence the same protocol is considered in this study. This paper mainly deals with the review of various works regarding the available bandwidth estimation problem and the solutions that have been made to improve the accuracy of these techniques. The paper is structured as follows: Section II presents the related metrics. Section III presents various types of bandwidth estimation techniques. Section IV presents the categories in active estimation techniques; Section V presents the works carried out in passive estimation techniques and Section VI deals with the mathematical model based estimation approaches. Finally, section VII concludes the paper.

## 2. METRICS

Applications are usually concerned with different metrics related to bandwidth metrics like capacity, achievable throughput, available bandwidth, and bulk transfer capacity. The bulk transfer capacity is defined for end to end paths whereas the other three metrics were denoted for both links in the channel and end to end paths.

### *A. Capacity*

Capacity of the medium can be defined as maximum achievable amount of data which can be sent over a link in the channel or end-to-end path between the source and sink [40]. In case of 802.11, link-layer technologies do not work with same transmission rate. The maximum capacity relies upon the size of the network, traffic models and the local radio interaction which are never constant. The achievable capacity is always less than the raw medium capacity. Due to the fixed overheads introduced by the protocols at different layers, such as protocol header and control packets, the maximum achievable throughput are always much less than the raw medium capacity.

### *B. Bandwidth*

The term bandwidth can be defined as the maximal quantity of data that can be sent out along a channel in a period of time. It is also defined as the data rate that can be sent through a network link or a network path over a time period. The term throughput, on other hand, relates to volume of data sent through in one direction over a link in the channel divided by the time taken for its transmission. Thu the value of throughput is never constant but varies over time.

### *C. Available Bandwidth*

Available bandwidth is another important metric which can be defined as maximal throughput that can be sent between two nodes without affecting current flow in the network. The available bandwidth in network is the time varying metric that relies not only on capacity of the link but also on amount of traffic. Calculating the available bandwidth is always essential before performing the admission control, flow control or QoS routing based on bandwidth constraint. The conventional way to calculate the available bandwidth is based on the utilization factor, µ, of the channel [40].

$$A_i = (1 - u_i)\, C_i \qquad (1)$$

In the above equation $A_i$ is available bandwidth at link *i* over a certain period. This utilization factor represents the busyness of the channel. The node can be busy whenever it is in transmission state, reception state or due to neighbor interference. In case of multihop ad hoc networks the value is determined as minimum available bandwidth among all H hops which can be represented mathematically as under

$$A = \min_{i=1,\ldots,H} A_i \qquad (2)$$

The above equation states that available bandwidth on the path is same as the minimum link bandwidth available over the path, i.e. the path from source to destination located H hops away.

### *D. Bulk Transfer Capacity*

The Bulk-Transfer-Capacity (BTC) is defined as the maximal throughput attainable by a single TCP connection [40]. The connection should carry out all TCP congestion control algorithms. Available bandwidth and BTC are basically different metrics. The BTC relies on how the TCP flows shares bandwidth among them, whereas the available bandwidth estimates the additional bandwidth that a path can provide before its link gets saturated.

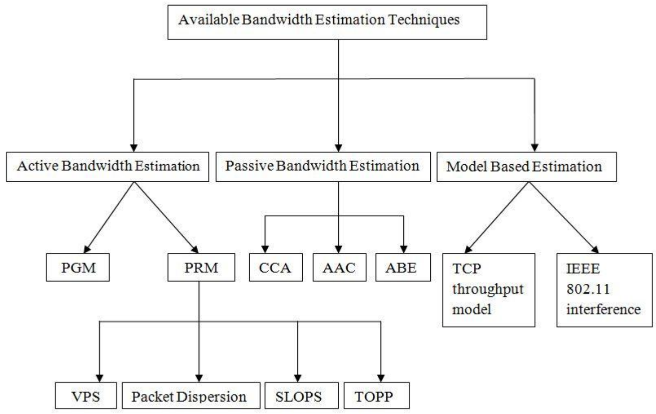


**Figure 1**: Types of available bandwidth estimation techniques

## 3. TYPES OF BANDWIDTH ESTIMATION TECHNIQUES

Number of works has been done in the area of estimating the available bandwidth. However there is still no clear consensus in terms of accuracy on the way of precisely measuring the available bandwidth in mobile ad hoc networks. The available bandwidth estimation technique can be categorized into three broad types such as Active bandwidth estimation; Passive based estimation and Mathematical model based estimation as shown in figure 1. The details of these schemes will be discussed in the following sections.

## 4. ACTIVE BANDWIDTH ESTIMATION TECHNIQUES

The active estimation method has two types such as probe rate model (PRM) and probe gap model (PGM) . PRM consists of three types of probing such as packet dispersion method, variable packet size probing method, and self loading probe. In PGM the available bandwidth is estimated based on the time interval between two successive probing packets at the receiver.

### *A. Probe Rate Model (PRM)*

Probe rate model is based on probe rate between the sender and receiver to estimate the amount of available bandwidth. The types of probing in PRM are as follows

#### *1. Variable Packet Size (VPS) Probing method*

VPS allows measuring the maximum data transfer rate of the network over the end- to-end path for each hop. The concept was introduced in [21][22] and refined in the tools [23][24][25]. This technique is based on measuring round trip time (RTT) for each hop in network. The RTT was measured approximately by the delay components such as serialization delay, propagation delay and queuing delay. The key assumptions while carrying out the analysis are

1) The one way delay of packet is increased along each hop of a path.
2) By injecting more number of same sized packets of to each hop of the network, without encountering queuing delay for at least one packet.
3) Propagation delays will not depend on size of the packet and each hop has same delay.

The work proposed in [4] is based on this technique. Some of the key advantages VPS model offered are: firstly there is no need of any special software to be installed on either side of the network. Secondly, the capacity for each hop along the entire network path can be measured and it helps in reducing the effects of cross traffic. However there are several limitations of this technique. VPS tool relies on a ICMP it is necessary to ensure its execution at each router along the path. And the second is that, this method estimates bandwidth along one way. Whenever huge numbers of control packets are injected, network suffers from stress and interference along the path.

***2. Packets Dispersion***

A packet dispersion technique injects packet pairs or train of packet probes to measure the full path capacity of a network. This method was first introduced in [26-28] and further refined in several tools [29-34]. It is based on sending two same sized packets continuously in the network. Once these packet passes through the narrow link the distribution time between two packets can be related to the link capacity. Packet train dispersion is extension of the above concept, in which more number of probing packets are sent consecutively transmitted across the network. One of the key assumptions of these techniques is absence of cross-traffic during probing interval. The works in [2], [6] were based on packet dispersion technique. This technique is faster as compared to other estimation techniques in terms of measuring time and generates less traffic on the path. However, in presence of cross traffic the accuracy is significantly degraded. Another disadvantage is tools needs to be implemented on both sides of path in the network.

***3. Self-loading Probe***

The two techniques discussed above helps in measurement of capacity in the network. Self-loading techniques, which includes Self-loading Periodic Streams (SLoPS) [35] and Train of Packet Pairs (TOPP) [36] which measure the bandwidth available along the end-to-end network path .Some of the key tools are there that executes a different types of self-Loading techniques, like in [4], pathload [37], Packet Transmission Rate (PTR) [38] and pathChirp [39]. It works on the concept of sending the probe packets at multiple rates in the network. If the bandwidth available is less than rate of probing packet sent at tight link, the queued packets at the router will increases delay on the receiver side. When the probing rate is lesser than the calculated available bandwidth then the packets are sent over the network by not increasing the delay.

The available bandwidth is obtained at tight link by considering the delay for packets at receiver side. The probing rate can be handled in many ways say it can linearly increase probing rate, exponentially probing rate and so on. The key assumption in case of SLoPS is all the routers having of FIFO queue along the path. The disadvantages of this technique are self-induced congestion and long time required to convert the measurements into available bandwidth estimates.

***B. Probe Gap Model (PGM)***

Probe gap model is same as packet train probing method. However, PGM calculates the available bandwidth instead of the path capacity. The work proposed in [5] is depending on this technique. Here the concept is estimating the available bandwidth with the time interval between two probe packets at the receiver. And the key assumption is that queue is not empty between the probing packet pair and the capacity at the high traffic link is known and constant.

Thus in active bandwidth estimation techniques probing packets at different rates are used to measure the bandwidth available in the network. These probe packets will cause additional traffic overhead in the wireless network which affects the performance of ongoing flows.

## 5. PASSIVE BANDWIDTH ESTIMATION TECHNIQUES

With the problems and drawbacks of the active bandwidth estimation techniques in wireless scenarios the research shifted towards the passive methods for estimating available bandwidth. The sensing based approaches are more suitable to wireless networks since it does not cause extra traffic. Here nodes utilize the 802.11 MAC physical carrier sensing or virtual carrier sensing to identify the channel idle and busy time. The MAC identifies the channel as idle when below given criteria holds true:

1) Network Allocation Vector (NAV) is less than or equal to the current clock time.
2) Receiving state is idle.
3) Sending state is idle.

Although the method is straight forward, the problem starts once the route is broken the corresponding sender will never know whether any node has changed its position until a new data transmission begins. The above problem is tackled by researcher in form of the HELLO packets, used by most of routing protocols. These HELLO packets are emitted periodically and can be utilized for exchanging the local information. The few advantages we can derive are: They help in maintaining list of one hop neighbors. They help in exchanging the bandwidth information up to two hops. They avoid sending any other control messages for carrying the information.

It is important to understand the difference between transmission range, interference range and carrier sensing rage while studying the passive methods. Since the medium is wireless it is shared by all nodes. In [15], BRUIT protocol was proposed. The author considers that the range of carrier sense is twice than the transmission range. It was seen that even if two nodes are not able to communicate with each other they still contend the resources of each other. To address this issue, information related to bandwidth is shared with all its neighbors. Such information can be propagated to two hop

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distance through HELLO packet. Each node performs the admission control, based on information thus collected.

CACP [7] is an admission control protocol which depends on the estimated available bandwidth in the network. In this work, available bandwidth is estimated by monitoring the channel idle time ratio. Different techniques are proposed for propagating the local available bandwidth to the nodes which are within the carrier sensing area. This technique is likely to be affected by the noise and interference present in the channel.

In AAC [8], the local available bandwidth of each node is measured in a similar manner to the one in CACP. However, the hidden terminal, the random backoff, and the problems due to synchronization were largely ignored.

ABE [9] is another bandwidth estimation approach based on monitoring CITR. This approach considers the random back off, collision probability, and synchronization. Assuming the carrier sense range is limited to two hops each node monitors its idle time, thus, calculating its upper bound of bandwidth available. The information is then sent to neighbors using the HELLO packets. Among many other contributions the authors addresses the problem of synchronization between the sender and receiver. Synchronization is related to idle time overlap between the sender and receiver. If either of them is busy the data packet will not be transmitted successfully. In order to evaluate the collision probability authors relied on HELLO packets often used by routing algorithms. If number of packets is limited, the approach can be considered as non-intrusive. Each node can estimate the number of HELLO packets it have to receive during certain duration. The collision probability of these packets can be calculated as the ratio of the number of HELLO packets received to the actual number of HELLO packet that have to be received in that time period. Since the size of HELLO packets can be small or big in comparison with data packets we can interpolate the data using Lagrange interpolating polynomial. The collisions leads to exponentially increase of contention window leading to loss of the bandwidth since the backoff time cannot be utilized for either transmission or reception. The authors evaluated the influence of contention window, which depends upon the success or failure of transmission, affecting bandwidth consumed in process. The available bandwidth between the two neighbouring node (s, r) can be calculated by the below given equation:

$$E_{final}\,(b(s,r)) \;=\; (1-K).(1-p).E\,(b(s,r)) \qquad (3)$$

Where the *E (b(s, r))* is the bandwidth available over the link *(s, r)* measured by monitoring the channel and by bringing their values together in a probabilistic way, the collision probability p is measured based on the HELLO packets received and adjusted to the correct packet size and then K represents the amount of the bandwidth lost by back off scheme calculated due to p. There are certain drawbacks in the above approach. Such as Lagrange interpolating polynomial does not possess the permanence property.

Thus the passive bandwidth estimation method uses carrier sensing mechanism to estimate the available bandwidth. Hence there is no extra traffic overhead as introduced in active techniques. But the issues related to the external factors such as noise, interference, lack of synchronization etc., are leading to underestimation of available bandwidth in this method.

## 6. MODEL BASED BANDWIDTH ESTIMATION TECHNIQUES

In addition to the above approaches, the available bandwidth can also be obtained based on the model-based approaches. This method helps in providing the quantitative analysis of the protocols, helping us to predict the result set if the network parameters are changed. This is not possible with the either active or passive estimation approach. There have been few analytical models proposed in late which models around the operation of DCF in ad hoc networks each with their own set of assumptions. The first work in this area was presented by Binanchi [16]. The author developed analytical model using two dimensional Markov chains which provide the closed form expression for calculation of throughput for 802.11 DCF at MAC layer. However, the model depends on many assumptions. The work in [17] improved the above said analytical model by introducing finite retransmission limit and defined saturated traffic. But, the model does not consider wireless errors. Recently, the work in [18] have drawn out Bianchi’s model by considering the factors like retransmission limit, wireless packet error under saturated traffic.

Recent models for evaluating the traffic throughput basically concentrate on TCP. [20] introduced the basic model for TCP throughput in which the congestion avoidance mechanism for TCP was analyzed. But, when the loss exceeds 5% this model provides low accuracy. The works in [19], [20] proposed a more definite model for TCP throughput by considering TCP time out and fast retransmission mechanism. Since the TCP flows affects significantly on the performance of video delivery, the proposed definite TCP transmission models for video traffic. However, there is no throughput models which consider UDP traffic.

In addition to the above mathematical approaches, Yuan et al. [1] proposed the MBE scheme to estimate the bandwidth available based on several throughput models which includes UDP traffic along with TCP over IEEE 802.11 WLANs. Hou et al. [10] presented a new method based on the 802.11 interference model to estimate the bandwidth available in a path by taking into account of wireless interference and network coding simultaneously.

Chen et al. [11] proposed a theoretical model, by considering interference due to the traffic along the path and also in the background. In this model, traditional clique is coupled with rate vector to identify the inconsistent relationships among the links in wireless networks. The mathematical model based techniques helps us to predict the result set which cannot be done with either active or passive method. However they are mostly based on network topology and does not support real time environment.

Though numerous tools are available for bandwidth estimation still accuracy is a problem. Based on the above study the results obtained from some of the works were analyzed based on accuracy, control overhead and computational complexity.

Table 1 shows the average deviation ratio for passive techniques CACP-CS, AAC and ABE. The deviation ratio is calculated by equation (4),

$$\frac{|AB-actualAB|}{actualAB} * 100\% \qquad (4)$$

Where *AB* and actual *AB* are the calculated and actual available bandwidth values.

**Table 1**: Average deviation ratio in passive techniques

| Packet size | Techniques | | |
|---|---|---|---|
| | CCAP-CS | AAC | ABE |
| 256 | 45% | 50% | 25% |
| 512 | 45% | 50% | 25% |
| 768 | 45% | 55% | 30% |
| 1024 | 42% | 65% | 35% |

**Table 2**: Comparison of bandwidth estimation for active techniques

| Physical data rate (Mbps) | Actual Available Bandwidth (Mbps) | Techniques | | |
|---|---|---|---|---|
| | | Pathload | Spruce | PathChirp |
| 9 | 3.5 | 3 | 8 | 4.5 |
| 24 | 8 | 6 | 14.5 | 12 |
| 36 | 9.5 | 8 | 25 | 12 |
| 54 | 13 | 10 | 31 | 18 |

It is observed that AAC shows the highest average deviation ratio which is approximately 50%. CACP (40%) and ABE (25%) are lower than that of AAC. Table 2 gives the comparison results between the actual available bandwidth and estimated available bandwidth from active techniques and their average deviation ratio was given in table 3.

**Table 3**: Average deviation ratio in active techniques

| Data rate (Mbps) | Techniques | | |
|---|---|---|---|
| | Pathload | Spruce | PathChirp |
| 9 | 14.28% | 128% | 28% |
| 24 | 25% | 81.25% | 50% |
| 36 | 15.78% | 163.15% | 26.31% |
| 54 | 23.07% | 138.46% | 38.46% |

Spruce and PathChirp over estimates the available bandwidth and their average deviation ratio is also high. Whereas pathload underestimates the available bandwidth and its deviation ratio is less compared to the other two techniques.

**Table 4**: Bandwidth estimation methods

| Techniques | Control overhead | Computational complexity |
|---|---|---|
| Active | High | Low |
| Passive | Low | Low |
| Model based | Low | High |

As stated above, the active method causes additional traffic overhead in the network which will degrade the performance of the ongoing flows and they are more suitable for wired than wireless networks. The schemes based on mathematical models may depend on the network topology, which is not stable in a mobile environment. The values in these methods reach closer to the real value only when the capacity of the network is moderate and in general, the computational complexity of these methods is also high. The methods based on passive measurement do not have much overhead as active and the complexity is also not high which suits for wireless networks. But due to the external factors such as noise, lack of synchronization, interference etc under estimation problem exists in passive measurement scheme.

## 7. CONCLUSION

In this paper, detailed study of various methods for estimating available bandwidth was presented. The available bandwidth estimation schemes and QoS solutions in MANETs have real progress in accuracy terms however each of the techniques discussed has its own set of drawbacks. No clear consensus has been reached which gives the accurate value of the available bandwidth in the dynamic environment. From the above study we infer that the probing based methods are suitable for wired than wireless environments. The mathematical model based techniques works well in the environment having a stable network topology and the passive scheme is suitable for wireless environment with low overhead. But most of the passive methods depend on the scenario of stable link topology. Further the mobility issue leads to change of links between the nodes and hence the utilization of resource changes dynamically. This requires prior information regarding the availability of link between the nodes along with the other factors, in the passive scheme where an accurate calculation of available bandwidth is necessary to provide better QoS.

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