A Study of Bandwidth Measurement Technique in Wireless Mesh Networks

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Abstract

Wireless mesh networks (WMNs) have been proposed as a key technology for next generation wireless networking to provide last-mile broadband access. Here we have given our observation and study for end to-end bandwidth estimation in WMNs. End-to-end Bandwidth Estimation is an important metric for network management and monitoring. It can also improve the effectiveness of congestion control mechanism, audio/video stream adoration and dynamic overlay. In recent years, many techniques have been developed for bandwidth estimation in the wired as well as the last-hop wireless networks, but they under-perform in WMNs. We investigate attributes that can affect the bandwidth estimation in WNMs; we found existing techniques do not consider the effect of attributes like CSMA/CA-based contending traffic and high interference interference that leads to the error full estimation.

In this paper, we present an active bandwidth measurement technique called Bandwidth Probe based on the packet dispersion principle. It measures the steady state bandwidth of the system while considering the effects of the FIFO cross and CSMA/CA-based contending traffic. It is also mitigating the effect of interference. We also show how to achieve the stationary state behaviour of the system to limit the number of probe packets. On simulation, Bandwidth Probe gives a accurate estimation of the available bandwidth using average convergence time and lower intrusiveness.

Keywords: *Bandwidth Probe, WMN, Bandwidth Estimation, Packet Train*

1. Introduction

Wireless Mesh Networks (WMNs)[1] is based on the IEEE 802.11s WLAN standard [3][21]. Being a different type of the architecture, WMNs can decrease the operational and infrastructure cost of traditional wireless network by being built all around the wireless and its self organizing nature. Also, it can resolve the problems of ad-hoc[24][22] network like loose connectivity and limited coverage area by keeping some node stationary which provides wireless backbone for service to the clients. But in actual, there is lack of end-to-end tools to estimate resources like path capacity and available bandwidth which is essential for the congestion avoidance[2], video/audio stream adoration and dynamic overlay[10]. Knowledge of these resources can improve the performance of the WMNs

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WMNs have the following properties as opposed to wired networks as well as last-hop wireless due to which errors may occur in the bandwidth estimation.

1 Fading and Interference Wireless channels' properties are highly variable due to fading and interference. Other potentially hidden stations implemented on same or different radio standards using the same frequency band create interference on the wireless medium which can often affect WMNs due to its multiple radio configuration. Its effects can cause high change of the signal-to noise ratio leading to high bit error rates. Even stations having different coding schemes combined with rate adaptation may be used for compensation and its available bandwidth can change dramatically.

2 Contention Wireless nodes share the same medium and contend for access to the channel. To avoid collisions, stations listen to the channel to detect nearby transmissions. It is controlled by the MAC protocol and bandwidth estimation is done on assumption that node gets the channel access in FIFO order[4]. This assumption may fail in case of hidden stations, so there is a need of additional mechanisms such as CSMA/CA[23] which handle the contention in a fully distributed manner and follow the random channel allocation to the node.

3 Frequent packet loss Wireless system manages the packet delivery by stop-and-wait ARQ technique. Retransmission can consume channel capacity and lead to varying one way delays which can affect the bandwidth estimation.

Two methods are available for the bandwidth estimation– Direct method and iterative method[5]. Spruce[6], WBest[7] and IGI[8] use direct probing with the assumption that link effective capacity ($C_{Effective}$) is already known and then using the rate response model [14], it calculates the available bandwidth (A). WBest is a two-step algorithm; in the first step its evaluate the link $C_{Effective}$ and then it sends the packet train to evaluate the A. Spruce assumes that the $C_{Effective}$ is already known and directly applies the rate response model to calculate the A. IGI uses probing trains with increasing gaps to evaluate A.

TOPP[9], DietTopp[12] and Pathchirp[13] use the iterative method which do not require the previous knowledge of link $C_{Effective}$. They use multiple probing rate, aiming to check the behavior of the rate response model and its turning point. TOPP uses trains of packet pairs with increasing rates and apply the rate response model for A estimation. DietTopp uses multiple node case with varying proving rates. Pathchirp increases the probing rates of chirp within a single probe.

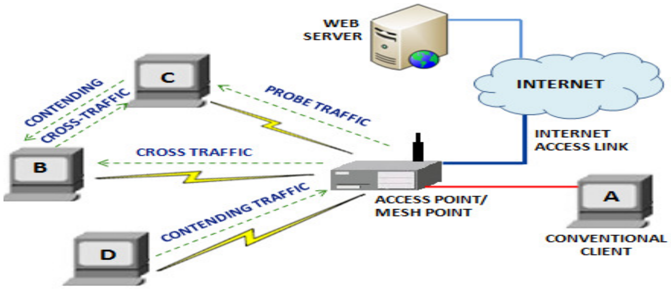


Fig. 1. Wired-Wireless Testbed Setup

These bandwidth estimation tools yield highly unreliable values because of their assumption to develop the bandwidth measurement model by considering only the effect of cross traffic. As discussed, they are based on the rate response model. It assumes the single bit-carrier multiplexing of several users in the FIFO order which is not applicable to WMNs. The contention among users is supported by CSMA/CA which often does not follow the FIFO assumption and nodes get the channel access in distributed manner. Fig.1 shows the traffic in WMNs – cross and contending traffic.

Motivated by the challenges in the existing model and properties of the WMNs, we have proposed a new model in lines with the rate response curve discussed in the next section. Based on the proposed model, we have developed a new algorithm "Bandwidth Probe", which is specially tailored towards WMNs for the A estimation. It is a single stage algorithm which sends the packet trains with certain spacing between the packets. The spacing between the packets in the train depend on the input rate of the packet trains with the assumption that the input rate is always greater than the $C_{Effective}$ of the network. Our main objective is to consider the effect of both cross and CSMA/CA based contending traffic in the steady state system and to reduce the random wireless error during the bandwidth calculation.

The rest of the paper proceeds as follows: In the second section we give the background work and proposed model. In the third section we describe the developed bandwidth estimation algorithm, Bandwidth Probe and its dispersion model that shows its actual behavior. In the last section we describe the analysis, experimental simulation and comparison with the existing tools and methods.

II Background and Proposed Model

The rate response curve[14][15] is one of the fundamental model for bandwidth estimation. Such a model places the fluid assumption for the cross traffic that it traverses the FIFO queue where the probing flows. Under the assumption, $C_{Effective}$ of the network is already known and then A of the network is given as

$$A = C_{Effective}(1 - \mu) \tag{1}$$

where μ is part of the capacity utilized by the cross traffic. If the input rate and output rate of probe flow are r_i and r_o respectively, the rate response curve behavior of the networks in the presence of cross traffic can be represented as

$$r_o = \begin{cases} r_i & if\ r_i \leq A \\ C_{Effective}\frac{r_i}{r_i + C_{Effective} - A} & if\ r_i > A \end{cases} \tag{2}$$

We can also estimate the available bandwidth in a direct way if $r_i = C_{Effective}$. In such a case the A will be

$$A = C_{Effective}\left(2 - \frac{C_{Effective}}{r_o}\right) \quad (3)$$

The probe packets rate can be presented in term of the input gap (Δ_i), output gap (Δ_o) between the packet pair and packet size(L), $r_i = L/\Delta_i$ and ro = L/Δ_o. As opposed to the above mentioned rate response curve which only considers the effect of cross traffic, an assumption is taken that all the nodes which get the channel access under FIFO mechanism

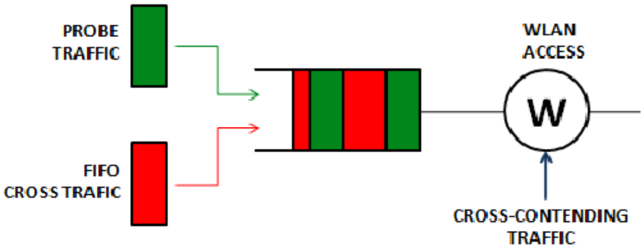


Fig. 2. Model of CSMA/CA based system

cannot hold any longer in the CSMA/CA based MAC environment. This is because it often handles the contention in a fully distributed manner and the nodes get the access of the channel in a random distributed manner. So A cannot be accurately derived from (2) in WMNs. Figure. 2 shows the typical model of CSMA/CA based wireless system and its traffic behaviors.

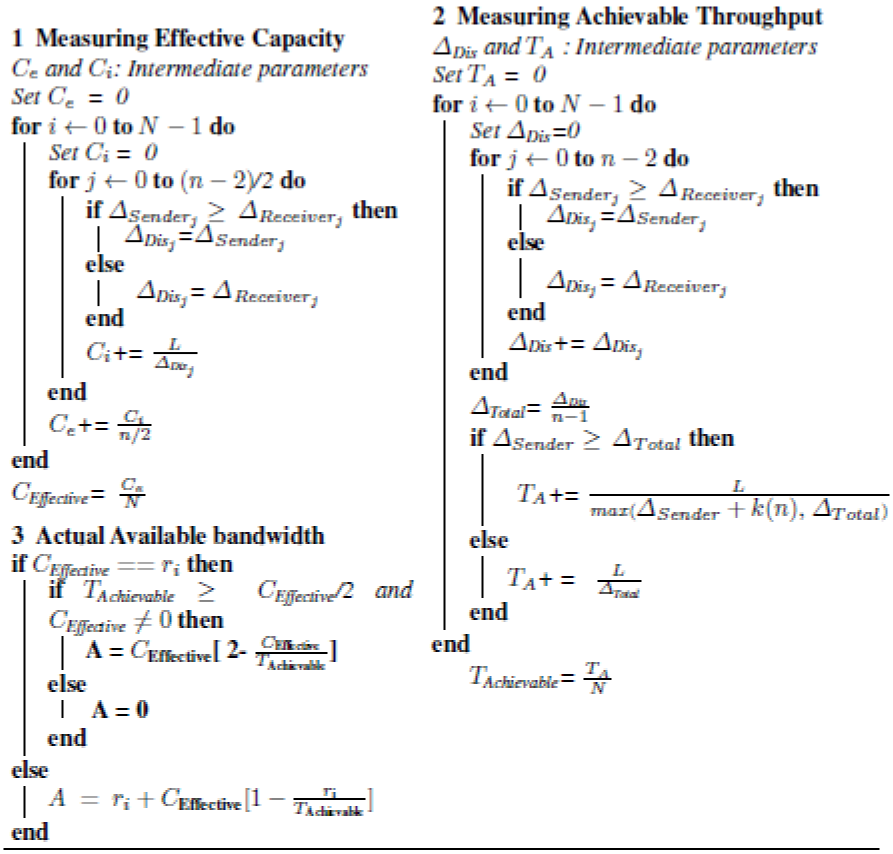
To deal with the effect of CSMA/CA we consider an extra parameter – achievable throughput ($T_{Achievable}$). The $T_{Achievable}$ is the average packet dispersion rate at the receiver side. It measures the bandwidth along the direction of probe traffic and later infers the accurate value of A. So with the help of this new parameter we proposed a new model for rate response curve (2) which will be suitable for the WMNs. If input rate of probe traffic r_i is described by the following equation: ro= min(ri; $T_{Achievable}$), Dispersion(Δ_{Dis}) measurement of the receiver side is $\Delta_{Dis}=\max(\Delta_{Sender}; \Delta_{Receiver})$

The above parameters gives the clarity about the value of $T_{Achievable} \leq r_i$, which will always be valid. So, proposed model for the WMNs is as follows

$$T_{Achievable} = \begin{cases} r_i & if\ r_i \leq A \\ C_{Effective}\frac{r_i}{r_i + C_{Effective} - A} & if\ r_i > A \end{cases} \quad (4)$$

III Bandwidth Estimation Algorithm

Bandwidth Probe depends on the proposed model mentioned in eq (4) and uses a similar mechanism where the rate of the packet train can be converted into certain spacing of the train's packets. That shows a direct relation to the gap model of the packet pair dispersion[16][20] at receiver side. It uses the independent packet pairs in the packet trains to calculate $C_{Effective}$ and packet trains for $T_{Achievable}$. To reduce the effect of the interference and uncertain nature of the wireless environments, it uses the mean value of $C_{Effective}$ and $T_{Achievable}$ to calculate A. In a single probe, it sends N number of packet trains with each packet train having n packets to capture the steady state behavior of the system and detect packet queuing behavior and its transmissions[15] at the wireless node and access point. It sends the packet train with the assumption $r_i \geq C_{Effective}$ that produces the smallest gap between the packets to get the narrow link capacity estimate[17].



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1 Measuring Effective Capacity
$C_e$ and $C_i$: Intermediate parameters
Set $C_e = 0$
for $i \leftarrow 0$ to $N-1$ do
    Set $C_i = 0$
    for $j \leftarrow 0$ to $(n-2)/2$ do
        if $\Delta_{Sender_j} \geq \Delta_{Receiver_j}$ then
            $\Delta_{Dis_j} = \Delta_{Sender_j}$
        else
            $\Delta_{Dis_j} = \Delta_{Receiver_j}$
        end
        $C_i += \frac{L}{\Delta_{Dis_j}}$
    end
    $C_e += \frac{C_i}{n/2}$
end
$C_{Effective} = \frac{C_e}{N}$
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2 Measuring Achievable Throughput
$\Delta_{Dis}$ and $T_A$ : Intermediate parameters
Set $T_A = 0$
for $i \leftarrow 0$ to $N-1$ do
    Set $\Delta_{Dis}=0$
    for $j \leftarrow 0$ to $n-2$ do
        if $\Delta_{Sender_j} \geq \Delta_{Receiver_j}$ then
            $\Delta_{Dis_j} = \Delta_{Sender_j}$
        else
            $\Delta_{Dis_j} = \Delta_{Receiver_j}$
        end
        $\Delta_{Dis} += \Delta_{Dis_j}$
    end
    $\Delta_{Total} = \frac{\Delta_{Dis}}{n-1}$
    if $\Delta_{Sender} \geq \Delta_{Total}$ then
        $T_A += \frac{L}{max(\Delta_{Sender} + k(n), \Delta_{Total})}$
    else
        $T_A += \frac{L}{\Delta_{Total}}$
    end
end
    $T_{Achievable} = \frac{T_A}{N}$
```

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3 Actual Available bandwidth
if $C_{Effective} == r_i$ then
    if $T_{Achievable} \geq C_{Effective}/2$ and $C_{Effective} \neq 0$ then
        A = $C_{Effective}[2 - \frac{C_{Effective}}{T_{Achievable}}]$
    else
        A = 0
    end
else
    $A = r_i + C_{Effective}[1 - \frac{r_i}{T_{Achievable}}]$
end
```

Table 1. Bandwidth Probe Algorithm

A Bandwidth Probe

Bandwidth Probe is a single stage algorithm, having three parts to calculate the $C_{Effective}$, $T_{Achievable}$ and A. Calculation of $C_{Effective}$ and $T_{Achievable}$ will be done parallelly. The sender sends the packet train with Δ_{Sender} time gap between each packet pairs and the receiver receives them with $\Delta_{Receiver}$ time gaps, if T_{Sendi} and $T_{Sendi+1}$ are the sending times of the i^{th} and $i+1^{th}$ packet respectively and $TReceive_i$ and $TReceive_{i+1}$ are the receiving times of the i^{th} and $i + 1^{th}$ packet respectively.

$$\Delta_{Sender_i} = T_{Send_{i+1}} - T_{Send_i}$$
$$\Delta_{Receiver_i} = T_{Receive_{i+1}} - T_{Receive_i}$$
$$\text{So } \Delta_{Dis_i} = max(\Delta_{Sender_i}, \Delta_{Receiver_i})$$

where Δ_{Disi} is the dispersion measurement of the packet pair in the packet train at the receiver side. Assume k(n) is the average service delay of the hop-workload by cross traffic. The complete Bandwidth Probe algorithm is described in Table 1.

B Bandwidth Estimation during Probe Packet Loss

If the probe packets are lost, Bandwidth Probe runs only on the packet pairs that are received successfully in the packet train. It passes A to the low pass filter. Here, A_{old} and $A_{current}$ are the old and current available bandwidths respectively.

$$A = 0.93 * A_{current} + 0.07 * A_{old} \tag{5}$$

For setting the constant value in (5) in packet loss situation we perform an experiment wherein we calculate the throughput of the performed application.

C Synchronization and Clock Skew Issues

For successful bandwidth estimation, System needs to rely on a perfectly synchronized clock [25]. Suppose δ is the time offset between the sender and the receiver

$$\Delta_{\text{Sender}} = T_{Send_{i+1}} - T_{Send_i}$$
$$\Delta_{\text{Receiver}} = T_{Receive_{i+1}} - T_{Receive_{i+1}} - 2\delta$$
$$\Delta_{Dis_i} = max(\Delta_{Sender_i}, \Delta_{Receiver_i}) \tag{6}$$

Eq. (6) shows the dispersion of the packet pair. Since it includes the time offset between the sender and receiver, the calculated A will not be affected by synchronization issues and the measured samples of dispersion will produce a good estimation. And clock drift can be avoided by considering the mean value of dispersion issues.

D Length of Packet Train and Input Gap between Packets

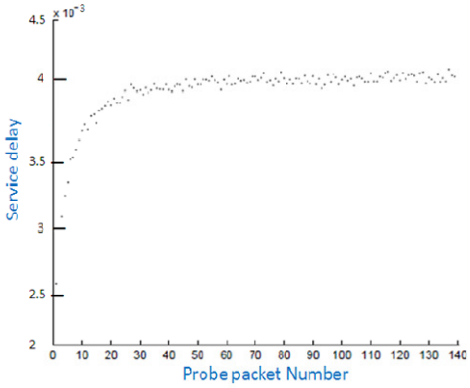

Fig. 3. Behavior of the system – Service Delay (sec) vs Number of Packets

The length of packet train is very important in the sense of accuracy, convergence and intrusiveness. We perform an experiment with the same scenario as in section 5-A to discuss the service delay and to retrieve the length of the packet which will produce the transient state. Service delay is the packet wait at the head of the transmission queue until it gains access to the channel and is completely transmitted. Transient state is the state in which the system is neither empty nor in backlog when the probing packet is transmitted. The transitory is maximum when the probe traffic and cross traffic send their fair share. To provide synchronization, we use syn-server which connects both sender and receiver. From fig. 3, we infer that the Service delay of the packets is initially low but gradually its distribution changes as more and more packets started reaching the queue link. In order to achieve the practical train length, we repeat the experiment more than 50 times. After sending 140 packets, we get the steady state of the system in every trial. The gap between the packets depends on r_i. So $\Delta_{Sender} = L / r_i$. The probing sequence depends on the Poisson distribution to assure proper interaction with the system and considering no context switch within a packet train accessing.

E What the Algorithm really does

In WMNs, dispersion due to both contending and cross traffic are at wireless nodes and access point. So traffic would not be FIFO manner. This causes random delay between two successive packets. Hence, to trace the behavior of WMNs, Bandwidth Probe measures two variables, $C_{Effective}$ and $T_{Achievable}$. $C_{Effective}$ indicates the maximum capability of the wireless networks delivered to the network layer traffic.Wireless network adopts the dynamic rate to send the traffic, so the $C_{Effective}$ is defined as the continuous function of packet size L and time t.

$$C_{\text{Effective}} = \frac{\int_{t_1}^{t_2} \frac{L}{\Delta(t)} \mathrm{dt}}{t_1 - t_2} \qquad (7)$$

where Δ(t) is the packet pair dispersion at time t. We can also model this equation in discrete manner.

$$C_{\text{Effective}} = \frac{\sum_{i=0}^{n-1} \frac{L}{\Delta(i)}}{n} \qquad (8)$$

where $\Delta(i)$ is the Dispersion of i^{th} packet pair. The second parameter $T_{\text{Achievable}}$ measures the dispersion of the packets due to the contention between the probe and contending traffic.

$$T_{\text{Achievable}} = \frac{L}{\frac{1}{n} \sum_{i=0}^{n-1} \Delta(i)} \qquad (9)$$

$T_{\text{Achievable}}$ is also known as the average packet dispersion rate i.e. the average time used to forward one single packet. It uses only the effect of contending traffic along the direction of the probing flow.

As discussed before, the relation can be established among the measured parameters by Bandwidth Probe and A as $A \leq T_{Achievable} \leq C_{Effective}$. With the assumption of Bandwidth Probe $r_i \geqslant C_{Effective}$, proposed model (4) can be described if $r_i = C_{Effective}$ then

$$T_{Achievable} = \frac{C^2_{Effective}}{2C_{Effective} - A} \qquad (10)$$

$$A = C_{Effective}\left(2 - \frac{C_{Effective}}{T_{Achievable}}\right) \qquad (11)$$

A can be derived from (10) but if $r_i > C_{\text{Effective}}$ then A can be derived by the following equation

$$A = r_i + C_{\text{Effective}}\left(1 - \frac{r_i}{T_{\text{Achievable}}}\right)$$

To derive the bound of A, if $C_{Effective}$=0 and $T_{Achievable} \leqslant C_{Effective}/2$ then A will be 0 otherwise it can be derived from the above equations. If A is equal to $C_{Effective}$, this implies that the network is idle (no cross traffic). Otherwise, the leftover portion of $C_{Effective}$ by the cross and contending traffic is A.

F Dispersion Model of Bandwidth Probe Algorithm

For considering the dispersion model assume that the probing sequence enters the transmission queue at instance $\{T_{\text{Send}i}$, i=0,1,..,n-1$\}$, their departure instance (i.e. instance at which they completely leave the transmission queue) is defined by $\{T_{\text{Receiver}i}$, i=0,1,..,n-1$\}$.

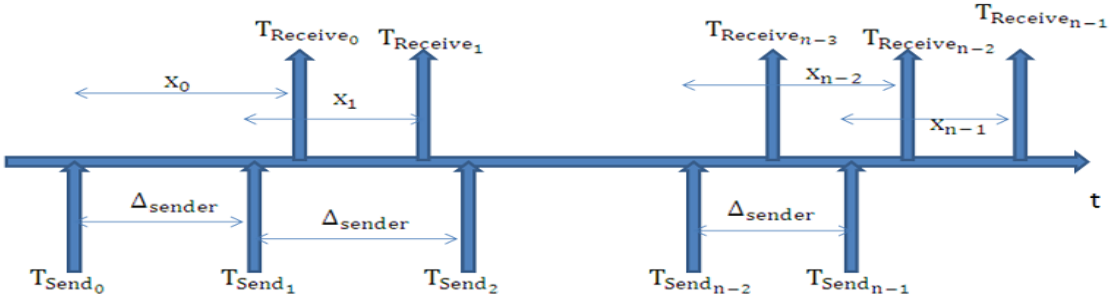

Fig. 4. Interaction among T_{Send}, T_{Receive} and Cross Traffic related Process (x)

Bandwidth Probe assumes negligible transmission time as compared to the dispersion and service delay. If cross traffic related process forms the sequence {xi,i=0,1, .,n-1}, fig. 4 shows the inter departure time at the output path. The output gap between the packet is defined as

$$\Delta_{\text{Receiver}} = \frac{T_{\text{Receive}_{n-1}} - T_{\text{Receive}_0}}{n-1} \qquad (12)$$

This can be expressed as the cross traffic related process form of sequence as follows

$$\Delta_{\text{Receiver}} = \frac{(n-1)\Delta_{\text{Sender}} - x_{n-1} + x_0}{n-1} \qquad (13)$$

The calculated value of Δ_{Receiver} and Δ_{Sender} can establish the relation between dispersion and r_i and r_o of rate response curve described in (2).

$$\frac{L}{\Delta_{\text{Sender}}} \approx r_i \qquad \frac{L}{\Delta_{\text{Receiver}}} \approx r_o \qquad (14)$$

From the above discussion, we infer that rate of packet trains can be used for the interaction with traversing system. Considering the cross traffic as the offered load, the dispersion equations can be modeled as dispersion perspective where E[.] is the limiting average of a sample of a path process.

If $\Delta_{\text{Sender}} \leq \frac{1}{n-1}\sum_{i=1}^{n-1} E\left[\nu_i\right]$, the output dispersion is the function of the average utilization of the cross traffic in FIFO order ($\mu_{f_i f_o}$) and service delay (ν_i) of i^{th} packets when they are contending for the medium then

$$\mathrm{E}[\,\Delta_{\text{Receiver}}] = \frac{1}{n-1}\sum_{i=1}^{n-1} E\left[\nu_i + \mu_{f_i f_o}\Delta_{\text{Sender}}\right] \qquad (15)$$

If $\Delta_{\text{Sender}} \geq \frac{1}{n-1}\sum_{i=1}^{n-1} E[\nu_i]$, and $k(n)$ is the average service delay of the hop-workload by cross traffic. The following equation can describe the aggregate bound

$$\begin{cases} E[\Delta_{\text{Receiver}}] \geq \max\left(\Delta_{\text{Sender}} + k(n), \frac{1}{n-1}\sum_{i=1}^{n-1} E\left[\nu_i + \mu_{f_i f_o}\Delta_{\text{Sender}}\right]\right) \\ E[\Delta_{\text{Receiver}}] \leq \min\left(\Delta_{\text{Sender}} + \frac{1}{n-1}\sum_{i=1}^{n-1} E[\nu_i] + k(n), (\mu_{f_i f_o} + 1)\Delta_{\text{Sender}}\right) \end{cases} \qquad (16)$$

The above equations shows the behavior of the rate response curve in the steady state. The output dispersion at the receiver's side denoted by equations (15) and (16) is used to calculate the $T_{\text{Achievable}}$ given in (9).

IV Analysis and Experimental Results

In this section we present the simulation results and analysis of the proposed model. We have used 802.11b/g standard for simulation and the nodes are configured to CSMA/CA; so simulated data packets are preceded by an RTS/CTS exchange [23]. The header size is as per the standard-RTS has 20 bytes, CTS has 14 bytes, ACK has 14 bytes and MAC has 34 bytes. In each of the subsections, we have run the simulation 50 times and the given result is the mean of all the estimated results

A Measurement of Available Bandwidth by Different Packet Sizes

In this simulation, we have created a topology with wired and wireless nodes and access point. The wired link capacity is 30 Mbps and the wireless channel is using the CMU wireless extension [18]. The wireless channel is tuned on the IEEE 802.11b based lucent way eLAN card at 5.5 Mbps with no mobility, with the effective transmission range as 250 meters and interference range as 550 meters. The origin of the Probe packet is the wired node and destination is the wireless node. Ad hoc On-Demand Distance Vector (AODV) [18] is as the route agent. Each wireless node is configured in the multi-hop scenario. The results estimated by Bandwidth Probe are as expected. Figure.5 shows that if the size of the probe packet is large then the estimated capacity is high and if its size is small then the estimated capacity is less. This is because, if the packet size is small, more number of ACKs contend for the medium with other packets at the link layer.

B Measurement of Available Bandwidth on Chain Topology

With the same scenario as in subsection A, all the wireless nodes are placed in a row. The result has come out favourably as expected[17] and the effective end-to-end capacity decreases as the length of chain grows. Bandwidth Probe is able to achieve the end-toend capacity estimation that closely matches the analytical prediction (of the single hop capacity).

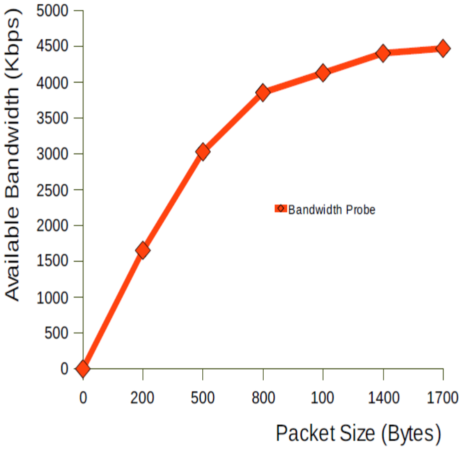

Fig. 5. Result of available bandwidth estimation (without interference)

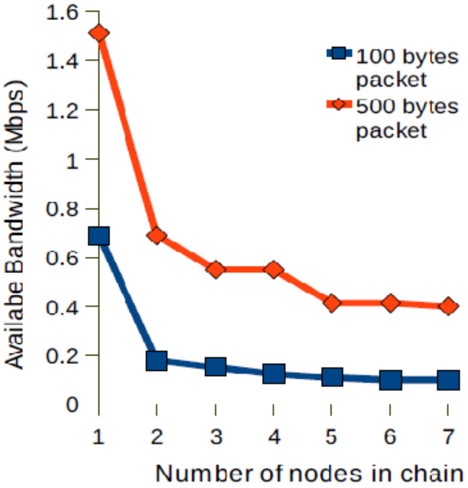

Fig. 6. Bandwidth estimation along a chain of nodes with different packet lengths

C Comparison with the Existing Bandwidth Estimation Techniques

In this subsection, we have created a test bed having two wired nodes with link capacity of 100 Mbps, one access point and four wireless nodes. Wireless nodes and access point have been placed in a mesh topology. Wired nodes have connected with access point. Each wireless node is using 802.11g standard. Table 2 shows the different link rate of the wireless nodes and rate of cross traffic in the different cases. The effective transmission and interference range is 250m and 550m respectively.We have set one of the wired nodes as the source and a wireless node as the destination. Cross traffic is created by CBR UDP with packet size as 1000 bytes same as probe packet size. The value ground truth of A is given by analytical method.

Table 2 clearly shows that the Bandwidth Probe estimates A more accurately than the rest of the measurement techniques. IGI/PTR and Pathload always underestimates A while Pathchirp overestimates it. WBest measures a good approximation of A but it is not considering the steady state behavior of the system and hence the estimated A can vary over time and produce inaccurate results.

Figure 7 shows the mean relative error in all the four cases mentioned in Table 2. IGI/PTR and Pathload gives high relative error in the estimation. Pathchirp and WBest show better accuracy and lower relative error. But, Bandwidth Probe is having the best accuracy and least relative error. It is also evident that Bandwidth Probe is having larger variability than the other estimation techniques

Intrusiveness is the probe byte sent by the estimation tools during measurement. Figure 8 shows that Bandwidth Probe has much lower intrusiveness as compared to the other techniques with values as low as 130 Kbytes. IGI/PTR and Patchirp have an intrusiveness

Table 2. Estimated Available Bandwidth by Different Techniques (in Mbps)

Tuned Capacity / Cross Traffic	54 / 2 Mbps	48 / 2 Mbps	36 / 2 Mbps	24 / 2 Mbps
IGI/PTR	3.726	3.312	2.484	1.656
Pathload	3.672	3.26	2.448	1.632
Pathchirp	10.612	9.544	7.408	5.272
WBest	6.696	5.952	4.464	2.976
Bandwidth Probe	7.452	6.624	4.496	3.312
Ground Truth	8.64	7.68	5.76	3.84

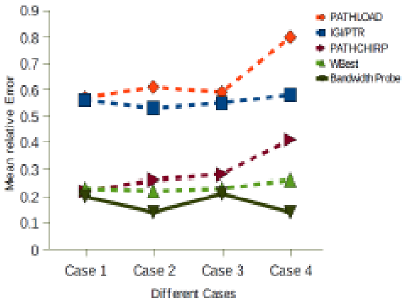

Fig. 7. Mean error while estimating available bandwidth

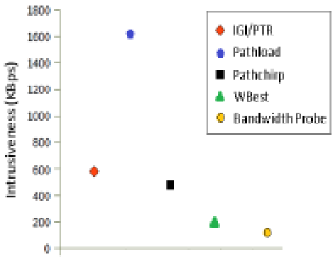

Fig. 8. Intrusiveness in different techniques

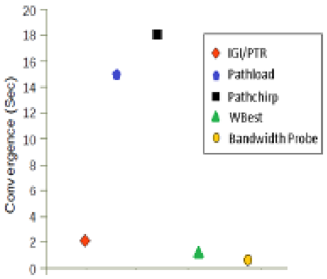

Fig. 9. Convergence of different techniques

of 570 Kbytes and 450 Kbyte respectively. Pathload has the largest intrusiveness around 1600 Kbytes. WBest is comparatively having better intrusiveness of 170 Kbytes. Convergence is the time spent by the estimation techniques during measurement. Figure. 9 shows that Bandwidth Probe seems to have much less convergence time compared to the others with 0.48 seconds. IGI/PTR uses convergence time 1.5 seconds. Pathchirp has the longest convergence time of 18 seconds and Pathload having around 15 sec . WBest is also comparatively better in the sense of convergence having convergence time 1.2 seconds.

V Conclusion

In this paper, we have proposed a new bandwidth estimation technique for the WMNs and multi-hop wireless network. To avoid estimation delay and the effect of random errors in the wireless channel, we use a statistical measurement technique in an iterative way. It is an estimation method which depends on the dispersion principle that uses probe packet trains for the measurement. Bandwidth Probe inserts certain spacing between the packet trains showing direct relation to the gap of packet pairs. We have also given the experimental details and comparison with the existing techniques. The results clearly shows that Bandwidth Probe is able to deal with the contending traffic, interference and mobility more efficiently.

References

[1] Ian F. Akyildiz and Xudong Wang, A Survey on Wireless Mesh Networks, IEEE Radio Communication, pp.523-530, 2005

[2] Jacobson, V., Congestion Avoidance and Control, Computer Communication review, pp.314-329 August 1988

[3] Parag S. M. Cross-layer bandwidth management and optimization in TDMA based wireless mesh networks using network coding , SIGMM Records Sep. 2010

[4] R. S. Prasad, M. Murray et al. Bandwidth Estimation: Metrics, Measurement Techniques and Tools, in Proc. of IEEE Network, vol 17, pp. 27–35, 2003

[5] Michael Bredel and Markus Fidler, A Measurement Study of Bandwidth Estimation in IEEE 802.11gWireless LANs using the DCF, in Proc. of NETWORKING 2008, LNCS 4982, pp. 314–325, IFIP 2008

[6] Strauss, Jacob et al, A measurement study of available bandwidth estimation tools, IMC ’03: Proc. of the 3rd ACM SIGCOMM conf. on Internet measurement, Oct 2003

[7] Li, M., Claypool, M., Kinicki, R., WBest: A Bandwidth Estimation tool for multimedia streaming application over IEEE 802.11 wireless networks. Technical Report WPI-CS-TR-06-14, Worcester Polytechnic Institute, March 2006

[8] Ningning Hu Steenkiste, P., Evaluation and characterization of available bandwidth probing techniques. IEEE JSAC 21(6), 879–894, 2003

[9] B. Melander, M. Bjorkman, and P. Gunningberg, Regression-based available bandwidth measurements, in Proc. of the 2002 International Symposium on Performance Evaluation of Computer and Telecommunications Systems, San Diego, July 2002

[10] Yong Zhu, C. Dovrolis, M. Ammar, Dynamic overlay routing based on available bandwidth estimation: A simulation study, Elsevier Computer Networks, 2006

[11] V. Konda and J. Kaur, RAPID: Shrinking the Congestion Control Timescale, in Proc. of IEEE INFOCOM, 2009

[12] Johnsson, Melander, B. et al., DietTopp: A first implementation and evaluation of a simplified bandwidth measurement method. In: Proc. of SNCNW, Nov 2004

[13] Ribeiro, V.J., Riedi, R.H., Baraniuk, R.G., Navratil, J., Cottrell, L.: Pathchirp: Efficient available bandwidth estimation for network paths. In: Proc. of PAM, April 2003

[14] Melander B.,Bjrkman M., Gunningberg P. Regression based available bandwidth measurements in Proc. of SPECTS, 2002

[15] Liu X., Ravindran K., Liu B., and Loguinov, D., A Queuing-Theoretic Foundation of Available Bandwidth Estimation: Single-Hop Analysis in ACM/SIG IMC,2005

[16] Mingzhe Li et al. Packet Dispersion in IEEE 802.11Wireless Networks, in Proc. of IEEE Local Computer Networks, 2006

[17] T. Sun, G. Yang, L. Chen, M. Y. Sanadidi, and M. Gerla, A measurement study of path capacity in 802.11b based wireless networks in WiTMeMo05, Seattle, USA, 2005

[18] Network simulator (ns2). http://www.mash.cs.berkeley.edu/ns/

[19] C.E. Perkins, E.M. Royer, S. Das, Ad Hoc On Demand Distance Vector (AODV) Routing, IETF Internet draft, draft-ietf-manet-aodv-08.txt, March 2001

[20] Dovrolis C., Ramanathan P., and Moore, D., Packet dispersion techniques and a capacity estimation methodology in IEEE/ACM Transaction on Networking, 2004

[21] IEEE P802.11 Task Group S - Status of project IEEE 802.11s - Mesh Networking, http: //www.grouper.ieee.org/groups/802/11/Reports/tgs_update.htm

[22] X. Liu, K. Ravindarn., and D. Loguinov, Multi-Hop Probing Asymptotics in Available Bandwidth Estimation: Stochastic Analysis, In Proc. of ACM/SIG IMC, 2005

[23] Kaixin Xu, Mario Gerla, Sang Bae. How Effective is the IEEE 802.11 RTS/CTS Handshake in Ad Hoc Networks?, IEEE GLOBECOM, 2002

[24] K. Xu, et al., M. An ad hoc network with mobile backbones , IEEE ICC 2002

[25] Zhang, L., Liu, Z., Xia, C. H. Clock Synchronization Algorithm for Network Measurements, IEEE Infocom 2002

Appendix 1. Architecture of Wireless Mesh Networks

Wireless Mesh Networks are gaining wide popularity because of their flexible and cross effective technology. The IEEE has set the 802.11s Task Group to develop a common standard for WMNs. But, it is still working on the draft and is yet to produce a final document. The proposed architecture 802.11s is based on some of the already approved amendments to standards like 802.11a/b/g/n. It is similar to the traditional set of disjoint IEEE 802.11 Access Points (APs).

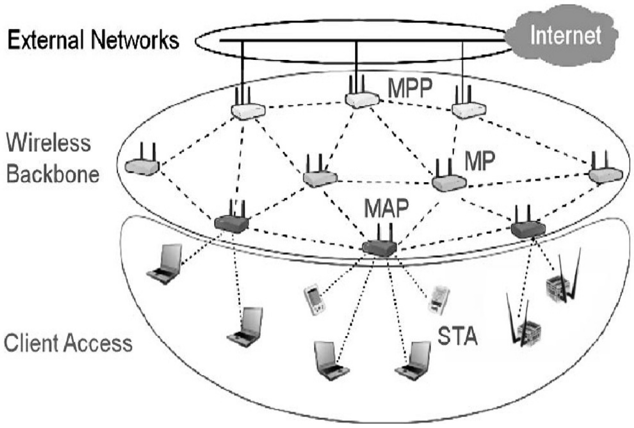

Fig. 10. Example of Wireless Mesh Network

Beyond having all the characteristics of a traditional 802.11 station (STA), every Mesh Point (MP) can also forward the traffic generated by other MPs, hence enabling them to reach the intended destination through a multi-hop path. A MP can have additional features like gateways and bridges to connect the external networks acting as a Mesh Point Portal (MPP). Clients can also communicate with each other in the peer-to-peer fashion. The described architecture shows that the WNMs are able to deploy many types of distributed applications for both residential premises and for hardly accessible places. So Bandwidth Probe can improve the performance of these applications by the actual measurement of Available Bandwidth on time. Figure. 10 shows the relationship among the various elements in WMNs.

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