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Toward efficient estimation of available bandwidth for IEEE 802.11-based wireless networks ☆

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ABSTRACT

Accurately measuring the available bandwidth information is critical for providing QoS (Quality of Service) assurance, especially for the bandwidth-limited 802.11-based wireless networks. However, the shared nature of wireless medium and IEEE 802.11 MAC pose great challenges for estimating the bandwidth accurately. This paper tends to tackle this issue. In particular, based on our formal definition of available bandwidth in IEEE 802.11-based wireless networks, a novel *P*assive *A*vailable *B*andwidth *E*stimation (PABE) approach is proposed. In PABE, the effective link capacity is analyzed by considering the random factors in transmission like backoff and the retransmission of frame. To estimate the available channel idle time ratio (CITR), a new, lower threshold (named No Collision Sensing Range threshold, *NCSR-threshold*) is introduced, and the underestimation problem raised by the new threshold is compensated by the non-affect case analysis. Our approach incurs very low cost to the network without any explicit message overhead. Through extensive simulation, our data validate that our approach consistently achieves much better performance than other existing algorithms in terms of estimation accuracy.

1. Introduction

Available bandwidth quantifies the maximum throughput of a link or a path, which can be used to transmit data without disrupting existing flows (Prasad et al., 2003). It is an important metrics for network QoS (Hou et al., 2007), including QoS routing (Hanzo and Tafazolli, 2009a), admission control (AC) (Hanzo and Tafazolli, 2009b; Hou and Kumar, 2009), and others. The contention access and adaptive rate of IEEE 802.11 along with the shared nature of wireless channel pose a great challenge to accurately estimate the link available bandwidth (Kashyap et al., 2007; Aguayo et al., 2004). In this paper, we focus on the estimation of the link available bandwidth in IEEE 802.11-based wireless multi-hop networks.

A number of approaches have been proposed to estimate the available bandwidth. Generally speaking, those approaches can be classified into two categories: active and passive. In the active probing approach, the node estimates the available bandwidth according to the characteristics of the received probing (Strauss et al., 2003). Nevertheless, actively probing the network introduces additional overhead to network, degrading the network performance and affecting the accuracy of the bandwidth estimation. Based on the existing study (Lee et al., 2006; Shriram and Kaur, 2007), these approaches do not work well in wireless networks. In addition, Gupta et al. (2009) conducted the experimental study toward the bandwidth estimation of algorithms and their results show that the active probing approaches perform poorly in terms of accuracy in comparison with the passive based approaches. Hence, we focus on the passive probing approach in this paper.

The passive probing approaches estimate the available bandwidth via the bandwidth utilization information obtained in a passive manner. The most common method is to monitor the channel usage based on the CSMA scheme of IEEE 802.11 via sensing radio medium. However, all the existing approaches do not completely consider all the random factors (e.g., random backoff, collision probability, synchronization, and others) in bandwidth estimation. In addition to estimate the available channel idle time, the passive channel sensing is limited to the node's carrier sensing range coverage area. Hence, some transmissions which are outside the area of carrier sensing range and may impact the node's available channel time are ignored. To overcome this limitation, a new sense threshold, which is lower than the carrier sense threshold, is adopted to monitor the available channel time. Then the node could sense all transmissions which could potentially reduce the available channel time without explicitly querying. Unfortunately, the transmissions which will not impact the available channel time may be sensed by mistake, therefore, those approaches with a larger sensing range may suffer from the underestimation problem. Differently, the bandwidth

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estimation approach in this paper adopts a new sensing range, which is different from the above approaches to estimate the available channel idle time ratio. In our proposed approach, to address the underestimation problem, the transmission with no impact on the available channel idle time and incorrectly sensed by the new sensing range is taken into consideration during the bandwidth estimation.

This paper makes the following three contributions. First, we clarify the link available bandwidth for 802.11-based wireless networks with the consideration of its unique characteristics and formally define the "available" channel for 802.11 MAC. Second, we present a *P*assive *A*vailable *B*andwidth *E*stimation (PABE) method to obtain the link available bandwidth for IEEE 802.11-based wireless networks. In PABE, the estimation process does not incur any explicit control message. Considering the random phenomenon, such as retransmission and backoff, the effective link capacity is analyzed. In addition to the carrier sensing mechanism of 802.11, the node also uses a new, lower sensing threshold (named *NCSR* (*No Collision Sensing Range*)*-threshold*) to obtain the channel idle time ratio (CITR) without impacting the normal operation of 802.11 MAC. Especially, the underestimation problem caused by *NCSR-threshold* is compensated by analyzing the transmission cases, which will not impact the available bandwidth. Third, we conduct extensive simulations to qualify how the background traffic load and the packet sizes may impact the accuracy of bandwidth estimation. The performance of PABE is evaluated in comparison with four representative passive approaches, namely AAC (de Renesse et al., 2007), ABE (Sarr et al., 2008), IAB (Zhao et al., 2009), and CACP-CS (Yang and Kravets, 2005). Simulation results show that our approach consistently outperforms other existing representative approaches.

The rest of this paper is organized as follows. In Section 2, we review the related works. In Section 3, we formally define the available bandwidth in IEEE 802.11 and present the novel technique for estimating the available bandwidth. In Section 4, we evaluate the accuracy of bandwidth estimation approach in comparison with the existing representative approaches. In Section 5, we conclude the paper.

2. Related work

A number of bandwidth estimation approaches have been developed in recent years for IEEE 802.11-based wireless networks. In this section, we review these approaches according to two major estimation techniques: active bandwidth estimation and passive bandwidth estimation.

2.1. Active bandwidth estimation

In the early studies, the node estimates the available bandwidth according to the characteristics of the received probing. According to the previous study (Strauss et al., 2003), the active bandwidth estimation approaches can be categorized into two models: the *probe gap model* (*PGM*) and the *probe rate model* (*PRM*). PGM estimates the available bandwidth based on the time gap between the arrivals of two successive probes at the receiver. Assuming that a probe pair is sent with a time gap t_s, and reaches the receiver with a time gap t_r, the available bandwidth (denoted as *AB*) can be estimated by

$$AB = C \times \left(1 - \frac{t_r - t_s}{t_s}\right), \tag{1}$$

where C is the capacity of the link/path. Spruce (Strauss et al., 2003) and IGI (Hu and Steenkiste, 2003) are typical examples using *PGM*.

PRM estimates the available bandwidth based on the probe rate between the sender and the receiver. The core idea of *PRM* is that if the probe traffic is sent at a rate lower than the available bandwidth along the path/link, the arrival rate at the receiver will match with the sender rate. On the contrary, a higher sending rate results in queuing and delay of transmitting probing packets. Based on this, *PRM* measures the available bandwidth by identifying the turning point, where the probe sending and receiving rates match. Approaches, including Pathload (Jain and Pathload, 2002), Train of Packet Pairs (TOPP) (Mel et al., 2002), pathChirp (Riberio et al., 2003), WBest (Li et al., 2008), all belong to this category.

In addition, an increasing effort has recently been put toward improving the theoretic understanding of measurement-based estimation of available bandwidth (Liebeherr et al., 2010; Lubben et al., submitted for publication). Particularly, these methods estimate the available bandwidth by exploiting properties of a stochastic min-plus linear system theory through the measurement of probing traffic. As we mentioned above, the active probe based bandwidth estimation approaches introduce extra overhead, degrade the network performance, and affect the accuracy of the bandwidth estimation. To this end, the active bandwidth estimation approaches are not the best choice for wireless networks (Gupta et al., 2009).

2.2. Passive bandwidth estimation

In recent studies, several passive bandwidth estimation approaches for 802.11-based wireless networks have been proposed. For example, CACP (Yang and Kravets, 2005) is an admission control protocol based on the available bandwidth estimation. In this work, each node first computes its local available bandwidth by monitoring the channel idle time ratio. Then, the three different techniques (i.e., CACP-Multihop, CACP-Power, and CACP-CS) are proposed to propagate the local available bandwidth to the nodes within the carrier sense coverage area. In AAC (de Renesse et al., 2007), the local available bandwidth of each node is measured in a similar manner to the one in CACP, and the available bandwidth of a link is defined as the minimum available bandwidth on the link between two nodes. However, the random backoff, the hidden terminal, and synchronization problems were largely ignored.

ABE (Sarr et al., 2008) is another bandwidth estimation approach based on monitoring CITR. This approach considers the random backoff, collision probability, and synchronization. As a result, the available bandwidth estimated by ABE can be derived by

$$AB = (1-k) * (1-p_m) * \frac{T^s_{idle}}{\Delta} * \frac{T^r_{idle}}{\Delta} * C, \tag{2}$$

where T^s_{idle}/Δ and T^r_{idle}/Δ are the idle time ratio of the sender and the receiver over the monitoring period Δ, respectively; k is the proportion of the bandwidth consume due to the backoff; p_m is the collision probability of the frame with m bits, which is calculated by $p_m = f(m) \cdot p_{hello}$, where p_{hello} is the collision probability of "hello" packet and $f(m)$ is a Lagrange interpolating polynomial measured by simulations with different packet sizes. Nevertheless, the collision probability p_m is evaluated in one specific simulation scenario, which is not able to reflect the collision in general scenario.

In Zhao et al. (2009), an Improved Available Bandwidth (IAB) estimation approach was proposed to improve the accuracy of ABE. Similar to ABE, IAB estimates the CITR by passively monitoring the transmission in the carrier sensing range. The difference lies in the more accurate estimation of the overlap probability of the CITR by considering the actual dependence of sender's idle time and receiver's idle time, and consequently the bandwidth estimation is improved. In particular, the available bandwidth of