Flow-based High Throughput Path Selection in 802.11-based Multi-rate Wireless Mesh Networks

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Abstract—Today’s 802.11-based wireless network interface cards (WNICs) can leverage multiple transmission rates to exploit various and dynamic channel conditions. Some link adaptation schemes (LASs) in the literature have been shown to adapt well to dynamic channel conditions, thereby achieving high link throughput. However, routing protocols unaware of the underlying LAS may achieve low end-to-end throughput due to inappropriate path selection. In this paper, we propose a cross-layer routing framework called EAB which aims at discovering a high throughput path using statistics from MAC and LAS layer for a newly initiated flow. Our simulation results reveal that EAB operating on top of some efficient LASs significantly outperforms existing routing protocols in terms of the achieved throughput and the impact on existing flows.

I. INTRODUCTION

This paper focuses on discovering a high throughput path for a newly initiated flow in 802.11-based multi-rate wireless mesh networks (WMNs). The key difference from previous studies is that we deal with multi-rate environments which are common in recent wireless networks. To benefit from the multi-rate capability, it is crucial to adopt an effective link adaptation scheme (LAS) which adjusts packet transmission rates based on current channel conditions. However, the introduction of LAS makes it difficult to calculate each link’s residual capacity, thus complicating the path selection procedure.

To handle this, we propose in this paper a routing framework called EAB (Effective Available Bandwidth). First of all, EAB obtains an available time fraction and an effective data rate from the underlying LAS and MAC layer. Based on these, it estimates the residual capacity of each wireless link in the network. Finally, taking into account some other factors that affect the routing performance, such as intra/inter-flow interference, a high throughput path for a new flow is determined.

The rest of this paper is organized as follows. The system model and assumptions are given in Section II. We elaborate on the design of our proposed framework in Section III, followed by simulation results in Section IV. Finally, we conclude this paper in Section V.

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II. SYSTEM MODEL

We assume an 802.11-based WMN where all nodes are equipped with a single-radio WNIC operating on the same physical channel. Some of the nodes (gateways) are connected to a wired network. Other nodes are referred to as non-gateways or relay nodes.

It is assumed that there are two types of data flows in the network: background and primary flows. Background flows refer to ones which already exist in the network and have a fixed sending rate. On the other hand, primary flows represent newly initiated flows at a non-gateway with their destinations being any gateway. The objective is to provide the maximum throughput for primary flows while minimizing throughput degradation of existing background flows. Routing decisions are made at a centralized controller which is assumed to reside in the wired network and have all information about the network. In order to select the best path for a new primary flow, the centralized controller calculates EAB-metrics (will be explained shortly) of a set of candidate paths and picks one with the maximum value.

III. EAB DESIGN

A. Available time fraction

When node \(i\) transmits to node \(j\), the time fraction available for node \(j\) to receive the new flow’s packets is

\[
\tau_{rx}^j = 1 - t_{tx}^i - t_{rx}^j, \quad (1)
\]

where \(t_{tx}^i\) and \(t_{rx}^j\) are the time fractions used by node \(j\) to transmit and receive packets of existing flows, respectively.

Then, one can calculate the time fraction available for node \(i\) to transmit as

\[
\tau_{tx}^i = 1 - t_{tx}^i - t_{rx}^i - \sum_k \rho_{i,k} \cdot t_{tx}^{k,(-i)}, \quad (2)
\]

where \(t_{tx}^i\) and \(t_{rx}^i\) are the same as in (1), and \(\rho_{i,k}\) is the probability that node \(i\) senses node’s \(k\) transmissions. Also, \(t_{tx}^{k,(-i)}\) stands for the time fraction used by node \(k\) to transmit to other nodes except for node \(i\).

From (1) and (2), we can obtain the available time fraction of link \((i,j)\) by taking the minimum of the two as

\[
\tau_{i,j} = \min(\tau_{tx}^i, \tau_{rx}^j). \quad (3)
\]
B. Effective data rate

We define effective data rate $R_{i,j}$ of the link $(i,j)$ as follows:

$$R_{i,j} = \frac{N_{i,j} \cdot L}{t_{i,(i+j)}^{tx}}; \quad (4)$$

where $N_{i,j}$ is the number of unicast packets which are transmitted by node $i$ and received at node $j$. $L$ stands for the predefined packet size, and $t_{i,(i+j)}^{tx}$ implies the time fraction used by node $i$ to transmit only to node $j$.

C. Effective available bandwidth of a clique

A common approach for calculating a link’s residual capacity is to calculate the available bandwidth of a clique rather than the available bandwidth of each link separately [1]. A clique is defined as a set of links which cannot be activated simultaneously due to contention and carrier sense relations. We propose to calculate the available bandwidth $B_C$ of a clique $C$ in multi-rate environments as

$$B_C = \min_{v(i,j) \in C} \tau_{i,j} \cdot \left( \sum_{v(i,j) \in C} \frac{1}{R_{i,j}} \right)^{-1}. \quad (5)$$

D. Effective available bandwidth of a path

In multi-hop wireless networks, a path from a source to a given destination consists of one or more overlapping cliques. The available bandwidth $B_p$ of a path $p$ is easily obtained from the available bandwidth of each clique as follows:

$$B_p = \min_{\forall C \in p} B_C. \quad (6)$$

Eventually, one can pick the best path $p^*$ which has the maximum effective available bandwidth as

$$p^* = \arg \max_{\forall p \in P} B_p, \quad (7)$$

where $P$ is the set of candidate paths from a given source node to any gateway.

IV. PERFORMANCE EVALUATION

To demonstrate the efficacy of our proposed scheme, we have conducted simulations using ns-2 [4]. As for performance metrics, we use the achieved throughput of a new primary flow and the average throughput degradation ratio of background flows. The used topology is illustrated in Fig. 1.

The simulation proceeds as follows. At time instant of 0.0 sec, we start a background flow with a sending rate of 20 kbps on every feasible wireless link with a PRR greater than 0.6 at 1 Mbps in both directions. At time instant of 50.0 sec, we initiate a primary multi-hop flow from node 0 with the destination being node 4. The performance results for 8 different routing and LAS combinations are depicted in Fig. 2. The wide and narrow bars correspond to the achieved throughput of the primary flow (left y-axis) and the average throughput degradation ratio of the background flows (right y-axis), respectively.

Unlike the combinations with a fixed transmission rate, both EAB and FIRM [2] exhibit significant performance gains in terms of both metrics when they operate on top of CHARM [3]. However, FIRM still assumes that a fixed transmission rate is in use and therefore sets the sending rate to a low value. That is why low throughput degradation of the background flows is achieved in FIRM+CHARM. However, EAB+CHARM achieves 1.75 times higher throughput than FIRM+CHARM without sacrificing the existing flows’ throughput.

V. CONCLUSION

In this paper, the problem of path selection in multi-rate wireless mesh networks is studied under the assumption of link adaptation scheme enabled at every wireless node and the requirement of no throughput degradation of existing flows. We showed that taking in account the performance of underlying LAS is crucial for discovering high throughput paths. Our simulation results exhibited that the proposed routing framework performs the best in the considered scenario.

REFERENCES


