Self-Interference Aware Opportunistic Routing Metric in Wireless Mesh Networks

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Abstract

In this paper, we present a new routing metric named SIOR which is designed for opportunistic routing in single-rate wireless mesh networks. Most of the existing routing metrics either assume too pessimistically that all links within the network interfere with each other or do not consider intra-flow interference at all. In fact, any flow which has its destination node at least two hops away from its source node suffers from intra-flow interference which results in network capacity degradation. If the impact of intra-flow interference is neglected, routing decisions might be not optimal. In contrast, our design of SIOR routing metric explicitly considers the impact of intra-flow interference. We demonstrate that one can expect to find anypaths with SIOR metric value reduced up to 15% against the anypath output by a well-known reference algorithm.

1. Introduction

Widely accepted modeling of opportunistic routing (OR) metric such as expected anypath transmission count (EATX) [4], [5] and expected anypath transmission time (EATT) [1] has some drawbacks. These metrics pessimistically assume that only one node within a network can transmit at a given time moment. However, this assumption is not always valid, especially in either large-scale or multi-radio multi-channel networks. References [6], [7] perform measurements in testbed environments and show that a node refrains from transmitting due to carrier sense of another node’s transmission probabilistically. Therefore applying routing metric unaware of adequate intra-flow interference may result in sub-optimal candidate selection and their prioritization, which in turn imposes on the lower achievable throughput.

Our motivation is to address the problem of incorporating intra-flow interference in OR metric to improve throughput performance. Several works have already studied on impact of intra-flow interference on routing decisions [3], [8], [9]. However, to the best of our knowledge none of the previous work has considered intra-flow interference in the context of opportunistic routing. In the rest of the paper, we use intra-flow interference and self-interference as synonyms.

In this paper, we introduce a new routing metric called Self-Interference aware Opportunistic Routing (SIOR) which generalizes both EATX [4], [5] and SIM [3] in the one combined metric. In contrast to single-path routing, in opportunistic routing packets injected from a source node take different paths to a given destination. To reflect such probabilistic nature of path-traversing we define a participation probability for each node. It stands for a probability of a node being an actual forwarder of the packet. A node can become an actual forwarder in case it has successfully received the packet from a previous node and all other candidates of the previous node with higher priority have failed to receive the packet. Our definition of SIOR metric makes use of the participation probability.

We organize the rest of the paper as follows. In Section 2 we review some concepts of opportunistic routing. In Section 3 we define SIOR routing metric and explain intuitions behind it. Section 4 describes our approach to compare performance against EATX metric. We conclude this paper in Section 5.

2. Background

This section briefly reviews the basic concepts of opportunistic routing decisions described in [2], [4], [5]. The opportunistic routing leverages the fact that several wireless nodes in vicinity of a transmitter (candidates) can overhear its transmissions. Among the nodes succeeded to decode (receive) the broadcast packet, the node closest to the destination should take responsibility of further packet forwarding. All the other nodes which overhear the same packet should drop it. A retransmission is necessary only if all candidates have failed to receive the packet.

Lauffer and Kleinrock in [1] define anypath as a union of paths between the source and destination. In Fig. 1 we show the anypath between node a and node f. Six paths: \{abf, abef, acef, acf, acdf, adf\} constitute the anypath. Next we denote a sorted list of candidates for node i as C(i). Candidates with higher priority precede candidates with lower priority. For example, in Fig. 1 node a has three candidates, C(a)=[d, b, c], with node d being the highest priority candidate. Node b has two candidates, C(b)=[f, e].
3. Design of SIOR metric

In this section, we define SIOR metric for a given destination node:

$$\text{SIOR}(\text{Ap}_s) = (1 - \beta) \cdot D_s + \beta \cdot \max_k \text{AESI}(k),$$  \hspace{1cm} (1)

where Ap_s denotes anypath from a source node s to the destination node. SIOR metric trades off the total anypath cost with a cost of the worst segment within the anypath. D_s is the total anypath cost expressed in EATX [1]. AESI stands for Anypath Expected Service Interval, similar to Expected Service Interval (ESI) described in [3]. However, ESI metric has been designed for single-path routing in wireless networks where a packet initiated from the source node always traverses the same path. This is not the case for OR. So our definition of AESI is different from ESI to consider probabilistic nature of path traversing:

$$\text{AESI}(k) = \rho_k \cdot d_{kC}(k) + \sum_{i \in CS(k)} c_{Si} \cdot \rho_i \cdot d_{iC(i)},$$  \hspace{1cm} (2)

where \(\rho_k\) is node k’s participation probability. We elaborate on participation probability later on in this section. \(d_{kC}(k)\) is expected transmission count for node k to deliver a packet to at least one of its candidates, when packet is destined to the given destination node. The interested reader may refer to [1] for the exact equation of \(d_{kC}(k)\). \(c_{Si}\) is a probability for node k to carrier sense node s’ transmission. \(CS(k)\) is a set of nodes whose transmissions can be carrier sensed by node k.

Intuitively, AESI(k) is a sum of node’s k ETX (expected transmission count) to deliver packet to its candidate set C(k) and ETXs of the nodes which can be carrier sensed by node k. Such that each ETX value is weighted by the corresponding node participation probability.

Now we explain how to calculate participation probability \(\rho_i\), which is probability that node i participates in forwarding a packet injected from the source node and destined to the destination node. We define it, as follows:

$$\rho_i = \sum_{i \in L(i)} \rho_i \cdot w_{ii},$$  \hspace{1cm} (3)

where L is a set of nodes which use node i as a candidate of any priority. We name set L(i) as “cLients” of node i.

For example, in Fig.2 L(e)={b, c} as nodes b and c use node e as a candidate. \(w_{ii}\) is a probability that node i becomes a highest priority candidate among candidates which succeeded to receive the packet after node’s l transmission. The interested reader may refer to [1] for the exact equation of \(w_{ii}\). It is worth to note that \(w_{ii}\) also accounts for retransmissions in case no candidate of node l was able to receive the packet.

For example, in Fig.2 we label each node with its participation probability. Participation probabilities for the source and the destination nodes are always equal to 1 as any packet injected from the source node should be eventually delivered to the destination node. However, intermediate nodes usually have participation probability less than 1. Nodes b, d and e have participation probability of 0.5, 0.44 and 0.46, correspondingly.

We provide intuitions behind (3) using a simple example. In Fig.2, the probability whether node e participates in forwarding a packet from the source node a depends on whether nodes b and c participate (\(\rho_b\) and \(\rho_c\)) and whether node e becomes an actual forwarder (\(w_e\)) after transmission of either node b or c. In case node c transmits node e becomes an actual forwarder if node f fails to receive the packet. This happens with probability 0.51.

The important property of AESI is that if all nodes within a network can carrier sense each other transmission, then AESI degenerates to the total anypath cost \(D_s\) and therefore SIOR metric generalizes EATX metric. We also note that in general case AESI value is less than the total anypath cost \(D_s\).

4. Performance Comparison

The goal of this paper is to show theoretically achievable performance improvement in terms of SIOR metric as it models expected number of anypath transmissions more realistically than EATX metric.

SIOR metric is not isotonic, i.e. concatenation of two anypaths with the least metric value from the source to an intermediate node and from the intermediate node to the destination does not guarantee resulting in an anypath with the least value. Therefore, devising an optimal algorithm or even good heuristic one is an extremely challenging problem considering metric complexity. Instead we compare SIOR metric value calculated for the anypath which can be obtained using Shortest Anypath First (SAF) algorithm [1] and minimum value of SIOR metric we could find by exhaustive search.
We perform comparison on some devised topology shown in Fig. 3. Node “0” is the source and node “15” is the intended destination. We allocate intermediate nodes into four layers; such that nodes in two neighboring layer can communicate reliably, i.e. wireless links have good or at least moderate qualities. We use green and blue color just for the sake of color perception. We also assume that a node can communicate with another node in next nearest layer, but quality of this link would be poor. In Fig. 3 we show only 4 links of the poor quality: 0→4, 3→10, 4→11, 10→15, as it is impracticable to show all of them.

We set $\beta=0.75$ to give more priority to AESI rather than the total anypath cost. We also intuitively assign carrier sense probabilities for each pair of nodes. However, in a real testbed one can exploit the scheme proposed in [7] to estimate carrier sense probabilities.

We show our comparison results in Table I. The first number 3.94 stands for SIOR metric value corresponding to anypath output by SAF algorithm. The second number is the minimum available SIOR metric found in this topology. We mention that there exist a significant number of anypaths from node “0” to node “15” with SIOR metric value lower than one corresponding to SAF.

<table>
<thead>
<tr>
<th>SIOR metric value for output anypath</th>
<th>SAF algorithm</th>
<th>Minimum</th>
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<tr>
<td>3.94</td>
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<td>3.32</td>
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5. Conclusions
Up-to-date candidate selection and prioritization in opportunistic routing is based on EATX metric which is unaware of intra-flow interference thus resulting in selection of non-optimal anypaths. Our work has proposed a new OR metric which accurately models anypath cost explicitly considering intra-flow interference. We also demonstrate that anypaths with SIOR metric value can be improved up to 15% against output of SAF-algorithm in the considered scenario.

6. References