On Selection of Candidates for Opportunistic Any-Path Forwarding

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I. Introduction and Motivation

Routing protocols for wireless networks have traditionally focused on finding the best path for forwarding packets between a pair of nodes. While such *single-path* forwarding is suitable for wired networks with relatively stable point-to-point links, it is not an ideal approach for wireless networks with broadcast links of time varying qualities. Fluctuations in the quality of any of the links along the predetermined single path can cause excessive retransmissions at the link layer or reroutings at the network layer. Exploiting the broadcast nature of wireless transmissions, several *opportunistic* routing schemes have been proposed to make the forwarding insensitive to link quality variations [1], [2]. The general idea behind these schemes is that, for each destination, a set of candidate next hops are selected in-advance and one of them is chosen for forwarding on a per-packet basis according to its reachability at that instant. By employing such opportunistic *any-path* forwarding (OAPF), these schemes reduce the number of transmissions needed for reliable delivery of a packet to its destination.

The candidate selection and prioritization are the two key issues that need to be addressed by any opportunistic routing scheme. Previously proposed opportunistic schemes such as ExOR [1] select many possible next-hops as candidates and prioritize them based on the best-path ETX from a candidate to the destination. We argue that, instead of many candidates, it is desirable to select a few good ones that do help reduce the number of transmissions. This would decrease the extent of interference caused by the candidates to their neighbors in transmitting per-packet ACKs [1] or the amount of delay in the delivery of a batch of packets [3]. In addition, prioritization based on the best-path ETX from candidate to destination does not account for the fact that the candidates also in turn employ any-path forwarding.

To address the above issues, in this paper, we define a new metric *expected any-path transmissions* (EAX) for a pair of nodes with a given set of candidates that captures the expected number of transmissions between them under opportunistic forwarding. We then describe a candidate selection and prioritization method based on EAX to minimize the number of candidates without adversely affecting the performance in terms of the number of transmissions needed for reliable delivery.

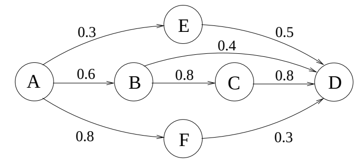

Fig. 1. Topology for illustration of candidate selection

II. Expected Any-Path Transmissions

We now define the EAX for a source s and a destination d. Let $C^{s,d}$ be the set of candidate next hops from s to d, and $C_i^{s,d}$ be the candidate with priority i (with 1 being the highest). Suppose the delivery probability from s to $C_i^{s,d}$ is p_i (considering both the forward data and backward ACK transmissions). Then, we have

$$\mathrm{EAX}(s,d) = \frac{1 + \sum_i \mathrm{EAX}(C_i^{s,d}, d) p_i \prod_{j=1}^{i-1}(1-p_j)}{1 - \prod_i (1-p_i)}$$

Consider the network shown in Fig. 1, where each edge is labeled with the associated delivery probability. Suppose D is the destination. Further assume that A selects B and E as candidates and similarly B has C and D, while all other nodes have just one candidate each. The corresponding EAX and best path ETX values from each node to the destination D are given below.

metric	A	B	C	D	E	F
ETX	4.47	2.50	1.25	0	2	3.33
EAX	3.24	1.82	1.25	0	2	3.33

III. Candidate Selection based on EAX

It is possible that the addition of a candidate next hop for a node pair, while not contributing much to the delivery of packets between that node pair, can actually degrade the overall network throughput. For example, under ExOR (that does not use RTS/CTS), when two candidates c_1 and c_2 receive a DATA packet from a sender s, both respond with ACK which can potentially interfere with other ongoing DATA transmissions in the neighborhood of c_1 and c_2. The proposed new metric *EAX helps determine the contribution of a candidate* to the delivery of packets between a node pair and enables judicious selection of candidates.

The selection of candidates based on EAX can be performed as follows at a node s for a specific destination d. First, a set of potential candidates, $\hat{C}^{s,d}$, is determined based on the best path ETX. A neighbor j is included

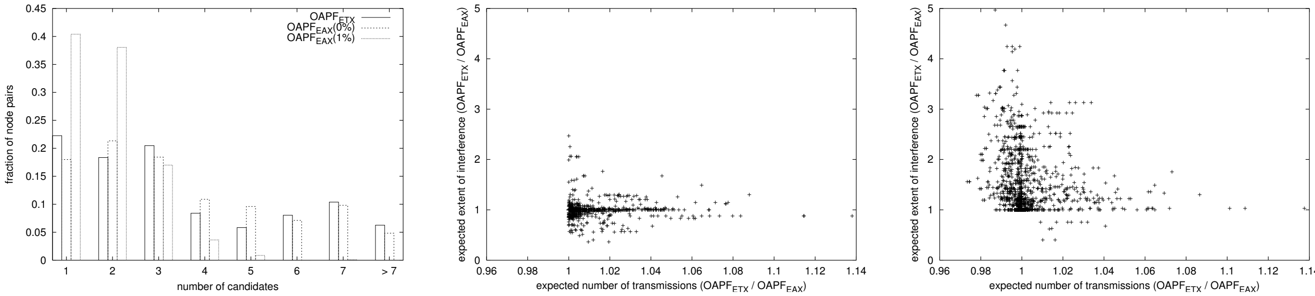

Fig. 2. $\mathrm{OAPF}_{\mathrm{ETX}}$ *vs* $\mathrm{OAPF}_{\mathrm{EAX}}$: (a) no. of candidates; expected interference and no. of transmissions with (b) $\psi = 0\%$ and (c) $\psi = 1\%$

in $\hat{C}^{s,d}$ only if ETX$(s,d) >$ ETX(j,d). Then, a subset of $\hat{C}^{s,d}$ is selected as the actual candidate set $C^{s,d}$. Note that the candidate selection for all the nodes in $\hat{C}^{s,d}$ is done before it is done for s. The set $C^{s,d}$ is initialized with the next hop having the smallest ETX to d. The rest of the candidates are selected incrementally as follows. A potential candidate is considered for inclusion in the set $C^{s,d}$ only if it reduces the EAX(s,d) by a factor of at least ψ, which is configurable parameter. Among such potential candidates, the one that reduces EAX(s,d) the most is added to $C^{s,d}$. This process is repeated till no new candidates are added to the set.

The candidate selection based on ETX and EAX is illustrated using Fig. 1. Assume node A is the source and node D is the destination. By using ETX, node A will choose 3 candidates: B, E, and F. Because paths from these nodes to D have smaller ETX than that from A to D. If we use EAX, then only 2 nodes, B and E, will be selected by source A. Because the EAX with these two candidates is less than the EAX of F, adding F to the candidate set does not decrease EAX between A and D. Similarly prioritization based on EAX yields different ordering among the candidates. Based on EAX, B gets higher priority than E. The differences in the candidate selection and prioritization based on ETX and EAX for source A and destination D are summarized below.

metric	(src, dst)	cand. size	candidates	priority
ETX	(A, D)	3	B, E, F	E $>$ B $>$ F
EAX	(A, D)	2	B, E	B $>$ E

IV. Evaluation of EAX-based OAPF

We now compare the performance of OAPF based on ETX with that based on EAX in terms of the number of candidates selected per each node pair, and also the resulting EAX. We use the link-level measurements data from MIT Roofnet [4] for the evaluation. Roofnet is a 38-node multi-hop wireless mesh network with 352 uni-directional links. The measurement trace records a delivery ratio for each link every 200 ms for 90 sec. We compute the average delivery ratio over 90 sec for each link and use these average values to select candidates for each pair of nodes as per ETX and EAX.

Fig. 2(a) shows the number of candidates and the corresponding fraction of node pairs having that many candidates under $\mathrm{OAPF}_{\mathrm{ETX}}$ and $\mathrm{OAPF}_{\mathrm{EAX}}$ with $\psi = 0$ and $\psi = 1\%$. There is no significant difference in the number of candidates between $\mathrm{OAPF}_{\mathrm{ETX}}$ and $\mathrm{OAPF}_{\mathrm{EAX}}$ with $\psi = 0$. However, even with a very small ψ value of 1%, there is a substantial decrease in the number of candidates. To demonstrate the effect of a smaller candidate set on the delivery, in Fig. 2(b) and Fig. 2(c), we plot for each node pair, the ratio of EAX under $\mathrm{OAPF}_{\mathrm{ETX}}$ and $\mathrm{OAPF}_{\mathrm{EAX}}$ against ratio of expected interference under $\mathrm{OAPF}_{\mathrm{ETX}}$ and $\mathrm{OAPF}_{\mathrm{EAX}}$, for $\psi = 0$ and $\psi = 1\%$ respectively. We approximate the extent of interference caused by a set of candidates $C^{s,d}$ with the expected number of nodes that receive (based on the average delivery ratios of links) an ACK, from at least one of the candidates, when a DATA packet is sent from s to d. It is clear that $\mathrm{OAPF}_{\mathrm{EAX}}$ with a small ψ value of 1% selects fewer good candidates and thus reduces the interference to others while delivering as well as $\mathrm{OAPF}_{\mathrm{ETX}}$ with many more candidates.

V. Conclusion

We proposed a new metric EAX for opportunistic any-path forwarding and described a candidate selection and prioritization method based on EAX. We demonstrated that EAX-based selection, without hurting the delivery for a node pair, can reduce the potential interference to other node pairs. We need to further evaluate the proposed approach with simulations and experiments.

References

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