# MobiCom Poster Abstract: On Selection of Candidates for Opportunistic AnyPath Forwarding

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## I. Introduction and Motivation

Opportunistic routing schemes that exploit the broadcast nature of wireless transmissions for selecting the best next-hop at that instant among a set of candidates are being actively explored [1–3]. These schemes which we refer to as opportunistic *any-path* forwarding (OAPF), reduce the number of transmissions needed for reliable packet delivery.

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 [2]. 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, 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.

## II. Expected AnyPath 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 packet delivery probability from $s$ to $C_i^{s,d}$ is $f_i$[1]. Then, we have

[1]Here, we assume that ACKs are delivered reliably (i.e., no duplicate transmissions of data packets as in [2] for bulk transfer).

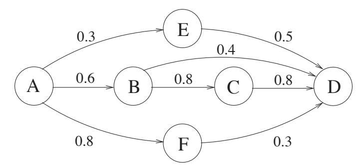


Figure 1: Topology used for illustration

$$\text{EAX}(s,d) = \frac{1+\sum_i \text{EAX}(C_i^{s,d},d) f_i \prod_{j=1}^{i-1}(1-f_j)}{1-\prod_i(1-f_i)}$$

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 from each node to the destination D are given below.

| metric | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| ETX | 4.17 | 2.50 | 1.25 | 0 | 2 | 3.33 |
| EAX | 3.24 | 1.82 | 1.25 | 0 | 2 | 3.33 |

## III. EAX based Candidate Selection

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.

Candidates based on EAX can be selected as follows at a node $s$ for a 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 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 $d$.

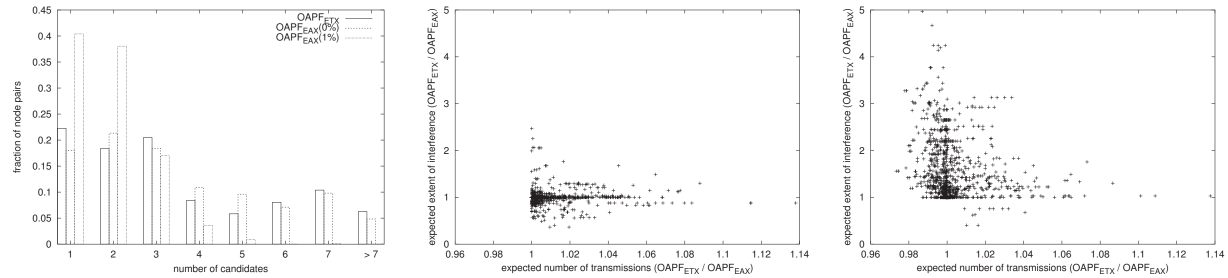


Figure 2: (a) no. of candidates; expected interference and no. of transmissions with (b) $\psi = 0\%$ and (c) $\psi = 1\%$

The rest of the candidates are selected incrementally as follows. A potential candidate is considered for inclusion in $C^{s,d}$ only if it reduces the EAX($s, d$) by a factor of at least $\psi$, which is a 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.

Candidate selection based on ETX and EAX is illustrated using Fig. 1. Assume A is the source and D is the destination. By using ETX, A will choose 3 candidates: B, E, and F, since their ETX to D is smaller than that from A to D. If we use EAX, only B and E will be selected. 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 node pair, and the resulting EAX. For evaluation, we use the link-level measurements data from MIT Roofnet [2]. The measurement trace records a delivery ratio for each link every 200 ms for 90 sec. We average the delivery ratio over 90 sec for each link and use these average values to select candidates for each node pair as per ETX and EAX.

Fig. 2(a) shows the number of candidates and the fraction of node pairs having that many candidates under $\text{OAPF}_{\text{ETX}}$ and $\text{OAPF}_{\text{EAX}}$ with $\psi$=0 and $\psi$=1%. There is no significant difference in the number of candidates between $\text{OAPF}_{\text{ETX}}$ and $\text{OAPF}_{\text{EAX}}$ with $\psi$=0. However, even with a very small $\psi$ 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 $\text{OAPF}_{\text{ETX}}$ and $\text{OAPF}_{\text{EAX}}$ against ratio of expected interference under $\text{OAPF}_{\text{ETX}}$ and $\text{OAPF}_{\text{EAX}}$, 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 $\text{OAPF}_{\text{EAX}}$ with a small $\psi$ value of 1% selects fewer good candidates and thus reduces the interference to others while delivering as well as $\text{OAPF}_{\text{ETX}}$ 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. We demonstrated that EAX-based selection, without hurting the delivery for a node pair, can reduce the potential interference to other node pairs. The proposed approach seems even more promising when ACKs are unreliable (as in [1] for non-bulk traffic) and is being further investigated.

## References

[1] S. Biswas and R. Morris, "Opportunistic routing in multi-hop wireless networks," in *HotNets-II*, Nov. 2003.

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[3] R. R. Choudhury and N. H. Vaidya, "Mac-layer anycasting in ad hoc networks," *Comput. Commun. Rev.*, vol. 34, no. 1, pp. 75–80, 2004.