MobiCom Poster Abstract: Load-balanced Routing For Mesh Networks

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I. Introduction

Due to the static nature of nodes, in mesh networks, a poor choice of paths may remain unchanged for a long time and create hot spots. Hence, it is very important to design path weight functions (also called routing metrics) to facilitate load-balanced routing in mesh networks. Such path weight functions (PWFs) must reflect the shared nature of wireless channels and support easy calculation of loop-free paths. In this abstract, we present our theoretical studies of the requirements on PWFs and design the first PWF, called *Metric of Interference and Channel-switching (MIC)*, that satisfies these requirements. Our simulation results show that MIC's performance is substantially better than existing PWFs. (See our technical report [5] for more details.)

II. Requirements of PWFs

Due to the shared nature of wireless medium, both *intra-flow interference* (interference between nodes on the path of the same flow) and *inter-flow interference* (interference between neighboring nodes) exist in mesh networks and affect the load on nodes. Hence, to balance network load, PWFs must capture both intra-flow and inter-flow interference. In addition, for efficient routing algorithms, such as link-state or distance-vector algorithms, to find minimum weight and loop-free paths, PWFs must have a fundamental property called *isotonicity* [3, 4].

Definition: *A PWF* $W(\cdot)$ *is isotonic if* $W(a) \leq W(b)$ *implies both* $W(a \oplus c) \leq W(b \oplus c)$ *and* $W(c' \oplus a) \leq W(c' \oplus b)$ *for all paths* a, b, c, c'*, where operator* $\oplus$ *represents the concatenation of two paths.*

II.A. Existing PWFs

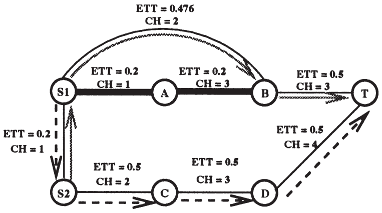


Figure 1: WCETT's non-isotonicity.

Although most of the existing PWFs, such as hop count, ETX [1] and ETT [2], are isotonic, they do not consider interference and hence cannot balance the load in mesh networks. The only interference-aware existing PWF is WCETT [2], where WCETT of a path p is:

$$WCETT(p) = (1-\beta) \sum_{\text{link } l \in p} ETT_l + \beta \max_{1 \leq j \leq k} X_j, \tag{1}$$

where $0 \leq \beta \leq 1$, ETT_l is the expected transmission time of a packet at link l and X_j is the number of times that channel j is used along path p. While ETT represents the capacity of wireless channels, X_j captures the intra-flow interferences of path p.

However, inter-flow interference is not considered in WCETT. In addition, WCETT is not isotonic, which can cause severe problems. For example, in Figure 1, two numbers are associated with each link, the ETT and the channel number (CH), respectively. Assuming β in Equation (1) is 0.5, the minimum weight path from S_1 to T is $S_1 \rightarrow B \rightarrow T$. However, due to the non-isotonicity of WCETT, when node S_1 uses Dijkstra's algorithm to calculate its path to node T, node S_1 incorrectly chooses $S_1 \rightarrow S_2 \rightarrow C \rightarrow D \rightarrow T$ as the minimum weight path (the dotted arrows in Figure 1). When node S_2 calculates its path to T, Dijkstra's algorithm correctly indicates $S_2 \rightarrow S_1 \rightarrow B \rightarrow T$ as the minimum weight path (the shadowed arrows in Figure 1). Hence, a forwarding loop is formed between S_1 and S_2.

III. MIC

Our novel PWF, MIC, not only captures both intra-flow and inter-flow interference, but also can be decomposed into isotonic link weight assignments so that loop-free minimum weight paths can be easily found.

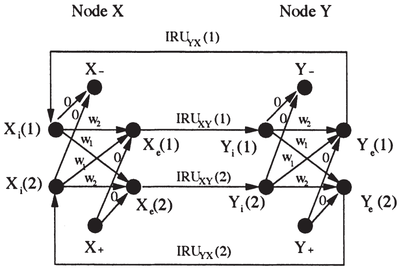
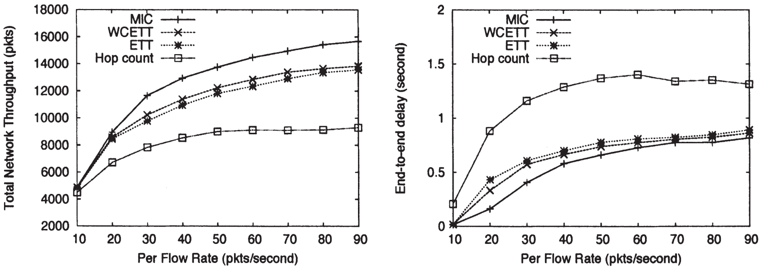


Figure 2: Virtual nodes for real nodes X and Y. Both nodes X and Y have two radios configured to channels 1 and 2 respectively.



(a) Total network throughput

(b) Average end-to-end packet delay

Figure 3: 1000m×1000m networks with 50 nodes. Each node has two radios.

III.A. Definition of MIC

MIC is composed of two metrics: *Interference-aware Resource Usage (IRU)*, which captures inter-flow interference, and *Channel Switching Cost (CSC)*, which captures intra-flow interference.

IRU metric is defined as follows:

$$IRU_{ij}(c) = ETT_{ij}(c) \times |N_i(c) \bigcup N_j(c)|,$$

where $N_i(c)$ is the set of neighbors that node i interferes with when it transmits on channel c. $|N_i(c) \bigcup N_j(c)|$ is the total number of neighbors that may be interfered with by the transmission between node i and node j over channel c. IRU captures the aggregated channel time of these neighbors consumed by the transmission between nodes i and j, essentially representing the inter-flow interference. Capturing intra-flow interference, CSC at a node X is:

$$CSC_X = \begin{cases} w_1 & \text{if } CH(prev(X)) \neq CH(X), \\ w_2 & \text{if } CH(prev(X)) = CH(X), \end{cases}$$

$$0 \leq w_1 < w_2,$$

where $prev(X)$ is the previous hop of node X and $CH(X)$ is the channel that node X uses to transmit to the next hop. The relationship $w_2 > w_1$ captures the fact that using the same channel at nodes X and $prev(X)$ imposes more intra-flow interference than using different channels. Combining IRU and CSC, MIC of a path p is:

$$MIC(p) = \alpha \sum_{\text{link } l \in p} IRU_l + \sum_{\text{node } i \in p} CSC_i, \quad (2)$$

where $\alpha > 0$ represents the trade-off between minimizing intra-flow and inter-flow interference.

III.B. Isotonic Decomposition of MIC

Although MIC captures interference, it is not isotonic if used directly. Therefore, we map a real network into a virtual network by introducing virtual nodes to represent the possible arrival/departure channels of packets at nodes. Then, we can decompose MIC into isotonic link weight assignments between these virtual nodes.

For example, in Figure 2, for each channel c of a real node X, two virtual nodes $X_i(c)$ and $X_e(c)$ are introduced, where $X_i(c)$ represents that packets arrive at node X from channel c and $X_e(c)$ stands for that node X transmits packets on channel c. Link $(X_i(c), X_e(c))$ represents that node X does not switch channel while forwarding a packet and hence weight w_2 is assigned to this link to capture CSC in this case. Similarly, weight w_1 is assigned to link $(X_i(c), X_e(c1))$, where $c \neq c1$. To represent IRU, if node X can transmit to node Y using channel c, link $(X_e(c), Y_i(c))$ with weight $IRU_{XY}(c)$ is added between ($X_e(c)$ and $Y_i(c)$). In addition, node X also has two additional virtual nodes: X_- and X_+. X_- is the destination virtual node for flows destined to the real node X and every $X_i(c)$ has a link with weight 0 to X_-. X_+ is the source virtual node for flows that start at the real node X and X_+ has a link with weight 0 to every $X_e(c)$.

By creating this virtual network, we essentially decompose MIC into isotonic link weight assignments on the virtual links between virtual nodes. Therefore, running Dijkstra or Bellman-Ford algorithms on this virtual network creates loop-free minimum weight paths.

III.C. Evaluation

Comparing MIC with other PWFs, our simulation results show that MIC substantially improves total network throughput and packet delay (see Figure 3).

References

[1] D. DeCouto, D. Aguayo, J. Bicket, and R. Morris. A High-Throughput Path Metric for Multi-Hop Wireless Routing. In *ACM Mobicom*, 2003.

[2] R. Draves, J. Padhye, and B. Zill. Routing in Multi-Radio, Multi-Hop Wireless Mesh Networks. In *ACM Mobicom*, 2004.

[3] J. L. Sobrinho. Algebra and algorithms for QoS path computation and hop-by-hop routing in the Inernet. In *IEEE INFOCOM*, 2001.

[4] J. L. Sobrinho. Network Routing with Path Vector Protocols: Theory and Applications. In *ACM SIGCOMM*, pages 49–60, 2003.

[5] Y. Yang, J. Wang, and R. Kravets. Interference-aware Load Balancing for Multihop Wireless Networks. Technical Report UIUCDCS-R-2005-2526, Dept. of Computer Science, Univ. of Illinois at Urbana-Champaign, 2005.