Split-n-Save: Path Multiplexing in Wireless Ad Hoc Routing

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I. Introduction

Due to the resource constraints (*e.g.*, energy, transmission range, computing power, memory) of mobile devices, on-demand routing protocols have been favored in wireless ad hoc networks such as Ad-hoc On-demand Distance Vector (AODV) [1] or Dynamic Source Routing (DSR) [2]. On-demand routing protocols do not require periodic flooding of routing messages; therefore they are energy efficient. However, dynamic nature of the routing environment (*e.g.*, power failure, mobility, channel fading, obstructions) causes frequent path failures and inevitable route discoveries.

Recent approaches adopt *multipath* routing, which keeps track of candidate paths as well as the main path during a route discovery phase. When the main path fails, multipath routing protocol selects one of the candidate paths and immediately shifts traffic onto the new path without any overhead of route re-discovery [3]. Therefore, multipath routing clearly improves the routing performance (*e.g.*, packet delivery ratio, average end-to-end delay, routing overhead) in the face of a path failure. Interestingly, multipath routing exploits the fact that a set of candidate paths can be discovered at the same or comparable cost of a typical route discovery. On-demand nature of route discovery requires flooding in the network to find one best path among all possible paths. With simple modification in the route discovery phase, multipath routing protocols can maintain a list of candidate paths without any additional flooding of routing messages. Examples of such protocols are AOMDV [4], AODVM [5], NDMR [6], MP-DSR [7], and SMR [8].

Here, we pose two questions that are quite fundamental but rather under-evaluated in wireless ad hoc routing: "Do multipath routing protocols perform well over a time period in terms of the number of active nodes in a network?" and "Are the routing and forwarding loads well-balanced throughout the network?" These questions are related to network lifetime [9], [10] and node fairness [11]. In order to quantify our questions, we introduce the following routing performance metrics: *network survivability* and *node satisfiability*. We define network survivability as the number of active nodes in a network over a period of time. Such metric can be used to measure the pattern of how networks change, evolve, or vanish over time. For each node in a network, we let node satisfiability be the ratio of the number of forwarding packets generated by itself and that by the other nodes. A typical multipath routing protocol persistently uses a single path until the main path becomes exhausted; possibly leading to unfair load distribution over the nodes and reaching suboptimal network lifetime. Motivated by this, we evaluate multipath routing based on our measures and devise a way to make improvement.

We propose `Split-n-Save` as an added feature to existing multipath routing protocol that performs *path multiplexing* as a method to satisfy the above goals. Path multiplexing is different from multipath routing in that the latter switches its path only after the main path is no longer available. Intuitively, path multiplexing distributes the forwarding overhead of communication between source and destination over the network, thus prevents concentrating the workload on a small number of nodes. This is done by multiplexing packets over a set of paths interchangeably instead of on a single path. We use a simple multiplexing policy which switches path among the multiple paths explored by the multipath routing after k number of packets are sent. Currently, Split-n-Save is implemented as a patch to AOMDV [4]. However, we do not limit our study to a specific multipath routing protocol, and we would like to further extend path multiplexing based on other multipath routing protocols as well.

We evaluate Split-n-Save through a set of simulations. As a preliminary simulation, we consider CBR (Constant Bit Rate) sources. We let the mobile nodes have various levels of mobility, number of sessions, and initial energy level. Based on our simulation, we show that the idea of path multiplexing can be implemented rather *efficiently* in wireless ad hoc routing. Moreover, we show that Split-n-Save increases network survivability and node satisfiability. We believe that path multiplexing needs to be further researched in wireless ad hoc networks and we hope that our work can be a good stepping stone for such research.

II. Methodology

In this section, we describe our path multiplexing idea and the routing performance metrics.

A. Split-n-Save

Split-n-Save is currently implemented as an added feature to AOMDV [4]. We use *ns-2* simulator [12], and our code is provided as a patch. We use parameter k to control the frequency of path multiplexing among multiple paths explored by AOMDV. When $k = p$, Split-n-Save switches paths per p packets. Likewise, $k = 1$ is per packet multiplexing, and $k = 0$ uses a single path until the current path is no longer available – which is the case for AOMDV. Since Split-n-Save is an added feature, it inherits the advantages of the underlying routing protocol. In case of AOMDV, the advantages are guarantee of multiple loop-free paths and discovery of link(node)-disjoint paths.

B. Routing Performance Metrics

In measuring routing performance, we first use three well-known metrics in wireless ad hoc networks [13], [14]: packet delivery ratio, average end-to-end delay, and routing overhead. Then, we use the following two proposed metrics to quantify our questions.

◦ Node satisfiability – the ratio of the number of forwarding packets generated by itself and that by the other nodes.

◦ Network survivability – the number of active nodes in a network over a period of time.

III. Simulations

In this section, we describe the simulation settings and give preliminary results based on our simulation.

A. Simulation Settings

Our preliminary simulation settings are based on the reference models in [13], [4]. We set out 50 nodes in 670×670 m^2 grid topology. For radio propagation model, we use Friss-space attenuation $1/r^2$ at near distance and two-ray ground model $1/r^4$ which is known to give accurate prediction at a long distance between nodes. The distributed coordination function (DCF) of IEEE 802.11 for wireless LANs is used as the MAC layer. Network interface model uses characteristics similar to a commercial radio interface, Lucents WaveLAN. WaveLAN is a shared-media radio with a nominal bit-rate of 2 Mbps and a nominal radio range of 250 meters. For mobility, we use Random Waypoint Model [13] and the speed of each node is varied between 0 and 5 m/s. The number of sessions and packet rate are fixed at 20 and 4 CBR packets/sec, respectively.

B. Preliminary Results

First, we measure packet delivery ratio, average end-to-end delay, and routing overhead of Split-n-Save, while varying the frequency of path multiplexing as $k = \{0, 1, 5, 10, 20, 40\}$. Figure 1 shows the result where the maximum value of each plot is normalized to 1.0. We can see that there exists a specific k value that performs best for each routing performance metric. Each best case of k is denoted by a star mark.

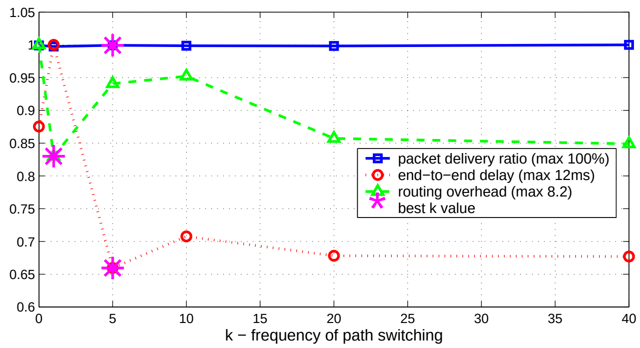

Fig. 1. Evaluation of routing performance with varying k value.

Figure 2 plots the detailed end-to-end packet delivery delay of each packet sorted by time. Interestingly, we find several surging points when $k = 0$ and 1. However, such sudden surges in delay do not appear for $k > 1$. We infer that a few nodes may be served as a critical connecting points between many connection pairs, namely, becoming hot-spots or bottlenecks. This is plausible since in multipath routing, a connection pair has a tendency to persistently use a single path until it is no longer available. Trivially, these nodes are more likely to be exhausted leading to the failures of many communication paths (possibly main paths as well as candidate paths) at the same time. This will lead to anew route discovery phase and end-to-end delay will increase suddenly. We suggest that carefully chosen k value can be used to proactively handle possible path failures and changes in path optimality.

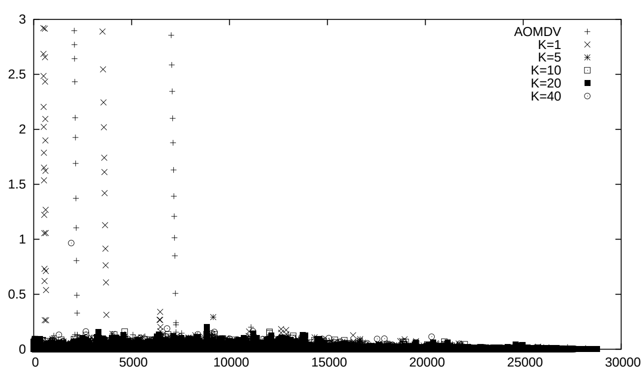

Fig. 2. Surge points in detailed view of end-to-end delay.

Figure 3 shows that the node satisfiability improves when $k > 0$. This is due to the fact that packet forwarding overhead is distributed over the network through path multiplexing. We confirm that CBR source nodes have relatively high node satisfiability values than the other nodes. Nodes with satisfiability value of 0 mean that these nodes are solely used to forward other nodes' packets but not their own.

In terms of network survivability, we are unable to find any prominent result by simply counting the number of active nodes in a network over a time period. For better analysis, we need to know the temporal as well as spacial information of each node such as topology snapshot of the network. Based on our preliminary results, we plan

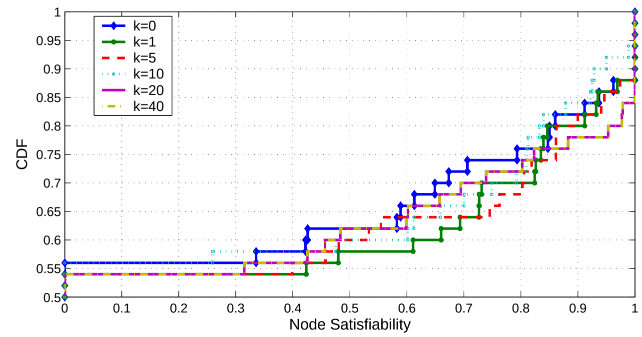

Fig. 3. Node satisfiability performs well using path multiplexing.

to set our future work to track down the location and causality of each node failure as well.

IV. Conclusion

In this poster, we propose and evaluate Split-n-Save, which exploits path multiplexing in multipath routing. Along with routing performance metrics (*i.e.*, packet delivery ratio, end-to-end delay, and routing overhead), we propose two other metrics: node satisfiability and network survivability. Our preliminary results lead us that multipath routing can be improved by path multiplexing when the frequency of multiplexing is carefully chosen. Also, we believe that such frequency can be an index to evaluate system-wide performance of the routing protocol against path fail prediction and path optimality. More precisely, we believe that the choice of path multiplexing should be closely related to the network dynamics (*e.g.*, number of nodes, connectivity, mobility, routing protocol, and physical medium).

References

[1] Charles E. Perkins and Elizabeth M. Royer, "Ad hoc On-Demand Distance Vector Routing," in *Proceedings of IEEE Workshop on Mobile Computing Systems and Applications*, February 1999.

[2] David B. Johnaon and David A. Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks," in *Mobile Computing*, 1996.

[3] Anand Srinivas and Eytan Modiano, "Minimum Energy Disjoint Path Routing in Wireless Ad-hoc Networks," in *Proceedings of ACM MOBICOM*, September 2003.

[4] Mahesh Marina and Samir Das, "On-demand Multipath Distance Vector Routing in Ad Hoc Networks," in *Proceedings of IEEE ICNP*, 2001.

[5] Yusuke Sakurai and Jiro Katto, "AODV Multipath Extension using Source Route Lists with Optimized Route Establishment," in *Proceedings of IWWAN*, 2004.

[6] Xuefei Li and Laurie Cuthbert, "On-demand Node-Disjoint Multipath Routing in Wireless Ad hoc Networks," in *Proceedings of IEEE Local Computer Networks (LCN)*, November 2004.

[7] Roy Leung, Jilei Liu, Edmond Poon, Charles Chan, and Baochun Li, "MP-DSR: A QoS-aware Multi-path Dynamic Source Routing Protocol for Wireless Ad-hoc Networks," in *Proceedings of IEEE (LCN)*, 2001.

[8] Sung-Ju Lee and Mario Gerla, "Split Multipath Routing with Maximally Disjoint Paths in Ad hoc Networks," in *Proceedings of IEEE ICC*, 2001.

[9] Jae-Hwan Chang and Leandros Tassiulas, "Maximum lifetime routing in wireless sensor networks," in *Proceedings of IEEE INFOCOM*, 2004.

[10] Hai Liu, Pengjun Wan, Chih-Wei Yi, Xiaohua Jia, Sam Makki, and Pissinou Niki, "Maximal Lifetime Scheduling in Sensor Surveillance Networks," in *Proceedings of IEEE INFOCOM*, March 2005.

[11] Thyagarajan Nandagopal, Tae-Eun Kim, Xia Gao, and Vaduvur Bharghavan, "Achieving MAC layer fairness in wireless packet networks," in *Proceedings of MOBICOM*, August 2000.

[12] Kevin Fall and Kannan Varadhan, "The VINT Project," November 1997.

[13] Josh Broch, David A. Maltz, David B. Johnson, Yih-Chun Hu, and Jorjeta Jetcheva, "A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols," in *Proceedings of IEEE Mobicom*, October 1998.

[14] Samir Das, Robert Castaneda, and Jiangtao Yan, "Comparative Performance Evaluation of Routing Protocols for Mobile, Ad hoc," in *Computer Communications and Networks (IC3N)*, October 1998.