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Adaptive multi-flow opportunistic routing using learning automata

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ABSTRACT

Opportunistic routing is a promising routing paradigm that achieves high throughput by utilizing the broadcast nature of wireless media. It is especially useful for wireless mesh networks due to their static topology. In the current opportunistic routing protocols, it is assumed that all nodes have enough incentive and resource to help the source regardless of their load and presence of other network flows. In addition, the effect of each active flow on other flows and network status is reflected latter by means of a link quality metric (e.g. ETX) which is updated periodically. The coarse-grained behavior of the metric is not in harmony with network flows dynamics. Therefore, some flows may undergo performance degradation between two consecutive periodic updates of the metric. Our proposed approach which is called Dynamic Cooperative Routing (DCR) modifies MORE and equips it with an adaptive decision making mechanism. We use learning automata to accommodate network dynamics when building an opportunistic path for a flow. The learning automata are activated whenever the source transmits a new data batch for the flow. We have shown through simulation that DCR outperforms MORE when two or more flows are active simultaneously and in the presence of background unicast traffic.

1. Introduction

Wireless mesh networks (WMN) is an efficient technology for supporting high quality services, such as multimedia and real-time applications in wireless networks. WMN has an inherent property, namely static topology, making it an excellent subject for applying various network optimization techniques such as opportunistic routing (OR) and network coding. OR is designed to take benefit from broadcast advantage of wireless media. Interestingly, it was deprecated as an annoying phenomenon in the past. OR will increase the overall throughput of unicast and multicast flows by employing wireless nodes that opportunistically overhear an ongoing transmission between two wireless nodes. In fact, it extends the classic notion of next-hop to almost all nodes that overhear the packet and hence spreads the traffic geographically in a wider area employing exposed nodes. Then, nodes that exposed to the traffic cooperatively forward the received data packets toward intended destination.

The notion of OR is first introduced by EXOR [1]. EXOR uses ETX [2] metric to predict reception probabilities of wireless links. It then uses this prediction to choose some intermediate nodes between source and destination as forwarding nodes. Clearly, the quality of selected forwarding

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set affects EXOR performance directly. Currently, the selection algorithm employed by many opportunistic proposals takes into account the quality of network links just before the transmission of first data packet. Then, it updates links qualities based on periodic updates of ETX metric by a central node. It is quite possible that several new flows emerge or some old flows vanish between two consecutive periodic updates of ETX metric. These events affect the quality of selected forwarder set and their eligibility to help sender. Therefore, current proposals for OR do not react to dynamic patterns of network flows properly.

Consequent works on OR examined many different aspects of this interesting routing paradigm [3]. Some work, such as MTS [4] tried to enhance the quality of selected forwarding set by proposing new metrics for link quality. Some other work extended the OR concept to different types of wireless networks [5] or combined it with emerging network technique such as network coding [6–9]. Among them, MORE [6] is regarded as a promising technique which efficiently addresses the main shortcoming of EXOR, i.e. strong coordination between forwarding nodes, by utilizing random network coding. It also efficiently reduces the number of duplicated packets. Subsequent work on OR combination with network coding focused on reducing the number of unnecessary coded packets (CCACK [7]) or optimizing the end to end delay associated with MORE acknowledgment mechanism (CodePipe [8], PipelineOR [9]). However, these work also did not considered dynamic interaction of multiple flows on the performance of selected forwarders.

In OR, there is a fundamental yet erroneous assumption that all network nodes should help current flow. In fact, some nodes may be at an appropriate geographical position making them excellent candidates for helping the flow, but they may be overwhelmed with other flows or even their internal traffics as well. We want to design a cooperative mechanism taking into account a node's willingness and motivation to help other nodes using reinforcement learning. For a motivational example, suppose that there are two opposite flows in the network as depicted in Fig. 1, namely A-B and D-C. There are some common forwarding nodes between these flows shown as bold nodes in Fig. 1a. These nodes must help both flow and therefore quickly become a critical bottleneck for the performance of both flows. If we segregate the flows as shown in Fig. 1b, the bottleneck nodes are avoided yielding in higher overall performance for both flows. In the later case, each flow intentionally uses a longer path to leverage extra forwarding capacities at the edges of the network.

Learning automata (LA) [10] is especially useful when undergoing system has incomplete knowledge about the environment in which it operates. Wireless network is a time-varying system with several dynamic characteristics which are unknown and unpredictable in many respects. Applications of LA in dynamic wireless networks are surveyed and studied in [11]. LA is suitable to random environment such as wireless networks where it can learn the optimal action from system feedback through a continuous interaction with the environment. Automaton is an adaptive decision making mechanism which optimizes its action using a predefined probability distribution function to maximize its reward from system and minimize incurred penalties. The environment responds to each action performed by automaton. Then, the probabilities used for decisions making are updated based on environment response to LA actions. Hence, the environment responses are used as a base for selecting next action. By repeating the above process, LA tries to maximize its reward and converge to an optimal point for system operation.

In this paper we have applied LA to a network coding based opportunistic protocol, namely MORE, to handle multiple dynamic flows in presence of background traffic efficiently. In our proposal named Dynamic Cooperative Routing (DCR), the source determines the identity of next forwarders for next three hops. One of the nodes residing in the third hop is selected as designated LA. It selects the forwarders for next three hops the very same as source. This process is repeated every three hops till reaching the destination. An LA is active in three-hop distances and dynamically responds to dynamic change of the traffic. LA is executed to refine the process for selecting forwarding nodes to choose better forwarders. To the best of our knowledge, DCR is the first application of LA in the field

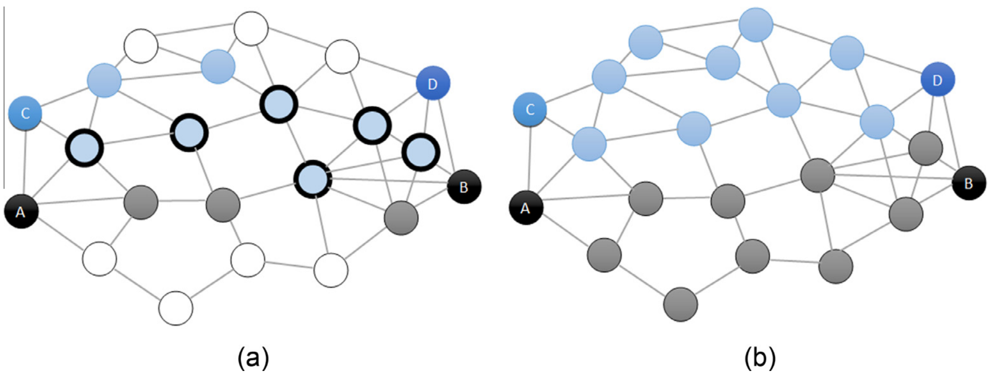

Fig. 1. (a) There are several common forwarding nodes between A–B and C–D flows. The bold nodes should help both flows. This extra burden harms the performance seen by both flows. (b) We could improve the performance by using two disjoint forwarding sets. Although both flows use longer opportunistic path than usual, the overall performance is improved due to traffic segregation.