

A Machine Learning Based Forwarding Algorithm over Cognitive Radios in Wireless Mesh Networks

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Abstract. Wireless Mesh Networks improve their capacities by equipping mesh nodes with multi-radios tuned to non-overlapping channels. Hence the data forwarding between two nodes has multiple selections of links and the bandwidth between the pair of nodes varies dynamically. Under this condition, a mesh node adopts machine learning mechanisms to choose the possible best next hop which has maximum bandwidth when it intends to forward data. In this paper, we present a machine learning based forwarding algorithm to let a forwarding node dynamically select the next hop with highest potential bandwidth capacity to resume communication based on learning algorithm. Key to this strategy is that a node only maintains three past status, and then it is able to learn and predict the potential bandwidth capacities of its links. Then, the node selects the next hop with potential maximal link bandwidth. Moreover, a geometrical based algorithm is developed to let the source node figure out the forwarding region in order to avoid flooding. Simulations demonstrate that our approach significantly speeds up the transmission and outperforms other peer algorithms.

Keywords: Mesh networks · Machine learning · Forwarding · Highest bandwidth capacity

1 Introduction

Mesh routers and client devices are self-organized and self-configured to form wireless mesh networks (WMNs) [1]. A device is called a node in WMNs. Each node is equipped with multiple radios to improve the whole capacities in WMNs [5]. The radios in WMNs are cognitive radios, by which the radio devices are capable of learning from their environment and adapting to the environment [2]. Cognitive radio is also called programmable radio because such radio has the ability of self-programming [3], learning and reasoning [2].

Machine learning has been studied for about 60 years. It evolved from simple artificial intelligence to a wide variety of applications in image processing,

vision, networking, and pattern recognition. In this paper, we propose a learning algorithm for a forwarding node to find one of its links with possibly maximal bandwidth, and then choose next forwarding node and then forward the message to that node. Each node only saves the last three changed bandwidth status of its links. Then the forwarding node learns the three status and predict the potential bandwidth of its links. So the forwarding node is able to find the neighbor with highest link bandwidth as its next hop. We further devise an algorithm to let the source node figure out the forwarding region in order to avoid flooding.

The rest of the paper is organized as follows. Section 2 discusses the related research on this topic. Section 3 proposes our novel forwarding method that selects the best next hop. We evaluate the proposed schemes via simulations and describe the performance results in Sect. 4. Section 5 concludes the paper.

2 Related Work

Some approaches on machine learning, wireless forwarding and related work have been studied [6–11]. Wang et al. [12] proposed a machine learning mechanism to improve data transmission in sensor network. The predication of link quality was used to implement the approach. Additionally, they developed a protocol called MetricMap to maintain efficient routing in case the regular routing is not working.

Sawhney et al. [13] presented a machine learning algorithm to handle congestion controlling in wireless networks. Their approach learns many factors that have impact to congestion controlling, and then uses the parameters in a fuzzy logic to generate better result when congestion takes place. The efficiency is assessed with machine learning tools.

3 The Learning Based Forwarding Mechanism

3.1 The Forwarding Problem

In wireless mesh networks (WMNs), the communications are over links. Link bandwidth is critical for transmission speed. Since each node may be equipped with multiple network interfaces with different radios and the radios are switchable, the bandwidth over two neighbor nodes may vary from time to time. The radios in WMNs are cognitive radios and then the nodes are able to learn the changes of past bandwidths and can further predict and select the desired link with potential highest bandwidth.

Assuming a source node s intends to send data to a destination node d , many traditional routing algorithms set up the forwarding path by simply selecting the shortest route. For example, $s - c - g - h - d$ is the forwarding path in Fig. 1. However, it may not be the best path in WMNs. In WMNs, the bandwidth over two nodes changes frequently. The bandwidth of the link sc is possibly much lower than that of sa . Or the past bandwidth of sc is higher than sa but two

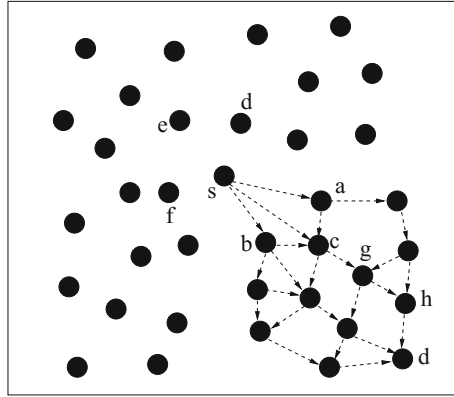


Fig. 1. Topology of a wireless mesh network

much traffic is over *sc* now so the available bandwidth of *sc* is going down while that of *sa* is going up.

Our goal is to let each forwarding node select the link for next hop with the highest potential bandwidth. In our approach, each node learns its links' past bandwidths and then predict their potential bandwidths. Then the forwarding node figures out its next hop with highest potential bandwidth.

3.2 Prediction for Future Bandwidth

Suppose node *i* saves the bandwidth changes of its links of the last three times t_0 , t_1 , and t_2 . Then for any of its neighbor *j*, *i* predicts the potential bandwidth of link *ij*. By computational method [14], we define

$$\alpha_{i,j,k} = \sum_{m=0}^k \frac{B_{i,j,m}}{\prod_{n=0}^k (t_m - t_n)} \tag{1}$$

at time t_k , where $B_{i,j,m}$ is the bandwidth between node *i* and node *j* at time m . Then the bandwidth of link *ij* at future time p can be calculated and predicated as:

$$B_{i,j,p} = \alpha_{i,j,0} + \alpha_{i,j,1}(t_p - t_0) + \alpha_{i,j,2}(t_p - t_1)(t_p - t_0) \tag{2}$$

Algorithm 1 describes node *i* learns the bandwidth of link *ij* in the last three changes and then it predicts the bandwidth of next time p .

3.3 Forwarding Region

When a node *s* intends to send data to node *d*, it selects the neighbor node with highest potential link bandwidth as its next hop and then same metric continues to select the best next forwarding node. Apparently, *s* will not select any nodes

Algorithm 1. *Prediction for future bandwidth of link ij*

- 1: Learn and keep the bandwidth changes of link ij at the last three times 0,1, and 2.
 - 2: Calculate $\alpha_{i,j,k}$ with equation (1)
 - 3: Calculate the predicted bandwidth of link ij of time p with equation (2)
-

in the opposite direction from s to d . How is node s aware of the region where the next hop falls? In current WMNs, each device is equipped with GPS and hence it knows its location. We assume that the sender knows its own location and the location of the receiver. The assumption is very common in geographic routing [6]. Figure 2 shows the scenario. Suppose node s intends to send data to node d , it figures out the forwarding region as Algorithm 2.

Algorithm 2. *Figure out the region for next hop*

- 1: s connects d .
 - 2: sd rotates 45 degrees anti-clockwise, the ray is the positive half of X axis.
 - 3: sd rotates 45 degrees clockwise, the ray is the negative half of Y axis.
 - 4: Oppositely extends the ray of X axis to generate the negative half of X axis.
 - 5: Oppositely extends the ray of Y axis to generate the positive half of Y axis.
 - 6: The plane is divided up to four quadrants. The 4th quadrant is where the forwarding will be conducted.
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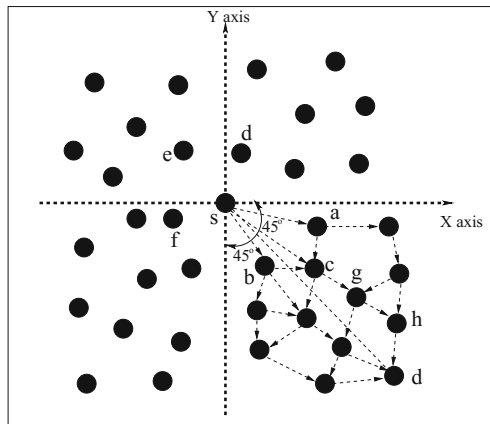


Fig. 2. Forwarding region

3.4 Forwarding Algorithm

Suppose each node in a Wireless Mesh Network regularly maintains the last three changes of bandwidths of all its links that connect its neighbors. When node s intends to send data to node d , s first uses Algorithm 2 to figure out the region

where the forwarding will be performed. Then s calls Algorithm 1 to find the node with potential highest bandwidth among all its neighbors as next hope. When the selected node relays the forwarding, it only considers its neighbors in the forwarding region as forwarding candidates, and it calls Algorithm 1 to forward the data to next hop with potential highest bandwidth. The forwarding resumes until the packets arrive destination node d .

Algorithm 3. *Forwarding algorithm*

- 1: s calls algorithm 2 to figure out the forwarding region.
 - 2: s calls algorithm 1 to find the node n with potential highest bandwidth of link sn as next hope, where n is in the forwarding region.
 - 3: if n is d , end the algorithm. Otherwise $s=n$, go to step 2.
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4 Evaluation

We evaluated our mechanism in a simulated noiseless radio network environment by MATLAB. We create a topology that consists of a number of randomly distributed nodes. We compare our approach (ML Forwarding) with two other algorithms. One is congestion control and fuzzy logic with machine learning for wireless communications, say Fuzzy Logic. The other one is supervised learning approach for routing optimization in wireless networks, say Supervised Learning. The compared metrics are transmission delay (Milliseconds) and transmission speed (MBs/Millisecond). We performed a sequence of experiments in which the number of nodes varies from 100 to 300 in increments of 25 over an area of 100×100 m in the reference network. For each number of mobile users, we conduct our experiments 10 times and present the average value.

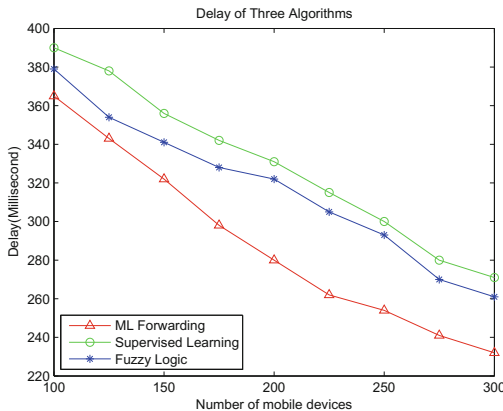


Fig. 3. Transmission delay of the three algorithms

Figure 3 shows that our approach results in the least delay. It is because our approach selects the link with potential maximum bandwidth of each hop. Figure 4 shows that with the same reason, our approach generates the maximal transmission speed among the three approaches.

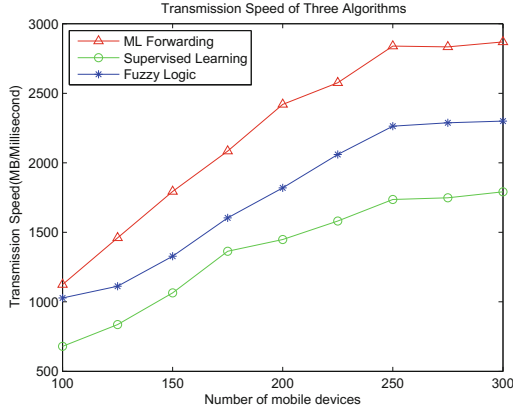


Fig. 4. Transmission speed of the three algorithms

5 Conclusion

A machine learning based forwarding algorithm in wireless mesh networks with cognitive radios is presented in this paper. In this algorithm, each mobile device keeps the last three times of bandwidth changes of its links that connect its neighbors. Then when a node intends to forward data, the node learns the historical changes of bandwidth and then predicts the possible future bandwidths of the links with neighbor nodes. Hence the forwarding node is able to select the next hop with highest bandwidth. We also designed a geometrical algorithm to let the source node figure out the forwarding region in order to avoid unnecessary flooding. Simulation results demonstrate that our approach outperforms peer approaches.

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