

# Forwarding with Prediction over Machine Learning based Nodes in Wireless Mesh Networks

<sup>1</sup>Jianjun Yang, <sup>2</sup>Ju Shen, <sup>3</sup>Mengyi Ying

<sup>1</sup>University of North Georgia, Gainesville, GA, USA

<sup>2</sup>University of Dayton, Dayton, OH, USA

<sup>3</sup>University of North Georgia, Dahlonega, GA, USA

[jianjun.yang@ung.edu](mailto:jianjun.yang@ung.edu); [jshen1@udayton.edu](mailto:jshen1@udayton.edu); [mengyi.ying@ung.edu](mailto:mengyi.ying@ung.edu)

## ABSTRACT

As part of the next generation Internet, Wireless Mesh Networks have emerged as a key technology to deliver Internet broadband access, wireless local area network coverage and network connectivity at low costs. The capacity of a wireless mesh network is improved 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. The new technology makes mesh nodes cognitive, thus a mesh node is able to adopt 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 new forwarding algorithm by which a forwarding node dynamically select its next hop with highest potential bandwidth capacity to resume communication based on learning algorithm. The efficiency of this approach 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. Additionally, a geometrical based algorithm is developed to let the forwarding node figure out the best forwarding region in order to avoid flooding. Simulations demonstrate that our approach significantly outperforms peer algorithms.

**Keywords:** mesh networks, machine learning, forwarding, highest bandwidth capacity, geometrical routing.

## 1 Introduction

Wireless mesh networks(WMNs) have emerged as one of the key technologies for wireless communications. They are undergoing rapid development and have inspired numerous applications because of their advantages over other wireless technologies. The networks, such as WiFi, 802.15, 802.16 and sensor networks, can be integrated into the WMN through gateways and mesh routers. Mesh clients, either stationary or mobile, can form client mesh networks among themselves and with mesh routers. WMNs are anticipated to significantly improve the performance of ad hoc networks, wireless local area networks (WLANs), wireless personal area networks (WPANs), and wireless metropolitan area networks (WMANs).

In wireless networks, devices (nodes) remain connected to the network through wireless links. The critical issue is to provide high bandwidths for nodes to communicate with each other. A wireless mesh network (WMN) is a communication network made up of nodes organized in a mesh topology[1]. WMNs are capable to connect diverse network nodes such as desktops, laptops, iPads, and smart phones. 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 many 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 Section 4. Section 5 concludes the paper.

## 2 The Existing Ranking Methods

Scholars have conducted research on machine learning, wireless forwarding and related work[6][7][8][9][10][11]. Wang Y. et al. [12] proposed a machine learning based mechanism that was used to supervise given input and output. The input includes the factors of memory utilization, channel loading evaluation, and signal strength. The output includes the transmissions on the channels where the packet is received. The authors created a machine learning based algorithm to automatically find out the relationship between input and output, making a new routing protocol with high efficiency. Further, they implemented their mechanism as MetricMap, which adopted knowledge acquired from a training phase.

Sawhney A. 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 Mechanism of Learning Based Forwarding with Prediction

### 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.

Fig. 1 shows an example of WMN, the dotted lines illustrate that there could be multiple possible channels to be assigned to a node, thus a node may have multiple choices for next step with different bandwidth in forwarding process.

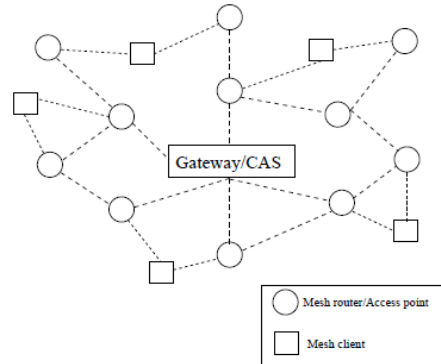


Figure 1. An example of Wireless Mesh Network

As shown in Fig. 2, 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. 2. 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 too much traffic is over  $sc$  now so the available bandwidth of  $sc$  is going down while that of  $sa$  is going up.

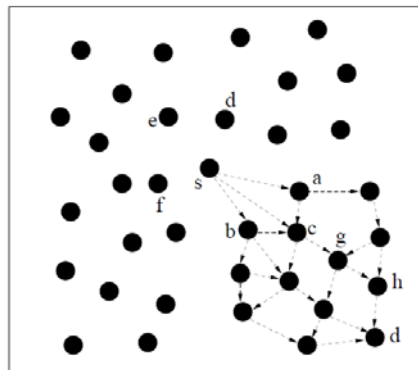


Figure 2. Topology of Wireless Mesh Networks

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

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

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:

$$B_{i,j,p} = \alpha_{i,j,0} + \alpha_{i,j,1}(t_p - t_0) + \alpha_{i,j,2}(t_p - t_1)(t_p - t_2) \quad (2)$$

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  $p$ .

#### Algorithm 1: Prediction for future bandwidth of link $ij$

Step 1: Learn and keep the bandwidth changes of link  $ij$  at the last three times 0,1, and 2.

Step 2: Calculate  $\alpha_{i,j,k}$  with equation (1)

Step 3: Calculate the predicted bandwidth of link  $ij$  of time  $p$  with equation (2)

### 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 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]. Fig. 3 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

Step 1:  $s$  connects  $d$ .

Step 2:  $sd$  makes  $45^\circ$  anticlockwise rotation, the ray is  $l'$ .

Step 3:  $sd$  makes  $45^\circ$  degrees clockwise rotation, the ray is  $l''$ .

Step 4: The intersection region with  $l'$  and  $l''$  will be the forwarding area.

Suppose the coordinates of nodes  $s$  and  $d$  are  $s(x_s, y_s)$  and  $d(x_d, y_d)$ , respectively. Then line  $sd$ , say  $l$  can be described as the following equation.

$$\frac{y - y_s}{y_d - y_s} = \frac{x - x_s}{x_d - x_s}$$

It can be written as:

$$(y_d - y_s)x - (x_d - x_s)y + (x_d y_s - x_s y_d) = 0 \quad (3)$$

When (3) makes  $45^\circ$  anticlockwise rotation, the line, say  $l'$  is represented as the equation:

$$\begin{aligned} (x_d + y_d - x_s - y_s)x - (x_d - y_d - x_s + y_s)y + \frac{\sqrt{2}}{2}(x_d - y_d)(x_s + y_s) \\ - \frac{\sqrt{2}}{2}(x_s - y_s)(x_d + y_d) = 0 \end{aligned} \quad (4)$$

When (3) makes  $45^\circ$  clockwise rotation, the line, say  $l''$  is represented as the equation:

$$(x_d - y_d - x_s + y_s)x - (x_d + y_d - x_s - y_s)y + \frac{\sqrt{2}}{2}(x_d + y_d)(x_s - y_s) - \frac{\sqrt{2}}{2}(x_s + y_s)(x_d - y_d) = 0 \quad (5)$$

Hence the forwarding region of the intersection area with  $l'$  and  $l''$  can be simply figured out by (4) and (5). However, if no such a node qualified for next step in the forwarding area, the forwarding will be changed to traditional GPRS[15].

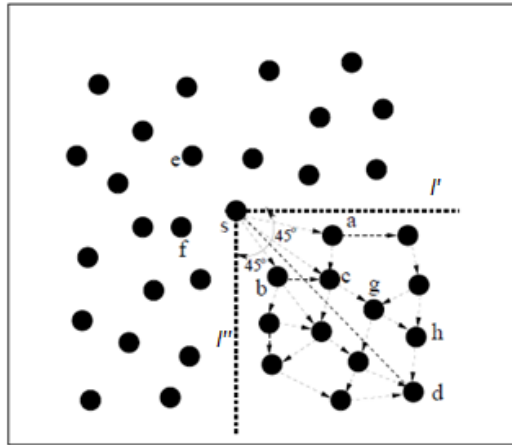


Figure 3. Forwarding Region

### 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

Step 1:  $s$  calls algorithm 2 to figure out the forwarding region.

Step 2. if no node exists in such region, change to traditional GPRS and go to step 4; otherwise go to step 3.

Step 3:  $s$  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.

Step 4: if  $n$  is  $d$ , end the algorithm; otherwise  $s = n$ , go to step 2.

## 4 Experiments and Analysis

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 100x100 meters in the reference network. For each number of mobile users, we conduct our experiments 10 times and present the average value.

Fig. 4 shows that our approach results in the least delay. It is because our approach selects the link with potential maximum bandwidth of each hop. Fig. 5 shows that with the same reason, our approach generates the maximal transmission speed among the three approaches.

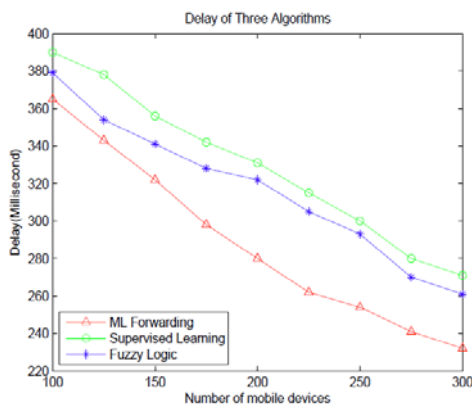


Figure 4. Transmission Delay of the Three Algorithms

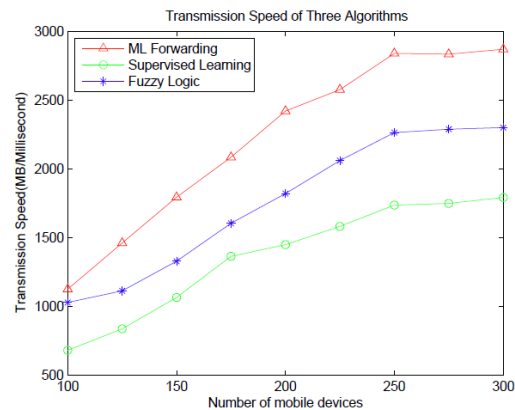


Figure 5. Transmission Speed of the Three Algorithms

## 5 Conclusion

We present a machine learning based forwarding algorithm with cognitive radios in wireless mesh networks in this paper. In this algorithm, each mobile device keeps the last three 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.

## REFERENCES

- [1] Akyildiz I.F., et al., *A Survey on Wireless Mesh Networks*, IEEE Communications Magazine, 2005.

- [2] Mitola, J, *Cognitive radio: An integrated agent architecture for software defined radio*, Ph.D. dissertation, Royal Institute of Technology (KTH), Stockholm, Sweden, 2000.
- [3] Costlow, T, *Cognitive radios will adapt to users*, IEEE Intelligent Systems, vol. 18, no. 3, p. 7, May-June, 2003.
- [4] Ayodele, T. O, *Introduction to machine learning*, New Advances in Machine Learning. InTech, 2010.
- [5] Yang, J., et al., *Fair Gain Based Dynamic Channel Allocation for Cognitive Radios in Wireless Mesh Networks*, Journal of Computers, 2014.
- [6] Yang, J., et al., *HDAR: Hole detection and adaptive geographic routing for ad hoc networks*, Computer Communications and Networks (ICCCN), 2010 Proceedings of 19th International Conference, pp. 1-6. IEEE, 2010.
- [7] Yang, J., et al., *Broadcasting with prediction and selective forwarding in vehicular networks*. International journal of distributed sensor networks, 2013.
- [8] Yang, J., et al., *Bipartite graph based dynamic spectrum allocation for wireless mesh networks*. In Distributed Computing Systems Workshops, 2008. ICDCS08. 28th International Conference, pp. 96-101. IEEE, 2008.
- [9] Shen, J., et al., *Layer depth denoising and completion for structured-light rgb-d cameras*. In Computer Vision and Pattern Recognition (CVPR), 2013 IEEE Conference on, pp. 1187-1194. IEEE, 2013.
- [10] Jianjun Yang, et al., *A Machine Learning Based Forwarding Algorithm Over Cognitive Radios in Wireless Mesh Networks*, EAI International Conference on Machine Learning and Intelligent Communications, Shanghai, 2016.
- [11] Shen, J., et al., *Image-based indoor place-finder using image to plane matching*, 2013 IEEE International Conference on Multimedia and Expo, 2013.
- [12] Wang, Y., et al., *A supervised learning approach for routing optimizations in wireless sensor networks*. Proceedings of the 2nd international workshop on Multi-hop ad hoc networks: from theory to reality, pp. 79-86, 2006.
- [13] Sawhney, A., et al., *Congestion Control in Wireless Communication Network Using Fuzzy Logic and Machine Learning Techniques*, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 3, Issue 11, October, 2014.
- [14] Kincaid, D., et al., *Numerical Analysis: Mathematics*
- [15] B. Karp, et al., *GPSR: Greedy perimeter stateless routing for wireless networks*, ACM/IEEE International Conference on Mobile Computing and Networking, 2000.