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A Novel MAC Protocol for Improving the Throughput in Multi-Hop Wireless Networks

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Abstract—**WLANs have become increasingly popular and widely deployed. The MAC protocol is one of the important technology of the WLANs and affects communication efficiency directly. In this paper, focusing on MAC protocol, we propose a novel protocol that network nodes dynamically optimize their backoff process to achieve high throughput in multi-hop wireless networks. Distributed model MAC protocol has an advantage that no infrastructure such as access point is necessary. On the other hand, total throughput decreases heavily under a high traffic load due to the hidden node problem, which needs to be improved. Through theoretical analysis, we find that the average idle interval per a node can represent current network traffic load and can be used together with estimated number of neighbor nodes for setting optimal CW. Through simulation comparison with a conventional method and recently a proposed method, we show that our scheme can greatly enhance the throughput in saturated case.**

Index Terms—**WLANs, multi-hop, MAC, backoff, throughput**

I. Introduction

WIRELESS Wireless local area networks (WLANs) have become increasingly popular and widely deployed. In two channel access methods DCF (Distributed Coordination Function) and an optional centralized PCF (Point Coordination Function), due to inherent simplicity and flexibility, the DCF is preferred in the case of no base station such as vehicle to vehicle communications. Since all the nodes share a common wireless channel with limited bandwidth in the WLANs, it is highly desirable that an efficient and fair medium access control (MAC) scheme is employed. In multi-hop wireless networks, the transmission range of a node is not large enough to transmit to every nodes in the entire network area. In that case, the transmission between two nodes may require more than one hop. Thus, the throughput decreases rapidly due to the hidden node problem. Several researches have been proposed in [1], [2], [3], [4], [5], [6], [7] for alleviating the hidden node problem. In [1], [2], [3], [4], the multi-channel MAC protocol was proposed. In [1], the authors proposed a MAC protocol, which employs two radio interfaces per node. One interface follows fast hopping and is mainly for transmission, while the other interface follows slow hopping and is generally for reception. The works in [3], [4] adopt the busy tone to deliver the data packets successfully. The other nodes that hear the busy tone should suspend their attempts for data transmissions. In [6], the authors proposed the multiple receiver transmission (MRT), the fast NAV (Network Allocation Vector) truncation (FNT) and the adaptive receiver transmission (ART) shceme. For alleviating the receiver blocking problem, each node transmits to multiple receivers in MRT scheme and the NAV duration in RTS packet reduces in FNT protocol. Considering the drawbacks from the MRT and FNT schemes, the ART scheme further improves the throughput.

The above most works are used in limited network and not flexible enough. For example, the works in [3], [4] assume that each network node needs to use at least two transceivers, which is merely utilized in wireless networks. The MRT and ART schemes in [6] assume that each node has multiple destination nodes. Also, most works do not take the backoff process into account to improve the throughput. In multi-hop wireless networks, the collisions are caused by the neighbor nodes or the hidden nodes, which is more than single hop wireless networks. Thus, for improving the throughput, the optimal backoff process is required to avoid the collisions. In [8], authors proposed a novel MAC protocol by observing the channel to estimate the number of nodes and tuning the network to obtain high throughput with good fairness according to the number of nodes. This is proved to be effective but assumes that the network is in single-hop wireless networks. In this paper, for expanding the work [8] in multi-hop wireless networks, we propose a novel MAC protocol that dynamically optimizes each node's backoff process for multi-hop wireless networks. We call it OBM. The models on throughput analysis have been investigated in [9], [10], [11], [12] for multi-hop wireless networks. These models is refered in the performance analysis of proposed OBM.

The remainder of this paper is organized as follows. In Section II, we elaborate on our key idea and the theoretical analysis for improvement. Then, we present in detail our proposed OBM scheme. Section III gives performance evaluation and the discussions on the simulation results. Finally, concluding remarks are given in Section IV

II. Analysis and the Proposal of Optimizing Backoff by Dynamically Estimating Number of Neighbor Nodes

In the IEEE 802.11 MAC, an appropriate CW (Contention Window) is the key to providing throughput. In multi-hop wireless networks, the collisions are caused by the neighbor nodes or the hidden nodes, which is more than single hop. Thus, network nodes need to obtain the optimal CW in order to avoid the collisions. In OBM, By observing the channel, all nodes adjust the optimal CW and we can obtain high throughput.

In this analysis, we have the following assumptions:

- For simplicity, the transmission, interference and sensing ranges for all network nodes are the same value.

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- Each node uses the RTS/CTS exchange and contends for the medium with the same probability p, where p denotes the transmission probability at a randomly chosen chosen time slot.
- All nodes always have packets to transmit.

A. Optimal Backoff

The analytical model is derived based on the standpoint of a tagged node. In a given time slot, there are three states in a tagged node, that is, the idle state, the successful transmission state, and the collision state. In the idle state, the tagged node counts down its backoff timer during the channel is idle. Otherwise, its backoff timer is freezed due to either the physical or virtual carrier sensing mechanisms because the neighbor node of the tagged node transmits a packet. In the successful transmisison state, after the backoff timer has reached zero, the tagged node transmits RTS and DATA packets successfully. In the collision state, the tagged node fails to transmit the RTS packet due to collision caused by either the neighbor nodes or the hidden nodes of the tagged node. By calculating the probabilities of these states, the throughput of the tagged node can be obtained. In the following, we give the probabilities that the tagged node is in the idle state, the successful transmission state and the collision state, respectively.

The tagged node in the idle state means that the tagged node does not transmit RTS or DATA packets, the probability that the tagged node is in the idle state is denoted by P_{idl}, it can be expressed as

$$P_{idl} = 1 - p. \tag{1}$$

There are three cases if the tagged node is in the idle state as follows: Case 1: All nodes within the carrier sensing range of the tagged node do not transmit any packets; Case 2: Only one node within the carrier sensing range of the tagged node transmits packets; Case 3: Two or more nodes within the carrier sensing range of the tagged node transmit packets. We denote by P_{idl_1}, P_{idl_2}, and P_{idl_3} the probabilities of the three cases, respectively. Thus, we can express the above probabilities as

$$\begin{aligned} P_{idl\_1} &= (1-p)^n \\ P_{idl\_2} &= (1-p)(n-1)p(1-p)^{n-2} \\ P_{idl\_3} &= P_{idl} - P_{idl\_1} - P_{idl\_2} \end{aligned} \tag{2}$$

where n is the average number of neighbor nodes including the tagged node, that is, the average number of nodes within the tagged node's carrier sensing range. The tagged node in Case 1 remains for the duration of a slot time t_{slt}. We denote by T_{idl_2} and T_{idl_3} the time duration of Case 2 and Case 3, respectively. These time durations can be expressed as

$$\begin{aligned} T_{idl\_2} &= T_{RTS} + T_{CTS} + T_{DATA} + T_{ACK} \\ &\quad +4\tau + 3SIFS + DIFS \\ T_{idl\_3} &= T_{RTS} + \tau + EIFS \end{aligned} \tag{3}$$

where T_{RTS}, T_{CTS}, T_{DATA} and T_{ACK} are the transmission duration for a RTS packet, a CTS packet, a DATA packet and a ACK packet, respectively. τ is the maximum propagation delay between two nodes.

For simplicity, we assume that the transmission is successful when a RTS packet is transmitted successfully. In fact, a DATA packet may be collided due to transmissions of the hidden nodes. This case is caused due to large interference range as shown in [13]. In this analysis, for simplicity, we assume that DATA packet is not collided. Therefore, the transmission of the tagged node is successful when the neighbor nodes of the tagged node do not transmit packets in the same time slot and the hidden nodes of that do not transmit during the vulnerable period η_{RTS}, which can be calculated as $\eta_{RTS} = \lceil (T_{RTS} + T_{SIFS})/T_{slot} \rceil$. We denote by P_s the probability that the tagged node is in the successful transmission state, which can be expressed as

$$P_s = p(1-p)^{n-1}(1-p)^{2\eta_{RTS}H(r)} \tag{4}$$

where r is the distance between the transmitter and the receiver. $H(r)$ is the number of hidden nodes of the tagged node and depends on r. We denote by T_{tx} the time duration for successful transmission, which equals T_{idl_2}.

Moreover, we denote by P_{col} the probability that the tagged node is in the collision state. The tagged node is in the collision state in the case that the tagged node transmits a RTS packet and a collision is caused by neighbor nodes or hidden nodes. The probability that the tagged node is in the collision state is expressed as

$$\begin{aligned} P_{col} &= p\{1-(1-p)^{n-1}\} \\ &\quad +p(1-p)^{n-1}\{1-(1-p)^{2\eta_{RTS}H(r)}\} \\ &= p - p(1-p)^{n-1}(1-p)^{2\eta_{RTS}H(r)} \end{aligned} \tag{5}$$

We denote by T_{col} the time duration for collision, which equals T_{idl_3}.

Consequently, using the above probabilities of three states, the throughput per a node is expressed as

$$\begin{aligned} \rho &= \{LP_s\}/\{t_{slt}P_{idl\_1} + T_{idl\_2}P_{idl\_2} \\ &\quad +T_{idl\_3}P_{idl\_3} + T_{tx}P_s + T_{col}P_{col}\} \end{aligned} \tag{6}$$

where L is the total number of bits in the payload. Our aim is to maximize the throughput shown in Eq.(6). To this end, we need to obtain the optimal CW according to the network condition such as the number of neighbor nodes. In the following, we give the method for estimating the number of neighbor nodes on line by three parameters P_{idl_1}, P_{idl_2} and P_{idl_3} which can be obtained directly by listening to the channel for a certain interval. Then, using obtained P_{idl_1}, P_{idl_2} and P_{idl_3}, we give the method for maximizing the throughput dynamically. Calculating the number of neighbor nodes directly by Eq.(2) is inefficient and unrealistic. Here, we use a simple and effective method which is suitable for real time estimating. With Eqs.(1) and (2), we obtain

$$P_{idl\_1} = P_{idl}^n. \tag{7}$$

Let $f_{idl}(n) = P_{idl}^n$, where P_{idl}, i.e., P_{idl_1}, P_{idl_2} and P_{idl_3} are known parameters and n is the unknown parameter that needs to be estimated. We find that $f_{idl}(n)$ is the monotone function. We take the derivative of $f_{idl}(n)$ with respect to n, and let $\frac{df}{dn} = \{log(1-p)\}(1-p)^n$. It can be found that $\frac{df}{dn}$ is not plus when p changes from 0 to 1.

We can estimate the number of neighbor nodes by simple calculation method, without solving a complicated equation. As shown in Fig. 1, the monotone function $f_{idl}(n)$ always

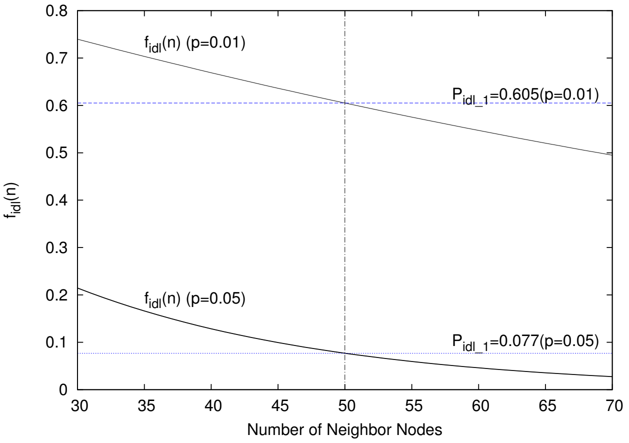

Fig. 1. Monotone function $f_{idl}(n)$ when the real value of n is 50

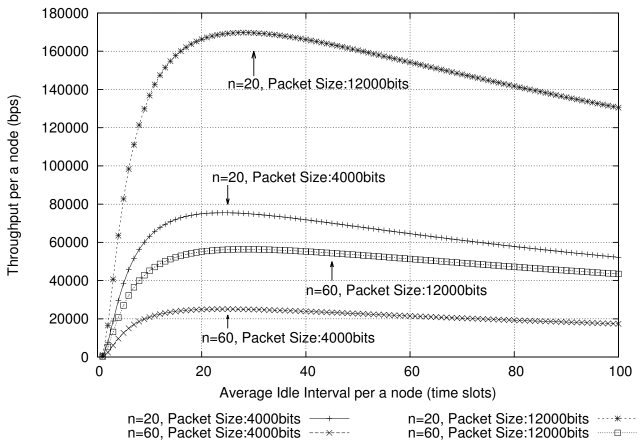

Fig. 2. Throughput with average idle slot interval per a node

decreases as the number of neighbor nodes is increasing. Since P_{idl_1} is a known value, $f_{idl}(n)$ should be adjusted in agreement with P_{idl_1}. When P_{idl_1} is equal to $f_{idl}(n)$, n is the number of neighbor nodes deployed in real network.

The above characteristic is favorable for estimating the number of neighbor nodes n which can be calculated by the following dichotomy. Supposing n is in a range $[0, n_{max}]$, initially let $n_{try1} = n_{max}/2$ and substitute it into $f_{idl}(n)$. Then compare $f_{idl}(n_{try1})$ with P_{idl_1}. If $f_{idl}(n_{try1}) > P_{idl\_1}$, we should set $n_{try2} = [n_{try1} + n_{max}]/2$. Otherwise, we should set $n_{try2} = [n_{try1} + 0]/2$ for the following calculation. Obviously, this method is simple and effective. For example, when $n_{max} = 100$, we just need to calculate four times to estimate n in the worst case with maximum error 3. In the following, we present the condition of high throughput. And then, we give the method of how to dynamically tune CW to enhance throughput. The average idle slot interval is denoted by L_{idl}, it can be expressed as

$$L_{idl} = \frac{P_{idl}}{1 - P_{idl}}. \tag{8}$$

With Eqs.(6) and (8), thinking IEEE 802.11b, we can express the throughput per a node as a function of L_{idl}/n with SIFS = 10s, DIFS = 50s, ACK = 304bits and slot time = 20s, as shown in Fig. 2. P_s and P_{col} are concerned with the distance r between the transmitter and the receiver. We assume that the transmission range is 250m and we set as $r = 125$ in Fig. 2. From the figure, first, we find that every curve follows the same pattern; namely, as the average idle slot interval per a node L_{idl}/n increases, the throughput first rises quickly, and then decreases relatively slowly after reaching its peak. Second, although the optimal value of L_{idl}/n that maximizes throughput is different in cases of different frame lengths or number of neighbor nodes, it varies in a very small range. Therefore, L_{idl}/n is a suitable measure that indicates the network throughput and we can obtain the following equation

$$L_{idl}/n = \alpha. \tag{9}$$

As shown in Fig. 2, considering the different frame lengths and number of neighbor nodes, we can set as $\alpha = 25$. From Eqs.(1) and (8), we have $p = 1/(L_{idl}+1)$, then $p = 1/(n\alpha+1)$ with Eq.(9). Substitute p in $P_{idl\_1} = (1-p)^n$, it becomes as following,

$$opt\_P_{idl\_1} = (1 - \frac{1}{n\alpha + 1})^n \tag{10}$$

where $opt\_P_{idl\_1}$ is the optimal P_{idl_1} that maximizes the throughput. From the Eq.(10), according to the number of neighbor nodes, each node can calculate the $opt\_P_{idl\_1}$, that is, set the optimal CW to obtain the high throughput. Each node can observe the current P_{idl_1}. (denoted by $cur\_P_{idl\_1}$.) By Comparing $cur\_P_{idl\_1}$ with $opt\_P_{idl\_1}$, the tagged node adjusts the CW to obtain the optimal CW as following,

$$\begin{cases} IF(cur\_P_{idl\_1} \cdot \mu_1 \leq opt\_P_{idl\_1}) \\ \quad CW \leftarrow CW \cdot \lambda_1 (\Rightarrow Increase) \\ IF(cur\_P_{idl\_1} \cdot \mu_2 \leq opt\_P_{idl\_1} < cur\_P_{idl\_1} \cdot \mu_1) \\ \quad CW \leftarrow CW \cdot \lambda_2 (\Rightarrow Increase) \\ IF(cur\_P_{idl\_1} \cdot \mu_3 \leq opt\_P_{idl\_1} < cur\_P_{idl\_1} \cdot \mu_2) \\ \quad CW \leftarrow CW \\ IF(cur\_P_{idl\_1} \cdot \mu_4 \leq opt\_P_{idl\_1} < cur\_P_{idl\_1} \cdot \mu_3) \\ \quad CW \leftarrow CW \cdot \lambda_3 (\Rightarrow Decrease) \\ IF(opt\_P_{idl\_1} < cur\_P_{idl\_1} \cdot \mu_4) \\ \quad CW \leftarrow CW \cdot \lambda_4 (\Rightarrow Decrease). \end{cases} \tag{11}$$

We set empirical datas $\mu_1 = 1.05$, $\mu_2 = 1.025$, $\mu_3 = 0.99$ and $\mu_4 = 0.95$ to determine the different densities of P_{idl_1}. Also, $\lambda_1 = 1.5$, $\lambda_2 = 1.1$, $\lambda_3 = 0.9$ and $\lambda_4 = 0.5$ are empirical datas to adjust the increasing or decreasing changes of CW. Since we are interested in tuning the network to obtain maximal throughput, given the Eq.(11), we can achieve this goal by adjusting the size of CW. In other words, each node can estimate the number of neighbor nodes and adjust its backoff window accordingly so that the throughput of the tagged node is maximized.

B. OBM Scheme

As mentioned above, we can obtain the optimal CW by Eq.(11) by using the estimated number of active neighbor nodes. Hence, each node can adjust its CW dynamically and tune the network to deliver high throughput. To obtain the P_{idl} and P_{idl_1}, we can count the number of backoff slots (denoted by C_{idl_1}) and RTS transmissions of neighbor nodes (denoted by $C_{idl\_2\_3}$). To avoid occasional cases, C_{idl_1} and $C_{idl\_2\_3}$ are expected to be measured in resetting

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the counters when a certain number of RTS transmissions reaches a certain number γ. The P_{idl} and P_{idl_1} can be calculated as

$$P_{idl} = \frac{C_{idl\_1} + C_{idl\_2\_3}}{C_{idl\_1} + C_{idl\_2\_3} + \gamma}$$
$$P_{idl\_1} = \frac{C_{idl\_1}}{C_{idl\_1} + C_{idl\_2\_3} + \gamma}. \quad (12)$$

The tagged node calculates the CW before packet transmissions. After new CW (denoted by newCW) is obtained, the CW can be updated as

$$CW = \beta \cdot CW + (1 - \beta) \cdot newCW \quad (13)$$

where β is a smoothing factor with the range of [0,1]. The higher β leads to stability but maybe reduces adaptivity to network changes such as in traffic and active nodes.

However we assume that all nodes have the number of neighbor nodes, in the actual network, all nodes do not have the same number of neighbor nodes and the same informations of the channel. The corner nodes which deploys in the corner of the network have smaller number of neighbor nodes than the center nodes which deploys in the center of the network have. Consequently, the corner nodes have more chances to transmit RTS packet and smaller CW than center nodes have. For keeping balance between the corner nodes and the center nodes, the corner nodes have almost the same CW as the center nodes have. After adjusting the CW as shown in Eq.(11), the CW of the corner nodes adjust as $CW = CW \cdot \lambda_1$, where $\lambda_1 = 1.5$ is an empirical data. Before adjusting the CW again, the CW of the corner nodes adjust as $CW = CW/\lambda_1$. In OBM, we adds the value of estimated the number of neighbor nodes in RTS packet to distinguish the corner node from the center node. The tagged node receives any RTS packets and obtains the average number of neighbor nodes which is calculated by the estimated number of neighbor nodes that the neighbor nodes have. Then, the tagged node is determined as the corner node when the estimated number of neighbor nodes of the tagged node is smaller than half of the average number of neighbor nodes. Otherwise, the tagged node is determined as the center node.

In the following, we give the tuning algorithm.

1) The tagged node begins listening to a channel and counts C_{idl_1} and $C_{idl\_2\_3}$ individually.
2) When the tagged node needs backoff and the number of RTS transmissions reaches a certain number γ, it calculates the optimal CW as a new CW and resets CW according to Eq.(13). If the tagged node is corner node, the CW of that is adjusted for resetting CW before calculating the optimal CW.
3) By comparing the estimated number of neighbor nodes with the average number of neighbor nodes, the tagged node is determined as the corner node or the center node.
4) If the tagged node is the corner node, the CW of that is adjusted for keeping balance between the corner nodes and the center nodes.
5) It resets counting C_{idl_1} and $C_{idl\_2\_3}$

The certain number of RTS transmissions γ needs to be set appropriately. When the γ is small, CW changes rapidly with network changes. In contrast, if the γ is large, the network can have higher stability but is short of adaptivity. In the following simulation, we set as $\gamma = 2$. As shown in [14], the maximal throughput is not obtained when all nodes have the same CW. In OBM, each node adjusts the CW around the optimal value according to $cur\_P_{idl\_1}$ and $opt\_P_{idl\_1}$. Using this method, high throughput is achieved, which can be found in the following simulations.

TABLE I
NETWORK CONFIGURATION

Parameter	Value
SIFS	10μsecs
Slot time	20μsecs
EIFS	364μsecs
DIFS	50μsecs
MinCW $\sim$ MaxCW	31 $\sim$ 1023
Max retry threshold	7
Buffer size	256000 bits
Data rate	11Mbps
transmission range	250m
carrier sensing range	550m
Path loss exponent	4

III. PERFORMANCE EVALUATION

In this section, we evaluate the performance of our OBM through simulations, which are carried out on OPNET Modeler [15]. For comparison purpose, we also present the simulation results for the IEEE 802.11b DCF and the FNT scheme in [6]. In [6], the authors proposed the MRT, the FNT and the ART scheme. The MRT and the ART scheme assume that each node has multiple destination nodes. We focus on the unicast mode and compare OBM with the FNT scheme. In the FNT scheme, the NAV duration in RTS packet reduces from $T_{CTS}+T_{DATA}+T_{ACK}+3SIFS$ to $SIFS+T_{CTS}+\tau$ in order to alleviate the receiver blocking problem. The simulation parameters are shown in TABLE I and the OBM-specific parameters in TABLE II. In the conventional method, sets the maximum CW but in OBM, there is no upper bound of CW. In analysis, we assume that the transmission, interference and sensing ranges of all network nodes are the same value. The simulations are carried out in a realistic setting, that is, the transmission and sensing rages are about 250m, 550m, respectively. We assume that network nodes are distributed at random within an area of 3000 $\times$ 3000 m^2 as shown in Fig. 3. We considere the only nodes that are deployed in the center of the network in order to avoid the effect of the corner nodes. To maintain the required density, the network is divided into nine areas. The nodes are distributed at random in each area. Each node selects another node at random as a receiver and generates traffics according to a Poisson process with the same arrival rate. The arrival rates are high enough to achieve the saturated network. The packet size is 8000 bits, which is the size of payload data at MAC layer and does not include MAC overhead. As shown below, OBM exhibits a better performance.

A. Estimated number of neighbor nodes

Firstly, we give the estimated number of neighbor nodes in OBM. Fig. 4 shows the results of the estimated number of neighbor nodes with simulation time when average number of neighbor nodes is 50. From Fig. 4, we find

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TABLE II
BACKOFF PARAMETERS

Parameter	Value
Maximum number of neighbor nodes	100
α	25
β	0.8
γ	2

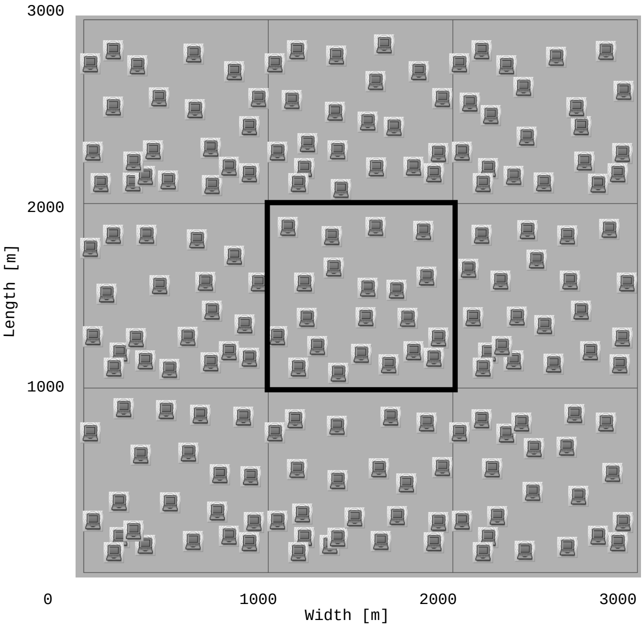

Fig. 3. A snapshot of node distribution in simulations when average number of neighbor nodes is 20

that the estimated number of neighbor nodes changes to inappropriate value because of the beginning of simulation and then converges to a comparatively stable value around 50 after about 20s, which is related to algorithm of backoff parameters shown in TABLE II. Also, the estimated number of neighbor nodes that the corner nodes have is smaller than the estimated number of neighbor nodes that the center nodes have. Thus, OBM can estimate the number of neighbor nodes dynamically and distinguish the corner nodes from the center nodes.

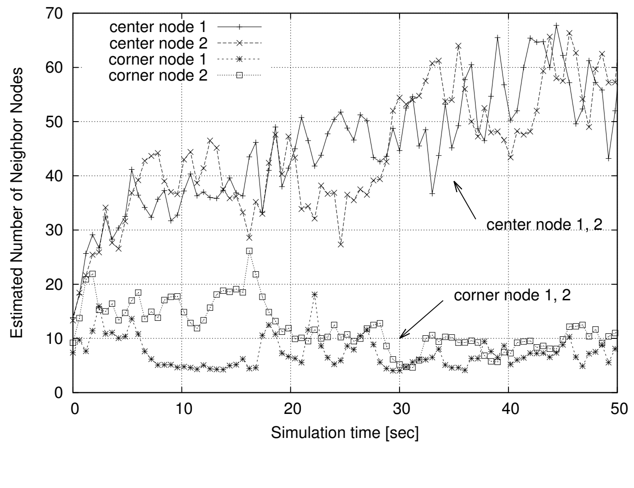

Fig. 4. Estimated number of neighbor nodes with simulation time when average number of neighbor nodes is 50

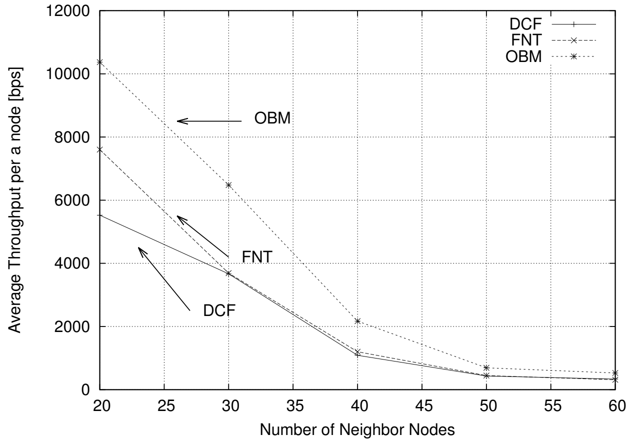

Fig. 5. Throughput with neibor node numbers

B. Throughput

Second, we give the throughputs of three schemes, i.e., OBM, IEEE 802.11b DCF and FNT in [6]. Fig. 3 shows the results of the average throughput per a node with a different number of neighbor nodes. The throughput is the only value of payload data successfully received and does not include other pakcets.

The throughputs of three shcemes decrease with the average number of neighbor nodes increasing because the number of hidden nodes increases. In DCF and FNT schemes, the hidden node problem has a significant influence. These schemes applies an binary exponential backoff algorithm which takes time for obtaining the CW around the optimal value. This is the mainly reason that many collisions and the sharp decrease of the throughput. The FNT scheme obtains higher throughput than DCF when the number of neighbor nodes is 20. In FNT, the NAV duration in RTS packet reduces and increase the transmission probability. Thus, the collision probability increases when the number of neighbor nodes is large. The throughput of FNT is improved when the number of neighbor nodes is small, however, the throughput of that is almost the same as DCF when the number of neighbor nodes is larger than 20. The FNT scheme does not alleviate the effect of the hidden node problem enough. In contrast, OBM alleviates the effect of the hidden node problem and obtain high throughput. The maximum improvement of throughput is about 2 times when the number of neighbor nodes is 40.

C. Retransmission attempts

Finally, Fig. 6 shows the results of average retransmission attempts per one hop with a different number of neighbor nodes. The average retransmission attempts per one hop is the total retransmission attempts of nodes within carrier sensing range of a node. In DCF and FNT schemes, the retransmission attempts increase as the number of neighbor nodes is increasing. There are many collisions by an binary exponential backoff algorithm. By contrast, in OBM, the number of the retransmission attempts increases relatively slowly as the number of neighbor nodes is increasing because OBM always obtains CW around the optimal value. In analysis, we assume that the transmission, interfenrece and sensing ranges for all network nodes are the same value.

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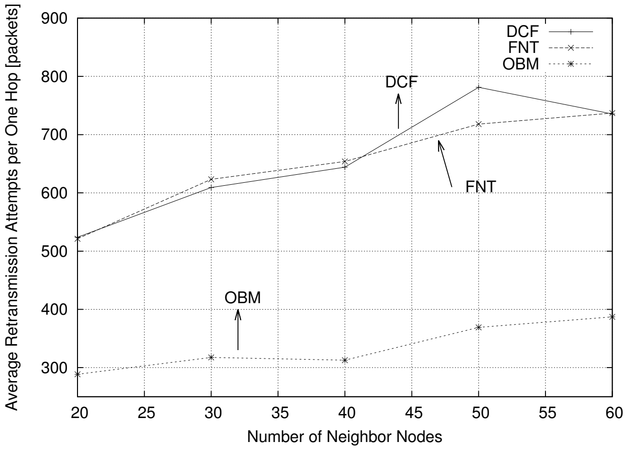

Fig. 6. Retransmission attempts with neibor node numbers

However, these ranges are not the same value in this simulation. As shown in simulation results, OBM can adopt in that case.

IV. Conclusion

In this paper, we proposed a novel MAC protocol OBM that enhance DCF in multi-hop wireless networks. In OBM, each node observes P_{idl_1}, P_{idl_2} and P_{idl_3} to estimate the number of neighbor nodes and then sets CW around the optimal value dynamically according to the number of neighbor nodes. Thus, OBM can obtain high throughput. From analysis and simulation results, this scheme is effective and can adjust the network change promptly. Moreover, OBM can alleviate the hidden node problem and achieve higher throughput than IEEE 802.11 DCF and recently a proposed method. Compared to recently proposed methods, OBM is flexible enough. In OBM, the RTS packet is added few bits in order to distinguish the corner node from the center node, however, the multiple transceivers, channels or destination nodes are not used. As a future work, we need verify by actual environment and evaluate the validity of OBM.

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