Probe Request based Load Balancing Metric with Timely Handoffs for WLANs

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***Abstract*—As the number of mobile devices accessing large-scale WLANs such as campus and metropolitan area networks increases, the need for load balancing among the cells becomes crucial. In addition, the network must also support some minimum handoff tolerance defined by an application. This paper proposes a new metric that provides load balance as well as timely handoffs for WLANs by taking into account both direct and hidden node collisions.**

I. Introduction

Large-scale WLAN deployment is popular in locations, such as conferences, university campuses, and airports, as well as metropolitan areas due to their low cost and ease of deployment [1]. A WLAN is made up of multiple Access Points (APs) with overlapping cells to provide a wide coverage and offer high transmission rates. In current implementations, each user associates with an AP with the strongest signal strength. However, recent studies have shown that this simple approach leads to inefficient association of mobile stations (STAs) to available APs [2]–[6]. Uneven distribution of user loads among APs increases congestion and packet loss, and reduces throughput. This results in inefficient medium utilization, and occasionally, network collapse. Therefore, AP selection has been an important issue in WLANs.

A number of load balancing techniques has been proposed in the literature that focus on formulating new load metrics rather than using Received Signal Strength Indicator (RSSI) as the association metric [7]–[18]. Although these schemes consider variety of factors to achieve balanced load, they fundamentally ignored hidden nodes. Since hidden nodes cause packet collisions, the presences of such nodes can severely affect the performance of WLANs. Moreover, the importance of handling the hidden node problem has increased with the increase in uplink data for applications, such as VoIP, video gaming, and video conferencing. The hidden node problem is well known in ad hoc networks; however, relatively little work has been done to consider the problem in wireless infrastructure networks. Although there have been numerous research efforts that separately consider load balancing and hidden nodes for WLANs, unfortunately very little work exists that considers both issues at the same time.

Therefore, this paper proposes a new *Probe Request based Load Balancing Metric* (PR-LBM). PR-LBM has several unique features. First, probe requests during the discovery phase are utilized to observe the states of all the adjacent channels to decide on the best AP to achieve balanced load and timely handoff. Second, a fixed, optimized backoff time, instead of random backoff time, is used for probe request frame. The choice of backoff time, which is represented in terms of number of slots, is optimized for each application to provide sufficient amount of time to observe the channel leading to a more accurately metric. Third, the analytical model for PR-LBM considers the frequencies of DIFS and probing delay in order to evaluate the contention rate of all channels. Fourth, the M/M/1/K queue model is employed to develop collision probability of hidden nodes.

II. Related Work

A number of techniques has been proposed that considers network load rather than just RSSI as the association metric for WLANs. For example, the metrics proposed in [7]–[9] consider factors such as the number of users currently associated with an AP, the mean RSSI value of users currently associated with an AP, or the RSSI of the new user and the bandwidth a new user can get when it associates with an AP. However, these methods require protocol modifications on the AP side, and the number of users and RSSI information alone cannot be used to predict the probability of collisions and the available bandwidth in the network. The authors in [10] proposed channel utilization as the main metric, which is the percentage of time the AP is busy transmitting or receiving data during some time interval. However, each STA needs to be equipped with extra client software to monitor the wireless channel quality of its nearby APs, and then report this information back to a central control [11].

Selective Dropping [12] and Traffic Shaping [13] have their benefits and provide modest performance improvement in WLANs. These proposals are beneficial since overloading often results in queue overflow, which then increases the frame drop rate during AP transmissions. However, Selective Dropping may worsen the starvation of some users, while Traffic Shaping restricts the throughput of individual connection in order to accommodate all users.

In [14], the authors proposed IQU, which a practical queue based user association management for heavily loaded WLANs. IQU maintains a queue of users requesting network accesses. Only STAs that can be simultaneously accommodated are permitted to access the network. Although each user is granted a fair opportunity to access the network while maintaining high overall throughput admitted users are limited to assigned work periods and unpermitted users need wait for admission in a queue. These limitations do not handle users requiring minimized handoff latency and real time services, such as multimedia applications, for an extended period with the AP.

In [15], a STA observes a skewed time period of beacon frame receptions to estimate available bandwidth. However, the observation time for multiple beacon frames increases because they are usually transmitted every $100ms$. Virtual Media Access Control (VMAC) [16] virtually runs the MAC process at each STA to estimate the collision probability and available bandwidth. However, the time required for the estimation to converge takes a long time as each estimated sample is collected only after completing the random backoff procedure. In [14], [18], requests are accepted if the predicted load level after the association does not exceed some threshold, and a heavily loaded AP can disassociate a selected STA from its Basic Service Set (BSS) by sending an unsolicited disassociation frame.

These approaches need modification to APs, and incur additional overhead since the AP should know not only the neighboring APs load information but also the details of the entire network. Also, a ping-pong effect might occur when it uses a dynamic association management. In our related work, the cell breathing techniques are not discussed since they beyond the scope of our metric.

In spite of these efforts that consider load balancing in WLANs, no work exists that considers both load balancing and the hidden node problem. The hidden node problem is a serious issue in WLANs since it causes packet collisions and severely affects the performance of wireless networks [10], [17].

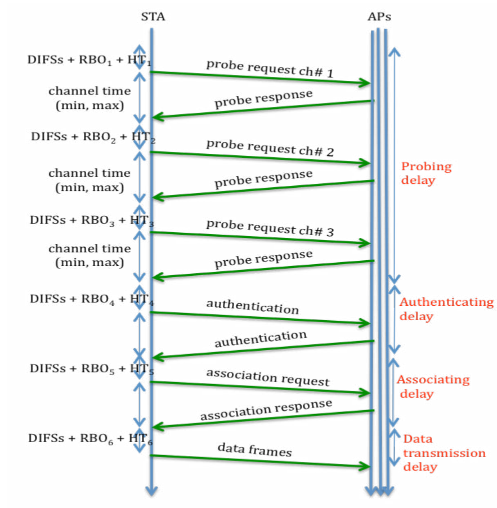

Fig. 1. Total delay between probe request frame and data frame.

III. The Proposed Method: PR-LBM

The proposed PR-LBM utilizes probe requests to observe the state of the channel and determines the best AP for association to balance the network load. There are several advantages of using probe requests compared to exiting methods that rely on data frames. First, the overall delay for a STA to achieve balanced load is reduced since contention rates of all the surrounding channels are evaluated during the discovery phase. In contrast, methods that observe the channel using data frames after association can only evaluate the load balancing metric of one specific channel. Moreover, these methods will incur extra delay when STAs reassociate with another AP to search for a better channel. Furthermore, the ping-pong effect increases when the channel condition degrades, which in turn affects the performance of WLANs.

A. *Timely Handoff Using Optimized Backoff Time*

Fig. 1 illustrates the timing for the discovery, authentication, association, and a successful data frame transmission. In order to obtain the most appropriate backoff time and thus provide timely handoff, the total delay D_{total} between when the first probe request is transmitted and when the association response is received needs to be known, which is given as

$$D_{total} = D_{probe} + D_{auth} + D_{assoc}, \tag{1}$$

where D_{probe} represents the probing delay, D_{auth} is the authentication delay, and D_{assoc} is the association delay.

D_{probe} is defined by the following equation:

$$\begin{aligned} D_{probe} = & n \cdot (DIFS \cdot d + RBO + PT) + \\ & n \cdot (t_{tx} + t_{prop} + t_{ch} + t_{switch}), \end{aligned} \tag{2}$$

where n is the number of channels, d is the average number of $DIFS$s, RBO is the average random backoff time, PT is the average pause time during the discovery phase, t_{tx} and t_{prop} are the transmission and the propagation time of the

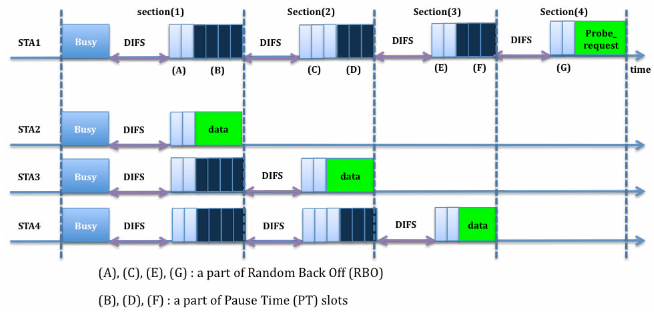

Fig. 2. Differentiation between RBO and PT.

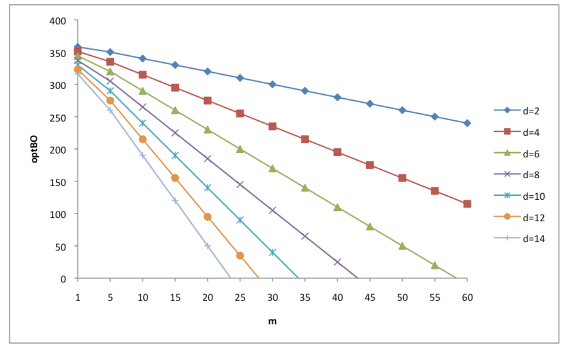

Fig. 3. Optimum backoff slots as function of m and d.

probe frame, respectively, t_{ch} is the channel time, and t_{switch} is channel switch time.

PT represents the additional *pause time* required when the medium is busy by other STAs or AP, and thus RBO is not decremented. Fig. 2 illustrates an example scenarios consisting of four contending STAs, where STA1 observes the traffic of the other three STAs. The RBO values in terms of number of slots for STAs 1-4 are 9, 2, 4, and 7, respectively. The groups of slots indicated by (A), (C), (E), and (G) represent parts of RBO or *CW* slots, while the other groups of slots indicated by (B), (D), and (F) are parts or sections of PT. Suppose STA1 observes 2 busy slots, then STA1 has 9 slots for RBO, and 12 slots for PT. Note that the slot time, $SlotTime$, is a constant value found in the STAs the Management Information Base (MIB). The $SlotTime$ for 802.11b is $20\mu s$, which results in a PT value of $240\mu s$.

t_{ch} can be either minimum channel time (t_{min}) or maximum channel time (t_{max}). t_{min} is the minimum amount of time a STA has to wait on an empty channel. On the other hand, t_{max} is the maximum amount of time a STA has to wait to collect all the probe responses, which is used when a response is received within t_{min}. Note that t_{ch} is always less than or equal to t_{max}. Finally, t_{switch} is the the average time required to switch from one channel to another.

In order to provide timely handoff, D_{total} should be not greater than some minimum tolerance level defined by a multimedia application. For example, the handoff delay for VoIP is recommended to be not greater than $80ms$ [20]–[23]. In our previous research [24], [28], D_{auth} and D_{assoc} were measured to be $6ms$ and $4ms$, respectively, which are similar to the experimental results in [25] and ns-2 simulation results in [26]. Therefore, D_{probe} for VoIP should be less than $70ms$. Suppose that t_{ch} (i.e, t_{max}) is $11ms$, t_{tx} and t_{prop} are both $1\mu s$, and t_{switch} is $5ms$ [26]. Moreover, Short Inter-Frame Space (SIFS) is equal to $10\mu s$, which leads to DIFS of $50\mu s = SIFS + 2 \cdot SlotTime$. Since APs in the adjacent cells use only non-overlapped channels 1, 6, and 11 to reduce interference among the cells [1], [19], [28], i.e., n=3, the time required to probe each channel should be lower than $23.3ms$. Based on these assumptions, the following inequality can be obtained from Eq. 2:

$$DIFS \cdot d + RBO + PT \leq 7.3ms. \tag{3}$$

As can be seen from Fig. 2, PT is proportional to d, and thus, can be written as

$$PT = d \cdot m \cdot SlotTime, \tag{4}$$

where m is the average number of pause slots in a section of PT, and thus term $m \cdot SlotTime$ represents the average pause time of a section. For example, STA1 observes 4 DIFSs and 12 pause slots in Fig. 2. Therefore, the average pause time in a section is $60\mu s$. Therefore, solving Eq. 3 for RBO leads to the following equation:

$$RBO \leq 50\mu s \left(146 - \left(1 + \frac{2}{5}m\right) d\right). \tag{5}$$

RBO can also be represented by the equation

$$RBO = optBO \cdot SlotTime, \tag{6}$$

where $optBO$ is the *optimized number of backoff slots* that provides a sufficient amount of time to observe the channel and leads to a timely handoff. Based on Eqs. 6 and 5, $optBO$ can be written as

$$optBO \leq \frac{5}{2}\left(146 - \left(1 + \frac{2}{5}m\right) d\right). \tag{7}$$

Fig. 3 shows the values for $optBO$ as function of m and d. For example, when m is 15 and d is 10, $optBO$ is about 180 slots. In this case, PT for one probe request is $3ms$ according to Eq. 4.

B. PR-LBM

Based on the $optBO$ discussed in Sec. III-A, the proposed PR-LBM metric is developed using the number of $DIFS$s, d and the probing delay, D_{probe}, to estimate the contention rate of all the channels. PR-LBM is defined by the probability that a STA x successfully transmits a data frame on channel i, P^i_x, which is represented as

$$P^i_x = (1 - P^i_{DC}) \cdot (1 - P_{HC}), \tag{8}$$

where P^i_{DC} and P_{HC} represent the probabilities that a data frame experiences a direct collision and a hidden node collision in a channel, respectively. A direct collision occurs when two STAs that can sense each other start transmitting packets

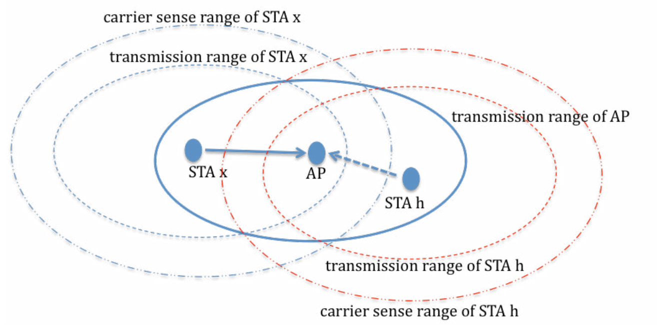

Fig. 4. Hidden node collision in the three-entity topology.

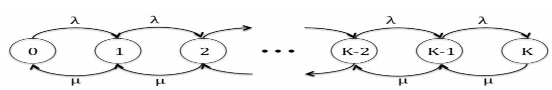

Fig. 5. State-transition diagram for M/M/1/K.

at the same time, while a hidden node collision occurs when multiple far away nodes that cannot sense each other transmit at the same time.

Fig. 4 depicts the conditions under which hidden node collisions occur. The dashed/dotted circles around STA x and h represent their transmission and carrier sense ranges, while the circle around the AP represents its transmission range. This figure shows that STAs x and h cannot hear each other, but AP hears both. Therefore, the transmission from STA x will collide with the transmission of STA h .

To estimate P^i_{DC}, a time-slot based observation method is used as was shown in Fig. 2. The ratio of d and the probe delay will increase as the level of contention increases in a channel. Therefore, both factors are used to estimate the contention rate, and P^i_{DC} is represented as follows:

$$P^i_{DC} = \alpha \cdot d^i \cdot D^i_{probe}, \tag{9}$$

where d^i and D^i_{probe} are the total number of DIFSs and the probing delay in channel i. On the other hand, α represents a weight that normalizes P^i_{DC} to be a fraction.

Unlike P^i_{DC}, P_{HC} cannot be evaluated by observing the channel since hidden nodes cannot be heard. Instead P_{HC} is modeled using M/M/1/K queue at each STA, which follows the Poisson process with packet arrival rate of λ, and service rate of μ. Thus, the probability distribution of the service time (T) is exponential with mean $1/\mu$. Since the queue can hold at most K packets, any additional packet will be refused entry into the system. Therefore, λ and μ based on the Birth-Death process shown Fig. 5 are given as follows:

$$\lambda_k = \begin{cases} \lambda & k \leq K \\ 0 & k > K \end{cases}$$
$$\mu_k = \mu \quad k = 1, 2, \cdots, K \tag{10}$$

P_{HC} is divided into two conditional probabilities representing when the queue length is greater than zero and when it is zero. Let q_h denote the queue length at a hidden STA h. Then, the probability that a *hidden node collision* (HC) will occur from STA h is given as

$$\begin{aligned} P_{HC} =& P(HC \mid q_h > 0) \cdot P(q_h > 0) \\ &+ P(HC \mid q_h = 0) \cdot P(q_h = 0). \end{aligned} \tag{11}$$

If $q_h > 0$, then STA h has packets in its queue and they will be transmitted. Therefore, the conditional probability that packets from STAs x and h will collide, i.e., $P(HC \mid q_h > 0)$, is one. In addition, even if the queue in STA h is empty at $t = 0$, a collision will occur if STA x starts transmitting a packet before $t = T$. Since STA h follows the Poisson process with the arrival rate of either λ_h or 0, $P(HC \mid q_h(0) = 0)$ follows an exponential distribution given by

$$P(HC \mid q_h = 0) = 1 - e^{-\rho_h}, \rho = \lambda/\mu. \tag{12}$$

Therefore, Eq. 11 can be rewritten as

$$P_{HC} = 1 \cdot P(q_h > 0) + (1 - e^{-\rho_h}) \cdot P(q_h = 0) \tag{13}$$

The probability that the queue length will be zero, $P(q_h = 0) = P_0$, can be obtained from the Birth-Death process and is given as

$$P_0 = \frac{1}{1 + \sum_{k=1}^{K} \prod_{j=0}^{k-1} \frac{\lambda_j}{\mu_{j+1}}}. \tag{14}$$

The probability that the queue length will be k, P_k, is obtained based on the finite Markov chain diagram shown in Fig. 5, which leads to

$$P_k = \begin{cases} P_0 \left(\frac{\lambda}{\mu}\right)^k & k \leq K \\ 0 & k > K \end{cases} \tag{15}$$

Thus, $P(q_h = 0)$ is given by

$$P(q_h = 0) = P_0 = \frac{1 - \frac{\lambda}{\mu}}{1 - \left(\frac{\lambda}{\mu}\right)^{K+1}} = \frac{1 - \rho}{1 - \rho^{K+1}} \tag{16}$$

Therefore, the following equation can be obtained for P_{HC}:

$$\begin{aligned} P_{HC} =& 1 \cdot \left(1 - \frac{1 - \rho}{1 - \rho^{K+1}}\right) + \\ & (1 - e^{-\rho_c}) \cdot \left(1 - \frac{1 - \rho}{1 - \rho^{K+1}}\right) \end{aligned} \tag{17}$$

IV. Simulation and Analysis

A. Simulation Environment

This section evaluates the accuracy of our model with Qualnet [29] based on the simulator parameters shown in Table I. Our simulation is based on an infrastructure WLAN with three overlapped cells without Request-to-Send (RTS) and Clear-to-Send (CTS) handshake. Although RTS/CTS is designed to mitigate the hidden node problem, a significant amount of overhead is incurred and thus is typically not used in infrastructure mode [18].

TABLE I
SIMULATION PARAMETERS.

Model	QualNet 5.0
Simulation Time	1000 seconds
Radio Types	802.11b
Antenna Model	Omni-directional
Pathloss model	Two Ray Ground
Propagation limit (dbm)	-111
Number of APs	3 (channels 1, 6, & 11)
Number of STAs	1∼50
Applications Types	CBR
Data Rates	2Mbps
Slot time	$20\mu s$
SIFS	$10\mu s$
DIFS	$50\mu s$
D_{auth}	$6ms$
D_{assoc}	$4ms$
t_{ch}	$11ms$
t_{switch}	$5ms$
Propagation delay	$1\mu s$

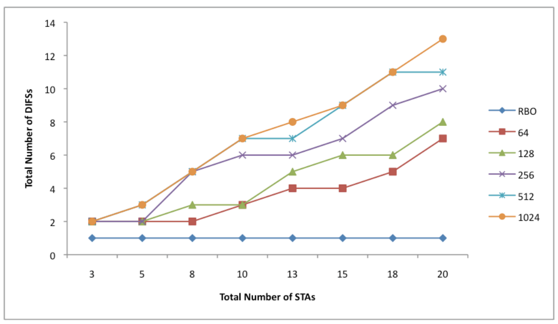

Fig. 6. Number of DIFSs vs. number of STAs and backoff slots.

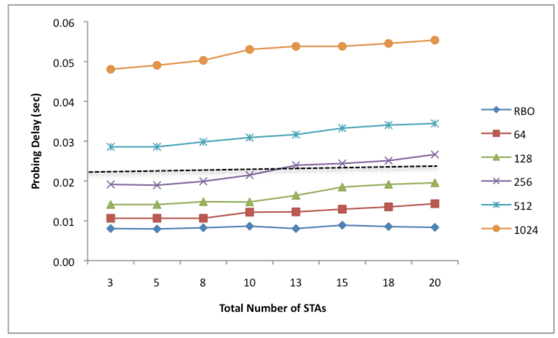

Fig. 7. Probing delay vs. number of STAs and backoff slots

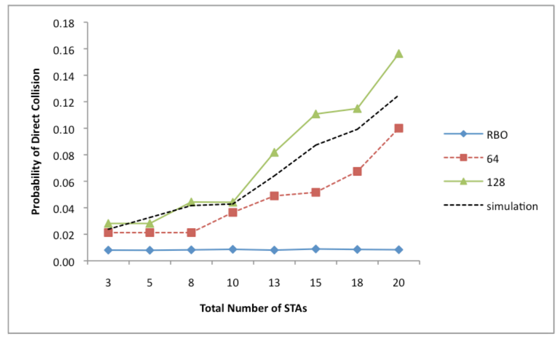

Fig. 8. Probability of direct collision vs. number of STAs and backoff slots.

B. Simulation results

The accuracy of our metric is measured with simulation by varying the number of contending nodes and the size of backoff slots. For the number of DIFSs and probing delays, and thus the probability of direct collision, P_{DC}, a scenario was set up where STA x enters a cell with varying number of STAs, and all of the STAs within the cell are positioned in such as a way that they can all sense each other. For the probability of hidden node collision, P_{HC}, a scenario similar to Fig 4 was set up.

1) Number of DIFSs: Fig. 6 shows the number of DIFSs as function of number of STAs and backoff slots. The average number of DIFSs is around 2∼9 slots. With the exception of the standard RBO, which is less than 32 slots, the number of DIFSs increases linearly for different values of backoff slots. For example, when a STA chooses a fixed backoff slots of 1024 and there are three contending nodes, it observes on average two DIFSs before it can transmit a probe request frame. However, the number of DIFSs increases linearly from 3 to 13 according to number of nodes between 5 and 20. In contrast, when a STA adheres to the standard RBO mechanism, it only observes one DIFS regardless of the number of nodes. Therefore, the standard RBO does not provide sufficient amount of time to properly observe the channel.

2) Probing Delay: Fig. 7 shows the probing delay as a function of number STAs with different backoff slots. The probing delay increases slightly as the number of nodes increases. In contrast, the delay increases significantly as the number of backoff slots increases. Based on the VoIP probing delay requirement of less than $23.3ms$ (see Sec. III-A), which is indicated by the dotted line in Fig. 7, backoff slots of 512 and 1024 do not satisfy the delay requirement. The results for 256 backoff slots indicate that when the number of nodes is between 3 and 10, the delay requirement can be satisfied. However, when the number nodes exceeds 10, the delay requirement cannot be satisfied. Therefore, choosing a backoff slot of less than 256 will provide timely handoff.

3) Probability of Direct Collision: Fig. 8 shows P_{DC} as a function of the number of STAs with different number of backoff slots that would satisfy the delay requirement. It is important to note that these results, with the exception of the dotted line indicated as ‘simulation’, were generated using Eq. 9 based on the number of DIFSs shown in Fig. 6 and probing delays shown in Fig. 7. On the other hand, the results indicated by the dotted line were generated by keeping track of the actual number of collisions that occur during simulation. As can be seen from the figure, the result for the backoff time of 128 slots is the closest to the simulation results, which indicate that the best value for $optBO$ is 128 slots.

4) Probability of Hidden Node Collision: Fig. 9 compares P_{HC} from Eq. 17 and simulations results as a function of

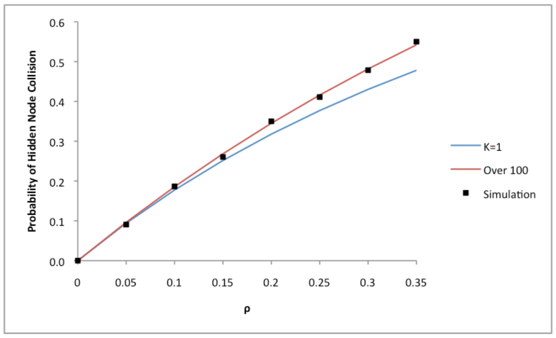

Fig. 9. Probability of hidden node collision vs. number of STAs.

ρ with queue size of $K = 1$ and $K > 100$. Note that the maximum queue size of 292 packets, which is the default value in Qualnet [29], was used for the simulation. As can be seen from the figure, the analytical results for $K > 100$ matches with the simulation results.

V. Conclusion

This paper proposed a new load balancing metric called PR-LBM. The unique features of PR-LBM are the use of probe requests to observe the channel and analytical models to estimate the probability of collision. Our simulation results show that the proposed metric is accurate and thus very applicable in WLANs for applications requiring timely handoff and load balance.

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