

Modeling the Performance of A Wireless Node in Multihop Ad-Hoc Networks

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Abstract: In this paper, we model a wireless node's state transition using a Markov Chain model in a multihop ad hoc network. To investigate how the metrics, such as transmit power, contention window size, and node density, affect a node's performance with interference, our model takes into account the interfering nodes in the entire system. Most of the previous work either didn't consider all the interfering nodes in the network or simply ignored interference. Based on a Markov Chain model, we calculate a node's throughput, consumed energy and delay time. From the numerical results, we conclude that: 1. Transmit power, contention window size, and node density will all affect the network performance. 2. Throughput and energy can be optimized together, whereas optimizing delay time results in tradeoffs in throughput and consumed energy. 3. A high transmit power can not guarantee a low delay time.

1 Introduction

The medium access control (MAC) protocol enables a wireless node to communicate, while attempting to enforce fair and efficient usage of the available channels. However, achieving this goal in an ad hoc network is challenging since the interference from the entire network must be considered. Too much interference decreases the SIR, which may prevent an acceptable bit error rate, thereby requiring retransmissions. This decreases throughput, and increases energy consumption and delay time.

Avoiding interference, therefore, is a crucial issue in the performance of a wireless node, yet, existing MAC protocols evaluate their performance under arbitrary interference. Existing techniques lack a complete and thorough analysis of interference in ad hoc networks. Some studies analyze the performance of a wireless node, but only consider interfering nodes at the receiver side [1,3]. Others calculate interference without considering the relation between interference and a node's performance [2,4].

What is needed, thus, is a model that lends itself to a performance analysis while considering the interference from the entire system. In this paper, we model a wireless node's state transitions using a Markov Chain model. We consider the effect of interfering nodes on each of a node's state transitions, which makes our model more complete than [1, 3]. To investigate a node's performance under the maximum interference, we use a honey grid model as in [2]. A honey grid models the worst case interference from interfering nodes. Based on these, we calculate throughput, consumed energy and delay time in a multihop ad hoc network. We analyze the effects of the transmit power, contention window size, and node density on the performance of a node under the maximum interference. Therefore, our analysis is complete in the sense that we con-

sider the interference from the entire network, and thorough, in the sense that we analyze significant performance metrics.

Our analysis has resulted in the following important findings that would help in the design of better MAC protocols:

1. Transmit power, contention window size, and node density will all affect the network performance.
2. Throughput and energy can be optimized together, whereas optimizing delay time results in tradeoffs in throughput.
3. A high transmit power can not guarantee a low delay time.

The rest of the paper is organized as follows. In Section 2, we review the related work, and in Section 3, we provide the technical background. In Section 4, we describe the Markov Chain and the honey grid model. We present the numerical results in Section 5 and conclude with Section 6.

2 Related Work

Y. Wang et al. [1] model a wireless node's collision avoidance protocols using two Markov Chain models. One is used to find the transmission probability and the other is used to find the successful transmission probability based on a node's state transitions. However, [1] does not consider the interference from the entire system and collisions caused by interference during a node state transition. S. Gobriel [3] calculates the maximum interference to a node without considering the effect of transmit power on the number of interfering nodes. [3] also does not consider the interference from the entire system in calculating throughput and consumed energy. M. M. Carvalho [5] models a node's energy consumption in a single-hop ad hoc network using IEEE 802.11 DCF. However, [5] does not consider the effect of interference on energy consumption. M. M. Carvalho [4] models channel access protocols in multihop ad hoc network considering the effect of physical-layer parameters. [6] computes the average service time and jitter experienced by a packet when transmitted in a saturated IEEE 802.11 ad hoc network. However, no model considers the effect of interference from the entire system on a node's performance.

3 Background

IEEE 802.11 is based on CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). Carrier sensing is performed using both physical carrier sensing (by air interface) and virtual carrier sensing. The effect of physical carrier sensing is determined by the transmit power of the sender. Virtual carrier sensing is performed by including the duration of the packet transmission in the header of RTS, CTS and DATA frame, which indicates how long the transmission will last.

In a wireless network, a frame is considered to be successfully received if the Bit Error Rate (BER) is acceptable. Additive white gaussian noise (AWGN) is used to model the noise

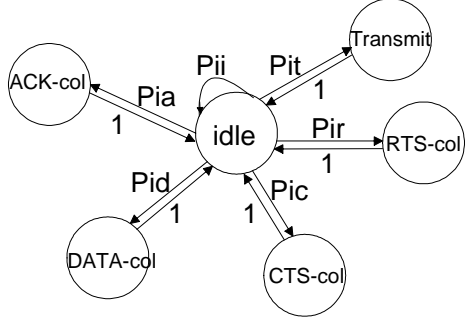


Figure 1 Wireless node state transition diagram

at the receivers, which is calculated by SNR (signal to noise ratio). The interference is calculated by SIR (signal to interference ratio). We assume AWGN is fixed in this paper. If no interference exists, high SNR can produce the target BER. If interference exists, then either SNR or SIR are insufficient to evaluate an acceptable BER. A low SIR will cause high BER.

We define a term related to the wireless radio, *Interference Range*. Interference Range is centered at the receiver and represents the range within which the other nodes are capable of interfering with the reception of frames at the receiver. The interference comes from all the transmitting nodes except the transmitter. Since the effects of interference are cumulative, a sufficient number of low interference causing nodes will disrupt the reception of a frame. The interference from a node depends on its transmission power, distance and the path loss.

RTS/CTS handshake effectively avoids interference from nodes inside the CCA (*Clear Channel Assessment*) busy range of a transmitting node and the transmission range of a receiving node (see details in [9]). However, the handshake can not avoid interference from interfering nodes. Therefore, RTS/CTS handshake can not guarantee a successful transmission.

Therefore, interference from all nodes must be included in a study to infer the effectiveness of a MAC protocol. In the next section, we present a model to calculate the interference.

4 Node State Transitions

In this section, we calculate a node's throughput, consumed energy, and delay time using a Markov Chain model.

4.1 Node State Transition

The node's state transition diagram is as shown in Figure 1. Our model is different than previous work [1, 3] in that: 1) we consider the interference from the entire system; 2) we consider the effect of interfering nodes on the collisions of RTS, CTS, DATA, and ACK (each of a node's transition states).

The state transitions occur during a randomly given slot time σ (σ is the length of a slot time), are as follows:

1) Idle to Idle: There is no transmission and the duration (T_{ii}) is σ ;

2) Idle to Transmit: There is a successful transmission and the duration (T_{it}) is $L_{DIFS}+L_{RTS}+L_{SIFS}+L_{CTS}+L_{SIFS}+L_H+L_{DATA}$

$+L_{SIFS}+L_{ACK}+L_{SIFS}$, where L_{RTS} , L_{CTS} , L_H , L_{DATA} , L_{ACK} , L_{DIFS} , and L_{SIFS} are the length of RTS, CTS, DATA header (including physical layer and MAC layer header), DATA, ACK, DIFS, and SIFS respectively;

3) Idle to RTS-col: There is a collision during RTS and the duration (T_{ir}) is $L_{DIFS}+L_{RTS}+L_{SIFS}$;

4) Idle to CTS-col: There is a collision during CTS and the duration (T_{ic}) is $L_{DIFS}+L_{RTS}+L_{SIFS}+L_{CTS}+L_{SIFS}$;

5) Idle to DATA-col: There is a collision during DATA transmission and the duration (T_{id}) is $L_{DIFS}+L_{RTS}+L_{SIFS}+L_{CTS}+L_{SIFS}+L_H+L_{DATA}+L_{SIFS}$;

6) Idle to ACK-col: There is a collision during ACK and the duration (T_{ia}) is $L_{DIFS}+L_{RTS}+L_{SIFS}+L_{CTS}+L_{SIFS}+L_H+L_{DATA}+L_{SIFS}+L_{ACK}+L_{SIFS}$.

We assume the network is saturated, where each node always has data to transmit. A node transmits with a probability, p , at a randomly given slot time, σ . p is calculated approximately as [7]:
$$p = \frac{2(1-2\beta)}{(1-2\beta)(W+1) + \beta W(1-(2\beta)^m)}, \quad (1)$$

where W is the size of the minimum backoff contention window size, β is the collision probability, and m is the backoff stage. Using p , we can derive the transition probabilities for node state transitions. Let P_{ii} represent the transition probability from idle to idle, $P_{ii} = (1-p)^N$, where N is the number of nodes inside the transmitting node's transmission range. Let P_{it} represent the transition probability from idle to successful transmission, and is given by:

$$P_{it} = p(1-p)^{N-1}P_{hidden_suc} \quad (2)$$

$$\text{where } P_{hidden_suc} = \left(\sum_{j=0}^{N_{lim}} p^j (1-p)^{N_{out}-N_{lim}} \right)^{(T_{suc}/\sigma)} \quad (3)$$

Equation 2 asserts that two kinds of nodes can transmit during T_{suc} : the transmitter itself (shown with p), and any other node whose transmission will not interfere with that of the transmitter (shown with P_{hidden_suc}). In the equation,

$(1-p)^{N-1}$ avoids transmission from the nodes inside the transmitter's transmission range. N_{lim} is the maximum number of interfering nodes which can transmit during T_{suc} , yet do not interrupt the frame's transmission (i.e., they do not cause a low enough SIR). We derive N_{lim} in Section 4.2. N_{out} is the number of the nodes outside of the transmitter's transmission range.

Let P_{ir} represent the transition probability from idle to RTS transmission with a collision, which could be caused by either 1) at least one other node inside the transmitter's transmission range transmitting at the same time as the transmitter; or, 2) the transmitter is the only one transmitting in its transmission range, but more than N_{lim} interfering nodes transmit simultaneously during T_{RTS} . P_{ir} is given by:

$$P_{ir} = p(1-(1-p)^{N-1}) + p(1-p)^{N-1}P_{hidden_rts} \quad (4)$$

$$\text{where } P_{hidden_rts} = \left(1 - \sum_{j=0}^{N_{lim}} p^j (1-p)^{N_{out}-N_{lim}} \right)^{(T_{RTS}/\sigma)} \quad (5)$$

where P_{hidden_rts} is the probability that more than N_{lim} interfering nodes transmit simultaneously during T_{RTS} .

Let P_{ic} represent the transition probability from idle state to CTS transmission with a collision. Since the RTS was a success, the collision must have been caused by more than N_{lim} interfering nodes transmitting simultaneously during CTS frame transmission. It is: $P_{ic} = p(1-p)^{N-1} P_{hidden_cts}$ (6)

$$\text{where } P_{hidden_cts} = \left(1 - \sum_{j=0}^{N_{lim}} p^j (1-p)^{N_{out}-N_{lim}} \right)^{(T_{CTS}-T_{RTS})/\sigma} \quad (7)$$

P_{hidden_cts} is the probability that more than N_{lim} interfering nodes transmit simultaneously during CTS frame.

Let P_{id} represent the transition probability from idle to DATA transmission with a collision. Since the RTS/CTS was a success, the collision must have been caused by more than N_{lim} interfering nodes transmitting simultaneously at the time period when the DATA frame is in transmission. It is given by:

$$P_{id} = P(1-p)^{N-1} P_{hidden_data} \quad (8)$$

$$\text{where } P_{hidden_data} = \left(1 - \sum_{j=0}^{N_{lim}} p^j (1-p)^{N_{out}-N_{lim}} \right)^{(T_{DATA}-T_{CTS})/\sigma} \quad (9)$$

where P_{hidden_data} is the probability that more than N_{lim} interfering nodes transmit simultaneously during DATA frame transmission.

Let $S_i, S_r, S_r, S_c, S_d,$ and S_a denote the steady-state probabilities of the node state: idle, transmit, RTS-col, CTS-col, DATA-col, and ACK-col respectively. Since $P_{ii}+P_{it}+P_{ir}+P_{ic}+P_{id}+P_{ia} = 1$ and $S_i+S_t+S_r+S_c+S_d+S_a = 1$, based on the closed-form for the Markov Chain, we have:

$$S_i P_{ii} + S_t + S_r + S_c + S_d + S_a = S_i, \text{ that is, } S_i = \frac{1}{2 - P_i}.$$

The transmit state limiting probability, τ_t , represents the percentage of time the node is successfully transmitting, i.e., it is the ratio of the successful transmission time to the total transmission time (including both successful transmission time and collision time). As for a successfully transmitted payload, it is the payload of the DATA frame, and is given by:

$$\tau_t = \frac{S_i L_{DATA}}{S_i T_{ii} + S_t T_{it} + S_r T_{ir} + S_c T_{ic} + S_d T_{id} + S_a T_{ia}} \quad (10)$$

$$= \frac{S_i P_{it} L_{DATA}}{S_i T_{ii} + S_t P_{it} T_{it} + S_r P_{ir} T_{ir} + S_c P_{ic} T_{ic} + S_t P_{id} T_{id} + S_t P_{ia} T_{ia}} \quad (11)$$

The throughput of the network is nothing but $\tau_t \times \lambda$, where λ is the packet arrival rate. In the next section, we derive λ .

4.2 Throughput, Consumed Energy, and Delay Time

We calculate a node's throughput, consumed energy, and delay time under maximum interference. To model maximum interference, we use a honey grid model [2].

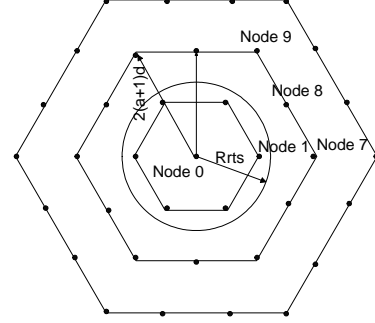


Figure 2 Honey Grid Model

Honey grid model: In a honey grid, the nodes are uniformly distributed and form concentric hexagons, called rings around a transmitting node. Based on such a model, we can obtain an upper bound on the interference experienced by a node without considering the node's moving patterns and its exact location. The model allows us to analyze how the maximum interference affects either a multi-hop or a single-hop ad hoc network's performance. A sample honey grid is shown in Figure 2. The j^{th} ring has $6 \times j$ nodes. We consider the interference from both control and data frames, and assume that transmit power for DATA and ACK is the same. Similarly, transmit power for RTS and CTS is the same. A node's reach, a , is defined as the number of rings covered by its transmission range. k is the total number of rings in the network. d is the distance between two consecutive rings. The maximum packet arrival rate, λ_{max} , to a node, is (See details in [9]):

$$\lambda_{max} = \frac{1}{\bar{H}} \ln \left(1 - \frac{G P_{data} d^{-\alpha} \Pi}{3 SIR_{min} (a+1)^{-(\alpha-1)} d^{-\alpha} \sum_{j=1}^{int(k/(a+1))} j^{-(\alpha-1)}} \right)$$

$$\text{where } \Pi = \frac{T_{total}}{P_{data}(L_{DATA} + L_{ACK}) + P_{rts}(L_{RTS} + L_{CTS})}$$

where G is the processing gain [8], which is 10.4dB in IEEE 802.11 DSSS; P_{data} is the transmit power of the transmitter; d_{data} is the distance from the transmitter to the receiver; SIR_{min} is the minimum required signal to interference ratio; α is the path loss exponent; P_{data} is the transmit power of the data frames; P_{rts} is the transmit power of the control frame; T_{total} is equal to T_{suc} in section 4.1.

$\bar{H} = 0.53 N_r^{0.5} + 2 \left(1 - \frac{N_r}{N} \right)$, is the average hop count, where $N_r = \sum_{j=1}^{k/a} 6j$, is the number of relay nodes, and $N = \sum_{j=1}^k 6j$, is the number of nodes in the entire network. The maximum number of interfering nodes (N_{lim} in equations 3, 5, 7, and 9) is given by: $N_i = \sum_{j=1}^{int(k/(a+1))} 6(a+1)j$ (12)

Throughput: Let S be the normalized system throughput, defined as the fraction of time the channel is used to success-

fully transmit data payload without causing a collision. S is given by: $S = \lambda_{max} \tau_t$

Consumed Energy: The energy consumed in the network, E , is the sum of the energy consumed by each hop in sending a packet. When the node state is at successful transmission, S_p , energy consumed in receiving the transmission must be added. The six states already consider retransmissions (due to collisions). Therefore, E is given by

$$E = \bar{H}(S_{ii}e_{ii}\sigma + S_{it}(e_{rts}L_{RTS} + e_{cts}L_{CTS} + e_{data}L_{DATA} + e_{ack}L_{ACK} + e_{r-rts}L_{RTS} + e_{r-cts}L_{CTS} + e_{r-data}L_{DATA} + e_{r-ack}L_{ACK}) + S_{ir}e_{rts}L_{RTS} + S_{ic}(e_{rts}L_{RTS} + e_{cts}L_{CTS}) + S_{id}(e_{rts}L_{RTS} + e_{cts}L_{CTS} + e_{data}L_{DATA}) + S_{ia}(e_{rts}L_{RTS} + e_{cts}L_{CTS} + e_{data}L_{DATA} + e_{ack}L_{ACK}))$$

where e_{ii} represents energy consumed in idle state; e_{rts} , e_{cts} , e_{data} and e_{ack} represent energy consumed in transmitting RTS, CTS, DATA and ACK, respectively; e_{r-rts} , e_{r-cts} , e_{r-data} and e_{r-ack} represent energy consumed in receiving RTS, CTS, DATA and ACK, respectively.

Delay Time: We consider the delay time, D , to be the sum of the time spent in all six possible states in each hop. The time spent in each transition state is equal to the duration of the state. So, the delay time in the network is given by:

$$D = \bar{H}(S_{ii}T_{idle} + S_{it}T_{it} + S_{ir}T_{ir} + S_{ic}T_{ic} + S_{id}T_{id} + S_{ia}T_{ia}) \quad (13)$$

Based on Equations 14, 15, and 16, we can calculate a node's throughput, consumed energy and delay time.

5 Numerical Results

In this section, we give numerical results on throughput, consumed energy, and delay time using a honey grid ad hoc network with 20 rings. The distance, d , between two rings is 30m. We then change d and the contention window size, and conduct a sensitivity analysis.

Parameter	Symbol	Value
RTS Length	L_{RTS}	160 bits
CTS Length	L_{CTS}	112 bits
DATA Length	L_{DATA}	4096 bits
ACK Length	L_{ACK}	112 bits
SIFS	SIFS	10 μ s
DIFS	DIFS	50 μ s
slot time	σ	20 μ s
channel B/W	bw	2 Mbps
Header (MAC+PHY)	H	416 bits
Processing Gain	G	10.4 dB
Path loss factor	α	2
Contention Window	CW	31
SIR Threshold	SIR_{min}	10 dB

Table 1: Network Parameters

min_R_{data} denotes the minimum required R_{data} and is 40m in the network. Table 1 lists the parameters we used [8].

5.1 Baseline results

In this section, we show how different transmit powers for RTS and DATA affect a node's throughput, consumed energy,

and delay time. All the numerical results are obtained with the minimum contention window size (CW=31) and the distance between two rings of 30 meters.

Figure 3 shows how the R_{data} (the transmission radius of DATA frame) and R_{rts} (the transmission radius of RTS) affect the throughput. The x-axis is the ratio of R_{data} to min_R_{data} . It increases from one to 4.5 times min_R_{data} (transmit power increases from 0.001mW to 0.0758 mW). The y-axis is the throughput. The three plots in Figure 3 represent throughput with three different R_{rts} , shown as multiples of min_R_{data} : 2.25, 3, and 4.5. For a fixed R_{rts} , when R_{data} is equal min_R_{data} , the throughput is not the maximum, and the maximum throughput occurs around 1.25 times the minimum required transmit power for data frame. We call this the *optimal transmit power* for a data frame. The throughput increases with increased R_{data} until this optimal value. This is because with the increase of R_{data} , the number of interfering nodes is reduced. When R_{data} exceeds the optimal value, the throughput decreases. This is because more nodes will be covered in the transmitter's transmission range and the contention between nodes is increased. Recall Equation 2, with the larger R_{data} , N is increased, and, P_{it} (probability of successful transmission) is reduced. With smaller but sufficient R_{data} , these nodes can transmit yet not interfere with the transmitter's transmissions. For the same reason, a longer R_{rts} results in lower throughput.

Figure 4 shows the relation between the consumed energy and R_{rts} . The y-axis is the energy consumed in the network. As shown in Figure 4, with a fixed value of R_{rts} , energy consumption increases at about the same rate as R_{data} . The reasons are: 1) a higher R_{data} means a higher transmit power; 2) a higher transmit power causes more interference between nodes, causing more collisions. As a result, energy consumption due to retransmissions increases. Varying R_{rts} , we see that a longer R_{rts} consumes more energy. The reason is the same as explained above. The minimum energy consumption per frame is achieved at the optimal R_{data} , which is calculated by dividing throughput by energy consumption. Although min_R_{data} consumes the least energy, transmission with optimal R_{data} achieves the maximum throughput, yet consumes just a little more energy than min_R_{data} .

Figure 5 shows the relation between the delay time and R_{rts} . The plots show that the delay time at min_R_{data} is less than the delay time when R_{data} is between 1.5 times to 3.5 times min_R_{data} . When R_{data} is larger, we would expect a lower delay since fewer hops would be necessary. However, now that the transmission power is increased, the contention between nodes is also increased, causing a longer delay time. Recall Equation 2, with the larger R_{data} , N is increased and P_{it} (probability of successful transmission) is reduced. This increases the

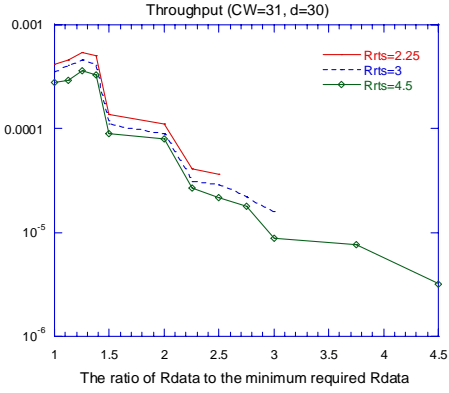


Figure 3 Throughput & Rrts

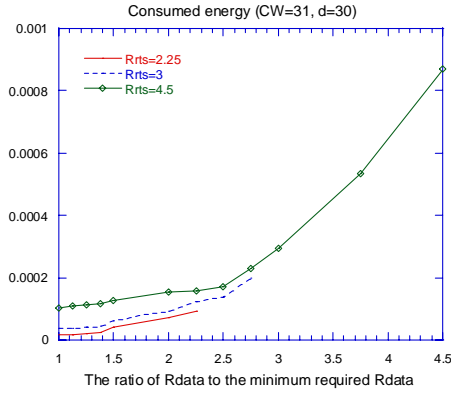


Figure 4 Consumed Energy & Rrts

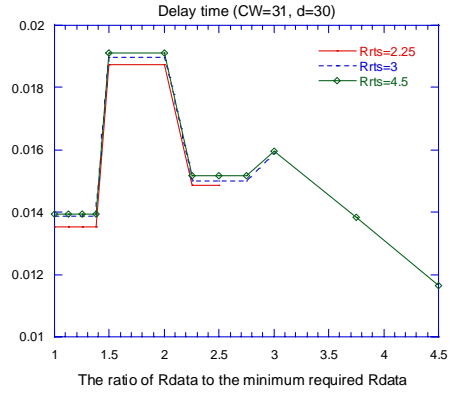


Figure 5 Delay time & Rrts

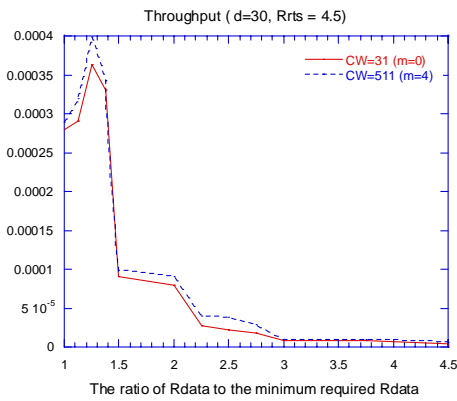


Figure 6 Throughput & CW (d=30)

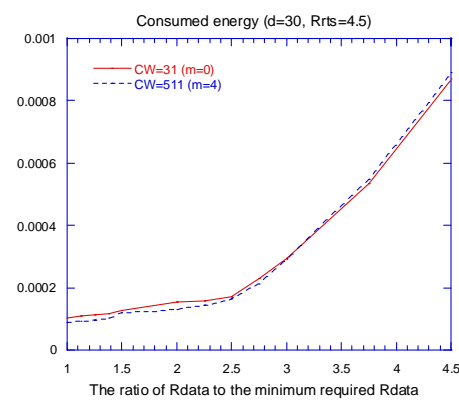


Figure 7 Consumed Energy & CW (d=30)

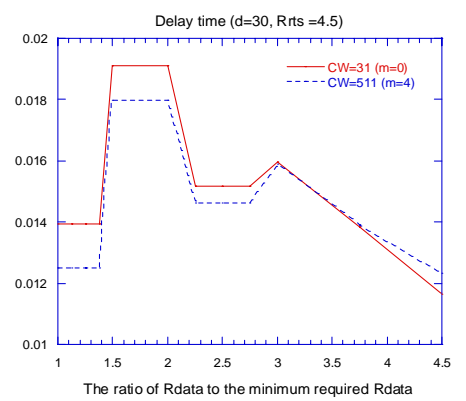


Figure 8 Delay time & CW (d=30)

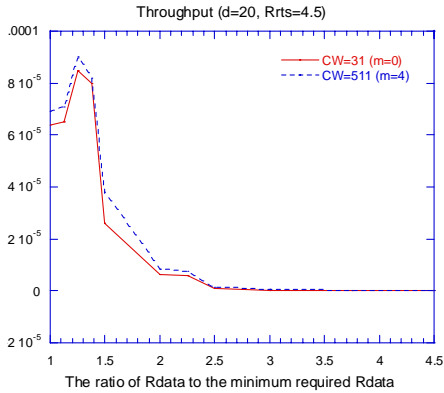


Figure 9 Throughput & CW (d=20)

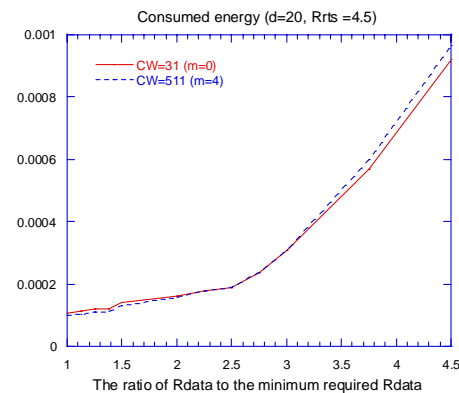


Figure 10 Consumed Energy & CW (d=20)

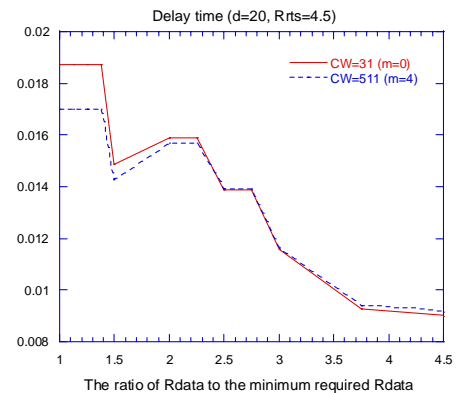


Figure 11 Delay time & CW (d=20)

delay time. When the number of hops is small enough, delay time is reduced. For example, when R_{data} is increased to more than 3.5 times min_R_{data} , the delay time is decreased and is less than the delay time achieved at min_R_{data} . The discontinuities are due to the abrupt change in the number of relay nodes used. When R_{data} is increased so that the next larger ring is reached, the number of relay nodes will be reduced, and will stay the same until the next higher ring. At a given R_{data} the

delay time is increased with a larger R_{rts} due to increased contention between nodes.

5.2 Sensitivity Analysis

In this section, we show throughput, energy consumed and delay time for different values of CW (contention window) and d (the distance between two rings). We fix R_{rts} at 4.5 times min_R_{data} . We plot two sets of results, first with $d=30m$ and then $d=20m$.

$d=30$: Figures 6, 7, and 8 include plots with CW of 31 (the minimum contention window size ($m=0$) in Equation 1) and CW of 511 ($m=4$ in Equation 1). CW 511 achieves a higher throughput than CW 31. This is because the contention between nodes is reduced with a higher CW . As shown in the Figure 7, the consumed energy is increased with the increase of R_{data} . When R_{data} is from 1 to 3 times min_R_{data} , the energy consumed by the larger CW is less than the energy consumed by the smaller CW . This is because the contention between nodes is reduced with the increase of contention window size. When R_{data} is from 3 to 4.5 times min_R_{data} , the energy consumed by CW 511 is more than the energy consumed by CW 31. This is because the contention between nodes is increased with the increase of R_{data} and the contention caused by increased R_{data} is larger than the contention reduced by increased CW . As shown in the Figure 8, when R_{data} is from 1 to 3 times min_R_{data} , the delay time with CW 511 is less than the delay time with CW 31. When R_{data} is from 3 to 4.5 times min_R_{data} , the delay time with the CW 511 is more than that with CW 31. The reasons are similar to consumed energy plots.

$d=20$: Figures 9, 10, and 11 show the throughput, consumed energy, and delay time in a honey grid network with $d=20$ and $R_{rts}=4.5$. As shown in Figure 9, the throughput achieved at the larger CW is always better than the throughput achieved at the smaller CW . Compared to Figure 6, the throughput is reduced by almost four times. As shown in Figure 10, when R_{data} is from 1 to 3 times min_R_{data} , the energy consumed with the larger CW is a little less than with the smaller CW . When R_{data} varies from 3 to 4.5, energy consumed by the larger CW is more than that of the smaller CW . Compared with Figure 7, the gap between them is increased due to increased contention between nodes when the density of the nodes is increased (the density of nodes is increased with smaller distance between two rings). Compared with Figure 7, slightly more energy is used. In Figure 11, the maximum delay time occurs at min_R_{data} whereas in Figure 8, delay time for min_R_{data} is much smaller. This is because the increased contention in the network more than offsets the reduction in the number of the relay nodes. The delay time is reduced with increased R_{data} since the effect of the reduction in the relay nodes becomes more pronounced than the effect of the increase in the contention.

5.3 Summary

From the numerical results, we conclude that 1) there exists an optimal R_{data} for maximum throughput; 2) throughput is reduced with the increase of R_{rts} (transmit radius of control frames as determined by transmit power of control frame); 3) throughput is increased with the increase of CW ; 4) throughput is reduced with the increase of node density. Concerning energy consumption, we conclude: 1) the consumed energy is increased with the increase of R_{rts} and R_{data} (transmit radius

of data frame as determined by transmit power of data frames); 2) the consumed energy is reduced with the increase of the node density; 3) the consumed energy is determined by combining transmit power, CW , and density of nodes; and 4) the minimum consumed energy per frame is achieved at the optimal R_{data} . We also see that using higher transmit power alone can not reduce delay time. Delay time is determined by a combination of transmit power, node density, and CW .

6 Conclusions

In this paper, we model a wireless node's performance using a Markov Chain model. We consider the effect of all interfering nodes on each of node's transition states. To investigate a node's performance under the maximum interference, we calculate a node's throughput, consumed energy, and delay time in a uniform honey grid model. From the numerical results, we see that transmit power, contention window size, and node density will all affect a node's performance. There is a trade off between the maximum throughput, the minimum consumed energy, and the delay time. The maximum throughput can occur with the minimum consumed energy per frame but not with the minimum delay time per frame. The higher transmit power can not guarantee to achieve a lower delay time. These results should be useful in designing power control protocols and other MAC related protocols. In particular, the derived Markov model probabilities are simple to use: it is sufficient to just plug in the numbers, such as transmit powers for data and control frames, contention window size, and packet arrival rate, to obtain system performance under maximum interference. Protocol designers could then decide which performance metrics are important to finalize the power levels. We are currently developing a power control protocol that adaptively adjusts the power levels based on the findings in this paper.

References:

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