A Simplified Analytical Model for End-To-End Delay Analysis in MANET

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ABSTRACT
In order to provide quality delivery to delay sensitive applications such as voice and video, it is extremely important that mobile Ad hoc networks provide quality of service (QoS) support in terms of bandwidth and delay. In spite of using IEEE 802.11 as medium access control (MAC), most of the Ad hoc routing protocols do not consider MAC delay contention time, which occurs, in the medium reservation. Large contention times can be more critical than hop counts in determining the end-to-end delay. Most existing MANET routing protocols such as AODV, DSR and OLSR are designed to search for the shortest path with minimum hop counts. However, the shortest routes do not always provide the best performance, especially when there are congested nodes along these routes. In this paper we present an analytical model for average end-to-end delay that takes into account the packet arrival process, backoff and collision avoidance mechanisms of random access MAC between a pair of source and destination and compares the end-to-end delay experienced by a QoS AODV protocol. The proposed analytical model results closely match with the results obtained from our simulations.

General Terms
Performance Measurement of Mobile Ad hoc Networks.

Keywords
Mobile Ad hoc network, AODV, QoS, delay, MAC, NS2, Modeling.

1. INTRODUCTION
A multi-hop wireless Ad hoc network [14] is a collection of nodes that communicate with each other without any established infrastructure or centralized control. Many factors interact with each other to make the communication possible like routing protocol and channel access. A number of routing protocols have been proposed for Ad hoc mobile networks. Generally speaking these protocols are classified into two broad categories: proactive (table driven) and on demand routing (source initiated) [15]. Proactive protocols are less efficient than the later, as they need more network resources to maintain up-to-date routing information to every other node in the network. On the other hand, on-demand routing protocols initiate route discovery (route request and route maintenance) as and when required and these protocols only maintain the part of routing table currently in use. On demand routing protocols react to topology change quickly and also save routing overheads compared to proactive routing protocols. Many routing protocols have been proposed for MANETs. Most of the current Ad hoc routing protocols only use number of hops as a measure of route cost in making routing decisions. But in this some important link capacity properties are ignored due to simplicity and ease of implementation. Firstly, as each node has a different traffic load, therefore the average number of packets in the queue and the associated queuing delay at each node is different. Secondly, as the number of neighbor nodes as well as their traffic patterns are different, and thus, nodes that have more number of active neighbors may encounter more collisions. If some of the heavily loaded nodes fall on the shortest route, it may actually introduce longer end-to-end delay, even though the number of hops along the chosen route is minimum. Furthermore, if some of the heavily loaded nodes are congested, it may lead to massive packet drop rates and subsequent retransmission. This increases end-to-end delay between two end points, which makes it unsuitable for delay bound applications. Most of the mobile Ad hoc networks use IEEE 802.11 [13] as the underlying MAC protocol. In IEEE 802.11, each node contends with its neighbor nodes and also the neighbors of its neighbors in the medium contention procedure. Since the range of possible medium contention of a mobile node is wide, medium contention times can greatly affect the end-to-end delay considerably. The main contribution of this paper is to propose a new analytical delay model that provides delay guaranteed route between source and destination pairs for mobile Ad Hoc Networks. Earlier papers [16,17,18] consider only minimum number of hops as route selection metric.

The remainder of the paper is organized as follows. In section 2, related work for end to end delay and throughput estimation in mobile ad hoc network has been briefly presented. Our analytical model has been presented in section 3. In section 4, we evaluate our analytical model in comparison with results obtained by simulation analysis. Section 5 concludes the paper.

2. REATLED WORK
Jun et al. [1] proposed an analytical model for estimating average end-to-end-delay and average throughput by using an analytical mobility model. Sharma et al. [2] proposed average end-to-end delay and maximum achievable per-node throughput for in-vehicle Ad hoc multimedia network with stationary and mobile nodes. The relative traffic load, number of slots assigned to each link, and the schedule frame length are used to compute expected end-to-end delay. LinFang et al. [3] used Markov chain

model to analyze the channel access delay of IEEE 802.11 DCF multi-hop Ad hoc networks. Each node was modeled as an M/G/1 queue and derived the queuing delay. The model has also been extended from analyzing the single-hop average packet delay to evaluating the end-to-end packet delay in multi-hop Ad hoc networks under different traffic loads. The delay in both saturated and unsaturated networks were studied in [8], where each node was modeled as a discrete time queue. Chen et al. [9] studied multi-hop delay in the context of mesh networks. In [10], throughput-delay analysis is studied in Ad hoc network with Kleinrock independence approximation by using TDMA. A disadvantage of [10] which use contention-free multiple access protocol is that the increasing complexity of TDMA in MANETs could not be the best solution.

3. ANALYTICAL MODEL

We present our analytical model in this section. IEEE has standardized the 802.11 protocol for Wireless Local Area Networks [13]. This standard works in two modes: DCF (Distributed Coordination Function) and PCF (Point Coordination Function). The primary medium access control (MAC) technique of 802.11 is called distributed coordination function (DCF). It is a carrier sense multiple access with collision avoidance (CSMA/CA) scheme with binary slotted exponential backoff. It is well known fact that 802.11 DCF can be used as MAC scheme of multi-hop wireless Ad hoc networks. In the following we use Sheu et al. [12] approach for predicting the medium access delay (MAC) of a mobile node in IEEE 802.11 DCF [13] mode. Data transmission by a mobile node MNi in DCF mode using RTS and CTS handshake to avoid hidden terminal problem is depicted in Figure 1.

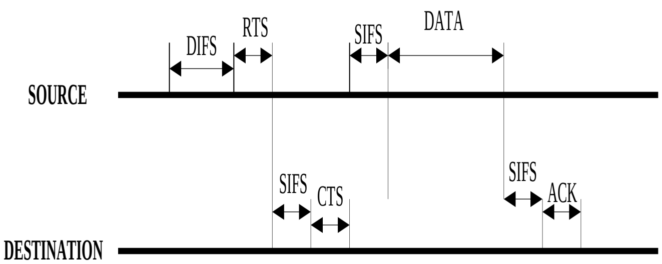

Figure: 1 Data transmission in IEEE 802.11 (DCF mode) using RTS and CTS

3.1 Network Model

The network consists of N nodes, which are distributed uniformly and independently over a rectangular area. Each node is assumed to have an equal transmission range, denoted by r(n). Let r_{ij} denote the distance between nodes i and j. Nodes i and j are said to be neighbors if they can directly communicate with each other, i.e. if $r_{ij} \leq$r(n). The transmission rate of each node equals R_t bits/seconds. Node i can successfully transmit a packet to node j only if i is a neighbor of j and no other neighbor of j is transmitting currently with node i. The traffic model for the network may be described as follows. Each node in the network could be a source, destination and/or relay of packets. In our model, for simplicity, we assume that the aggregate packet arrival rate at a mobile node is λ packets/sec, which includes packets generated by the mobile node itself as well as packets arrived from neighbor nodes for forwarding and it is given by equation (1)

$$\lambda = n \times \lambda_i \tag{1}$$

where λ_i is the packet arrival rate of mobile node MN_i itself and n is its neighboring nodes. Further, the size of each packet is assumed to be constant and equals L bits in length. Figure 2 depicts the delay model with parameters we derive.

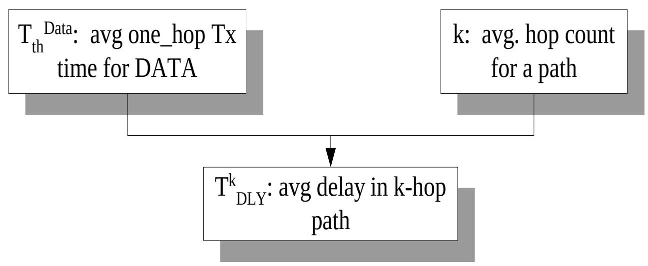

Figure: 2 Performance model parameters: end-to-end delay

3.2 Delay Analysis

3.2.1 Node Delay Analysis

Figure 3 depicts the state transition diagram of a mobile node MN_i , trying to transmit packets to another mobile node in a mobile Ad hoc Network which uses IEEE 802.11 standard [13] at the MAC layer. The MAC delay at a mobile node MN_i , which includes MAC contention and transmission delay is calculated using equation (2) given in [12]. This delay is the delay from the moment a packet reaches the head of the queue to the time the sender knows the packet is successfully received through the reception of an ACK. This expression of MAC delay gives average service time of a packet in a node. It consists of three parts:

- Time to transmit packet successfully once
- Total time a node spends in backoff
- Total transmission time used for retransmission of the packet

$$D^{i}_{delay} = P^{i}_{idle}(DIFS) \times (\text{DIFS} + \text{avg\_bt} + \text{DA(i)}) + (1- P^{i}_{idle}(DIFS)) \times (\text{SIFS+DB(i)})+(\text{L}/ R_t)$$
(2)

where

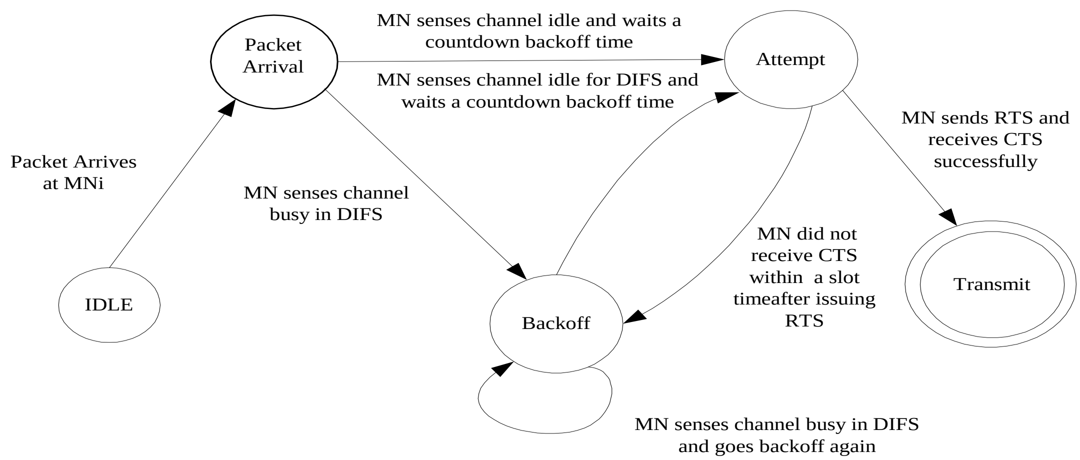

Figure 3: State transition diagram of a mobile node (MN_i) in IEEE 802.11 protocol

P^i_{idle}(t) is the probability that mobile node MN_i detects no other mobile node transmitting data during time interval t and is given by

P^i_{idle}(t)= $e^{-\lambda t}$, λ is the aggregate arrival rate (including neighbor nodes) at mobile node MN_i .

DA(i) is expected delay encountered in the Attempt state and given by

$$DA(i)= P^i_{idle}(slot)\times(RTS+2\times SIFS+CTS)+(1-P^i_{idle}(slot))\times(RTS+2\times SIFS+DB(i)) \quad (3)$$

DB(i) is expected delay encountered in the Backoff state and is given by

$$[P^i_{idle}(DIFS)\times(DIFS+avg\_bt+RTS+2\times SIFS+P^i_{idle}(slot)\times CTS)]+[(1-P^i_{idle}(DIFS))\times X] \quad (4)$$

avg_bt is a random backoff time interval before transmission and is given by Equation (5)

$$avg\_bt=\sum_{n=0}^{4}(P^i_{idle}(slot)\times(1-P^i_{idle}(slot))**n\times 2**(n-1)\times W)+(1-P^i_{idle}(slot))**5\times 2**4\times W \quad (5)$$

L and R are packet size and data rate respectively,

W is contention window size and X is given by the following expression

X=RTS+3$\times$SIFS + CTS + L + ACK,

ACK is length of acknowledgement packet. In wireless links, the propagation delays are very small and almost equal for each hop along the path. So, here we assume that the propagation delay is negligible.

D^i_{delay} is one hop delay when each node in the network is contending with N-1 nodes.

Table 1 Parameters used in Analytical and Simulation

Parameter	Value
Slot time	20 μ s
SIFS	10 μ s
DIFS	SIFS+2$\times$ slot time=50 μ s
RTS	352 μ s
CTS	304 μ s
ACK	304 μ s
MSDU (MAC Layer Data Unit)	1500bits
Bandwidth	2 Mbps
Radio signal transmission range	250m
Arrival Rate	8 packets/sec
CWmin	32 slots
CWmax	1024 slots
PHY scheme	DSSS
Noumber of mobile nodes	50
Terrain size	1500m $\times$ 300m
Simulation time	900 seconds
Transmission radius	100m
Mobility model	Random Waypoint
Traffic	CBR
Packet size	512 bytes

3.3 End-to-End Delay Analysis in Multi-hop Network

In mobile Ad hoc Network, the end-to-end delay is the delay encountered by a packet which is measured from the time the packet is generated to the time the source node receives an ACK packet indicating successful reception of the packet by the destination node. The packet delay consists of the queuing delay experienced at the source node, the queuing delays incurred at the intermediate nodes as well as MAC delay observed at the source and intermediate nodes.

3.3.1 Average Path Length

Let us call node delay D^{i}_{delay} which is one hop delay as E(T). Then we can express E(T) by the following equation (6)

$$E(T) = P^{i}_{idle}(DIFS) \times (DIFS + avg\_bt + DA(i)) + (1 - P^{i}_{idle}(DIFS)) \times (SIFS + DB(i)) + (L/R_t) \quad (6)$$

As every node in the network has the same settings and therefore packets in these nodes will experience the same delay i.e. E(T). In [6] Rom et al. provide an average hop count with uniformly distributed nodes on a rectangular area for a wireless Ad hoc Network. The average hop count represents the number of hops between an arbitrary source and destination pair in the network. If the average number of hops traversed per packet between a source and a destination is n_p , then the average end-to-end delay per packet can be obtained by the following equation

$$D_{E-TO-E} = n_p \times E(T) \quad (7)$$

The average number of hops traversed per packet n_p in connected networks is given by

$$\frac{E\{S\}}{r(n)} \quad (8)$$

where $E\{S\}$ in a rectangular area is given as follows[5].

$$E\{S\} = \frac{1}{15}\left[\frac{a^3}{b^2} + \frac{b^3}{a^2} + \sqrt{(a^2+b^2)} \times \left(3 - \frac{a^2}{b^2} - \frac{b^2}{a^2}\right)\right] + \frac{1}{6}\left[\frac{b^2}{a} ar\cosh\frac{\sqrt{(a^2+b^2)}}{b} + \frac{a^2}{b} ar\cosh\frac{\sqrt{(a^2+b^2)}}{a}\right] \quad (9)$$

with $ar\cosh(x) = \ln(x + \sqrt{(x^2-1)})$

In order to compute n_p, we assume a rectangular network topology for a wireless Ad hoc network with terrain size a $\times$ b m where a and b denote its length and width. We choose MN_A (source node) and MN_B (destination node) along a path as depicted in Figure 4 to compute average hop count.

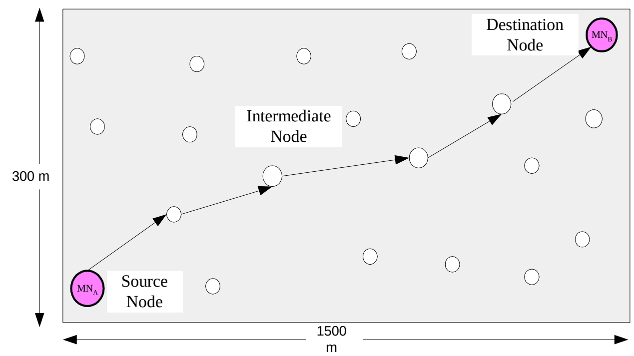

Figure 4: Network topology (Terrain size 1500 $\times$ 300 m)

As the network size is 1500 $\times$ 300 m, the average distance between MN_A and MN_B in this case by applying equation (9) is 6 hops as the radio range of each mobile node is 250 m (Table 1).

4. MODEL EVALUATION

In this section, we evaluate the precision of our mathematical expressions by comparing the delay performance behavior of a multi-hop network system as predicted by our analytical model in comparison with results obtained by simulation analysis [11]. In [11] authors proposed a QoS routing protocol for delay sensitive applications. All simulations were carried out using the ns-2 simulator [7] and the simulation parameters are presented in Table 1. We perform a comparison for a network of 50 nodes in a 1500m $\times$ 300m terrain with traffic uniformly distributed across the network. Figure 5 depicts the expected MAC delay i.e. D^{i}_{delay} at mobile node MN_i in an Ad hoc network for different aggregate packet arrival rate obtained using Equation 2. The media access delay of a mobile node remains relatively low for lower packet arrival rate but as the packet arrival rate increases, beyond 40 Kbps, media access delay increases rapidly.

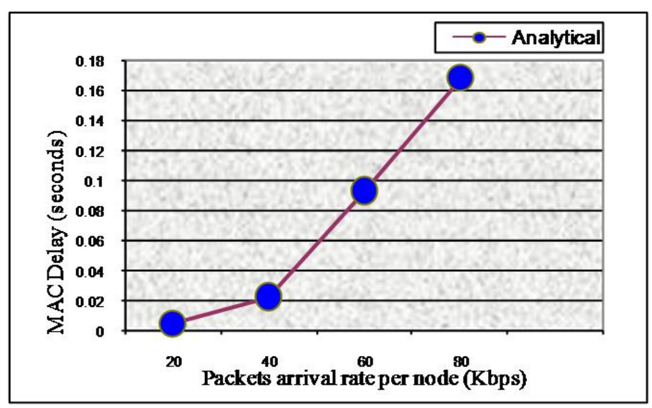

Figure 5: Expected MAC delay of mobile node MN_i under different packet arrival rate

The theoretical values of the average end-to-end delay per packet obtained analytically using equation (7), with respect to different packets arrival rate has been plotted along side the simulation results in Figure 6. The values of the parameters used to obtain numerical results, for both the analytical model and the simulation runs, are summarized in Table 1. We use the ns-2 [7] simulator to validate our delay modeling. It is observed that the simulation results agree closely with the theoretical values when packet arrival rates are between 20 and 60 Kbps. Hence the model validates the simulation results.

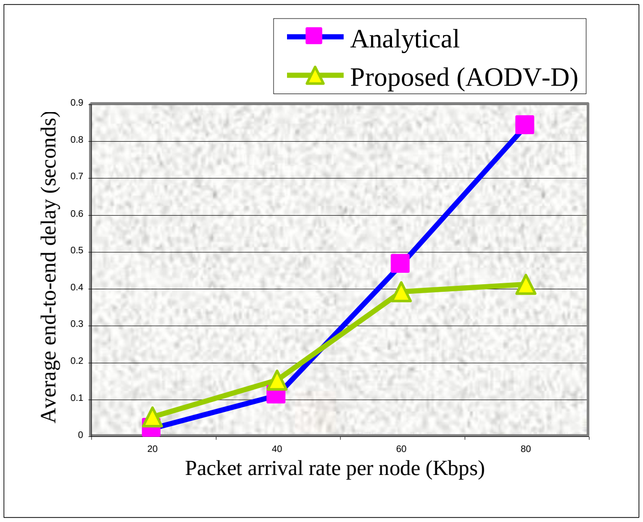

Figure 6: Average end-to-end delay of mobile node MN_i under different packet arrival rate through analytical and simulation

5. CONCLUSIONS

In this paper, we presented an analytical model for computation of end-to-end delay experienced by a packet when transmitted in an Ad hoc network in which the IEEE 802.11 DCF is used at the MAC layer. Our analytical results confirm our previously presented simulation results in [11]. We investigated contention delay in a node in MANETs under symmetric conditions. Our analytical model captures a per node delay in MANETs, and the model was validated by simulations.

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