Performance Analysis of Traffic Load and Node Density in Ad hoc Networks

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Abstract: **In ad hoc mobile networks nodes typically communicate over wireless channels and are capable of movement. Wireless nodes also have the unique capability of transmission at different power levels. As the transmission power is varied, a tradeoff exists between the number of hops and the overall bandwidth available to individual nodes. Nodes in mobile ad hoc networks are typically battery operated. Because both the battery lifetime and the channel bandwidth are limited resources, it is important to determine the effect different transmission power levels have on the overall performance of the network. This paper explores the effect different traffic loads have on the network performance when the transmission power is varied. It is shown that in order to find an optimum node density, both the traffic load and the rate of mobility have to be taken into account. It is also shown that for sparser networks there exists a threshold after which the delivery ratio starts to decline. When the traffic load is below the point where network saturation occurs, denser networks achieve a higher delivery ratio, but at a higher cost.**

1. Introduction

Ad hoc networks are multihop wireless networks consisting of mobile hosts communicating with each other through wireless links. These networks are typically characterized by scarce resources (e.g. bandwidth, battery power etc), lack of any established backbone infrastructure and dynamic topology. A challenging but critical task that researchers have tried to address over the past few years have been development of routing protocols that suit the characteristics of ad hoc networks.

Several such routing protocols for ad hoc networks have been developed and evaluated [1], [2], [3]. These evaluations mainly focus their performance evaluations upon determining the throughput, packet delivery ratio and overhead of the different protocols. However, since many of the devices used in ad hoc networks are battery operated, they also need to be energy conserving so that battery life is maximized. Thus, when new routing protocols are being developed, these considerations should be taken into account.

In the 70s Kleinrock et al. theoretically studied the performance of Packet Radio Networks and tried to determine the optimum transmission radius. Their results were summarized in their paper “Optimum Transmission Radii for Packet Radio Networks” which was published in 1978 [4]. The paper provides an analytical analysis that explore the tradeoff between increased transmission radius, which result in fewer hops between source and destination, and the effective bandwidth lost at each node as a result of the increase in transmission range. The paper shows that the optimum number of neighbors for a given node is 6, and concludes that a node’s transmission radius should be adjusted so that it has six neighbors.

In [5] Royer et al. explore the nature of the transmission power tradeoff in mobile ad hoc networks to determine the optimum node density for delivering the maximum number of data packets. They conclude that there does not exist a global optimum density, but rather that, to achieve this maximum, the node density should increase as the mobility rate of nodes increases. Their simulations were aimed at determining the maximum throughput of the network and therefore the traffic load upon the network was adjusted so that saturation occured.

This paper examines how the traffic load upon the network and the transmission power effect the overall performance of the network. While increasing the transmission radius, i.e. the node density, does reduce the available bandwidth, it may also be important to study how the optimum node density varies with different traffic loads and mobility rates. To investigate this, the reactive Ad Hoc On-Demand Distance Vector (AODV) routing protocol [6] is used for routing packets in the network. It is likely that different routing protocols will have different route characteristics, but the results obtained here can be generalized to most on-demand protocols. To make a comparison against more proactive routing protocols, the simulated scenarios were also run with the Optimized Link State Routing (OLSR) protocol [7]. The remainder of this paper is organized as follows. Section 2. briefly describes the basic mechanism of AODV’s unicast routing. Section 3. describes the OLSR routing protocol. Section 4. describes the simulation model and environment. Section 6. discusses related work and Section 7. concludes the paper.

2. Ad hoc On-Demand Distance Vector Routing

The Ad hoc On-Demand Distance Vector (AODV) routing protocol is a reactive protocol designed for use in ad hoc mobile networks. AODV initiates route discovery whenever a source needs a route, and maintains this route as long as it is needed by the source. Each node also maintains a monotonically increasing sequence number that is incremented whenever there is a change in the local connectivity information for the node. These sequence numbers ensure that the routes are loop-free.

2.1. Route Discovery

Route Discovery follows a *Route Request* (RREQ), *Route Reply* (RREP) query mechanism. In order to obtain a route to another node, the source node broadcasts a RREQ packet across the network, and then sets a timer to wait for the reception of a reply. The RREQ packet contains the IP address of the destination node, the sequence number of the source node as well as the last known sequence number of the destination. Nodes receiving the RREQ can respond if they are either the destination, or if they have an unexpired route to the destination whose corresponding sequence number is at least as great as that contained in the RREQ. If these conditions are met, a node responds by unicasting a RREP back to the source node. If not, the node rebroadcasts the RREQ. In order to create a reverse route from the destination back to the source node, each node forwarding a RREQ also create a *reverse route entry* for the source route in its routing table.

As intermediate nodes forwards the RREP towards the source node, they create a *forward route entry* for the destination in their routing tables, before transmitting the RREP to the next hop. Once the source node receives a RREP, it can begin using the route to send data packets.

If the source node does not receive a RREP before the timer expires, it rebroadcasts the RREQ with a higher time to live (TTL) value. It attempts this discovery up to some maximum number of attempts, after which the session is aborted.

2.2. Route Maintenance

Nodes monitor the link status to the next hops along active routes. When a link break is detected along an active route, the node issues a *Route Error* (RERR) packet. An active route is a route that has recently been used to send data packets. The RERR message contains a list of each destination which has become unreachable due to the link break. It also contains the last known sequence number for each listed destination, incremented by one.

When a neighboring node receives the message, it expires any routes to the listed destinations that use the source as of the RERR message as the next hop. Then, if the node has a record of one or more nodes that route through it to reach the destination, it rebroadcasts the message.

3. Optimized Link State Routing

The Optimized Link State Routing (OLSR) protocol is an optimization of the pure link state algorithm adapted to the requirements of a mobile wireless network. The key concept used in the protocol is that of multipoint relays (MPRs). MPRs are selected nodes (by their one hop neighbors) which forward broadcast messages during the flooding process. This technique lets OLSR substantially optimize the standard Link State algorithm in two ways:

Firstly it reduces the size of the control packets by declaring only a subset of links towards its neighbors, the MPRs. Secondly it minimizes flooding of the control traffic by only using the selected nodes to diffuse the control information. All other neighboring nodes receive the information, but do not rebroadcast it.

All nodes select its set of MPRs such that the set covers all of the nodes that are within two hops away. The OLSR protocol relies on this selection when calculating the routes to all the other known nodes. To achieve this, each node periodically broadcasts information about their one hop neighbors that have chosen it as a multipoint relay node. Each receiving node then uses this information to calculate a route to all other nodes in the network. These routes will be a sequence of hops consisting of MPR nodes between the source and destination node.

4. Simulation Model

The simulation platform used for evaluating the proposed approach is GloMoSim [8], a discrete-event, detailed simulator for wireless network systems. It is based on the C-based parallel simulation language PARSEC [9].

In our experiments, the MAC layer is implemented using the default characteristics of the distributed coordination function (DCF) of IEEE 802.11 [10]. This standard uses Request-To-Send (RTS) and Clear-To-Send (CTS) control packets to provide virtual carrier sensing for *unicast* data transmissions between neighboring nodes. A node wishing to unicast a data packet to its neighbor broadcasts a short RTS control packet. When its neighbor receives the packet, it responds with a CTS packet. Once the source receives the CTS, it transmits the data packet. After receiving this data packet, the destination sends an acknowledgement (ACK) to the source, signifying reception of the data packet. The use of the RTS-CTS control packets reduces the potential for the well known hidden-terminal problem. *Broadcast* data packets and RTS control packets are sent using CSMA/CA [10].

Two-Ray Path Loss with threshold cutoff is used as the propagation model. This model uses the Free Space Path Model for near sight and Plane Earth Path Loss for far sight. For a distance r, the Free Space model attenuates the signal as $1/r^2$ and the Plane Earth model as $1/r^4$. If the received power level of a packet is below the noise level plus the specified Signal to Noise Ratio (SNR) threshold, a collision is detected.

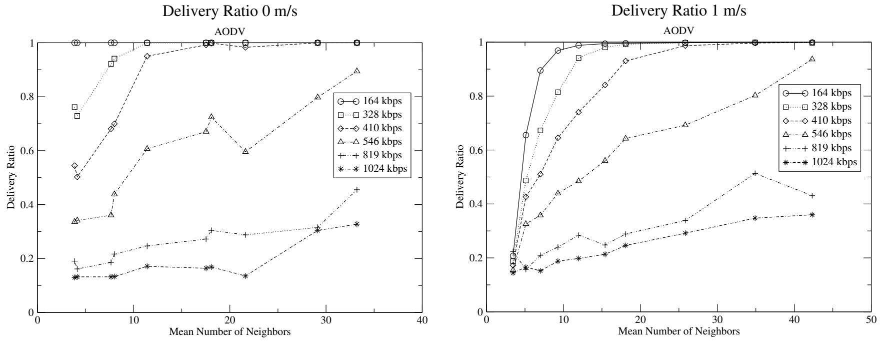
The data rate for the simulations is 2 Mbits/sec.

4.1. The Mobility Model

The mobility model used for the simulations is the Modified Random Direction model [5]. Each node randomly selects a direction in which to travel, where a direction is measured in degrees. The node then randomly selects a speed and destination along the direction and travels there. Once it reaches the destination, it remains stationary for some pre-defined pause time. At the end of the pause time, a new direction and speed is selected, and movement is resumed. If a node reaches a border of the simulation area, it is bounced back. This model avoids the inherent problems of the popular *random waypoint model* [11, 5] and results in a uniform node distribution as well as causing continuous changes in the topology of the network. The pause time in the simulations is set to 10 seconds and the speed varies between 0 and 10 m/sec.

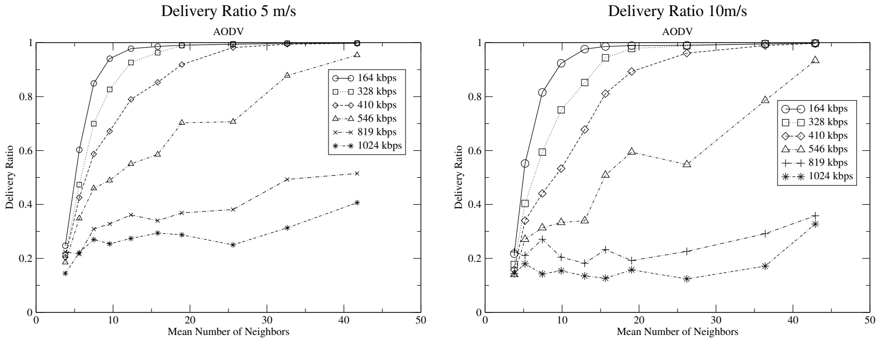
4.2. Simulation Setup

Four different node mobility's between 0 m/s and 10 m/s are modeled. The average number of neighbors in each simulation is varied by adjusting the transmission range. This is typically done by increasing the transmis-



(a) 0 m/s.

(b) 1 m/s.



(c) 5 m/s.

(d) 10 m/s.

Figure 1: Delivery Ratio for AODV

sion power of each individual node.

The total amount of traffic injected into the network is varied between 82kbps and 1Mbps. This is done by varying the number of sources in the network and the number of 512-byte data packets sent per second. The type of traffic injected into the network is 10 short-lived CBR sources spread randomly over the network. When one session ends, a new source-destination pair is randomly selected. Thus the input traffic load is constantly maintained.

Each mobility/transmission range/traffic load combination is run for 6 different initial network configurations, and the results are averaged to produce the data points. All in all the total number of simulations run to produce the data points in this study are around 3200. Each simulation simulates 300 seconds and models a network of 100 nodes in a 1000 X 1000 m area.

5. Results

5.1. Delivery Ratio

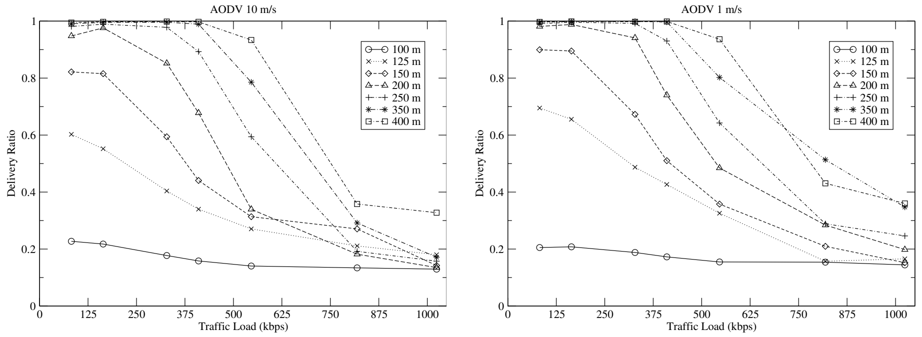
The delivery ratio is defined as the ratio between the number of packets delivered to a destination to those generated by the sources. This metric illustrates the effectiveness of best effort routing protocols, such as AODV and OLSR, for delivering packets to their intended destination.

The delivery ratio when AODV is used as the routing protocol is shown in Figure 1. Four different mobility rates and their graphs are illustrated in the subfigures. The figure shows that for small node densities and lower connectivity, fewer data packets are delivered due to lack of a route. However, when nodes are mobile and the connectivity increases, the delivery ratio rapidly increases for small traffic loads, until the curves level off. For small traffic loads it is therefore possible to find an optimum number of neighbors where almost all packets are delivered. This optimum value does however, depend on both the traffic load and the mobility rate. As mobility increases the optimum value shifts to the right. The faster nodes move, the more frequently link breaks occur. Hence, even though the effective bandwidth seen at individual nodes suffer due to increased transmission power and collisions, the delivery ratio still increases compared to sparser densities. This is because link breaks are less frequent and routes are maintained for longer periods of time.

As the amount of traffic increases, the rate of increase becomes slower untill it is almost linear. This occurs as a result due to the increased number of collisions, as well as reduced channel access. For these higher traffic loads it is therefore more difficult to find an optimum node density.

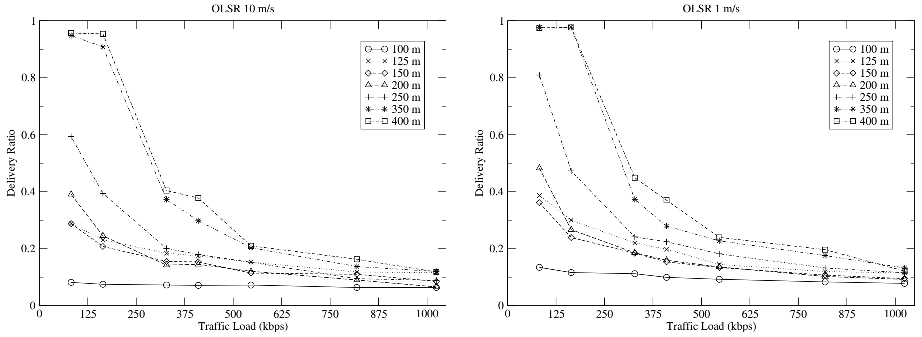
It should also be noted that when the transmission range is increased, thus increasing the node density, the mean number of hops between a source and destination decreases. This also have a positive effect on the delivery ratio.

Figure 2(a) illustrates the relationship between the



(a) 10 m/s for AODV.

(b) 1 m/s for AODV.



(c) 10 m/s for OLSR.

(d) 1 m/s for OLSR.

Figure 2: Delivery Ratio per Traffic Load and Transmission Range

traffic load and the delivery rate for different transmission ranges. Two mobility rates, 1 m/s and 10 m/s have been used in this setup. As the transmission range of a node is increased, the mean number of neighbors is also increased. It should be noted that the transmission ranges denoted here is the ideal transmission range when we have no interference. As the number of neighbors increase so does the interference, resulting in more collisions and restransmissions at the MAC layer. The effective transmission range is therefore lowered. These effects are studied in section 5.2..

In figure 2(a) and figure 2(b), AODV is used as the routing protocol. The figures show that as the traffic in the network is increased, the delivery rate becomes lower. For the higher transmission ranges it is possible to sustain a very high delivery rate up to a certain point where the delivery starts to decline. For higher transmission ranges it therefore seems possible to find an optimum traffic load with respect to the delivery ratio. However, for very sparse networks the delivery ratio seems to be fairly independent upon the amount of traffic in the network. This is due to both the lower connectivity as well as the higher probability for channel access. Because of the lower connectivity, it is also harder to establish a route and the delivery ratio is therefore quite low.

Figure 3 show the delivery ratio when OLSR is used as the routing protocol. The figure illustrate that OLSR can acheive very high delivery rates for small traffic loads and dense networks. There are two reasons as to why OLSR performs better for dense networks.

Firstly, the network connectivity is higher for denser networks and the probability for an available route is therefore also higher.

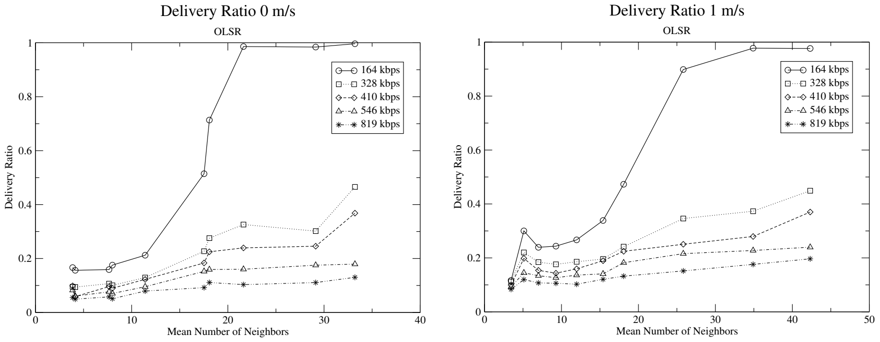
Secondly, as the network becomes denser, fewer MPRs are selected. As only MPR nodes will relay link state update messages, the control overhead will drop quickly.

For higher data rates the delivery ratio for OLSR is only slowly increasing. Although fewer MPRs are being selected, the contention for channel access also becomes greater.

Figure 2(c) and figure 2(d) illustrates the relationship between the traffic load and the delivery rate when OLSR is used as the routing protocol. We can see the same indications as we could when AODV were used. For higher transmission ranges it is possible to sustain a higher delivery ratio up to a certain point, after which the ratio rapidly drops. The difference between AODV and OLSR seems to be that the drop comes a bit earlier for OLSR than it does for AODV. The decline in delivery ratio is also faster for OLSR than for AODV.

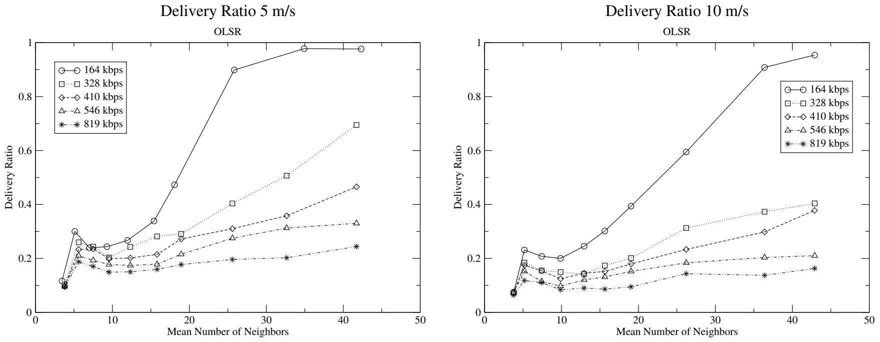
5.2. Collisions

Figure 1 and figure 3 seems to indicate that denser networks have better delivery ratio. If this is correct, the optimum network design choice would be to make the network as dense as possible. However, as we can see in figure 4, the number of collisions also increases with in-



(a) 0 m/s.

(b) 1 m/s.



(c) 5 m/s.

(d) 10 m/s.

Figure 3: Delivery ratio for OLSR

creasing network density. Figure 4 shows the mean number of collisions at the radio layer per delivered packet. This ratio is an indication of the energy cost needed in order to deliver a packet. More collisions at the radio layer typically means that energy has been wasted because the signal could not be received.

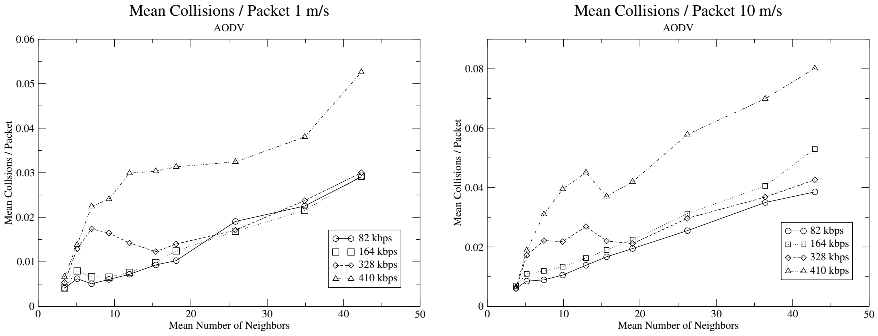
Here we see that although denser networks have higher delivery ratios, the price for actually delivering the packets becomes higher. Because more collisions means that additional control information at the MAC layer might need to be sent, more energy have to be spent for delivering the packets.

Because the mobile nodes in an ad hoc network are typically battery operated, it therefore isn't optimum to make the network as dense as possible.

There are also some interesting variations in the displayed graphs. In figure 4(c) and figure 4(d) OLSR have been used as the routing protocol. For small traffic loads the number of collisions increases up to a certain point where it levels off and then starts decreasing. The reason for this is the same as explained earlier. As the the network becomes denser, fewer MPRs will be selected and the control overhead will therefore be lower. As a result of this, fewer collisions occur. But as the traffic load is increased, the contention for channel access will increase, again causing more collisions to occur.

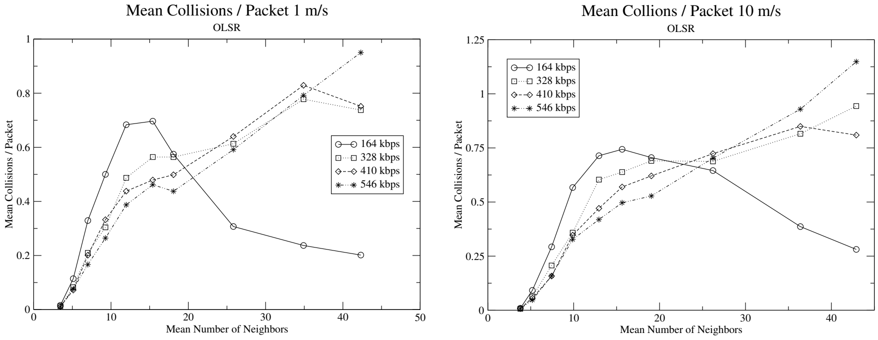
It is interesting to see that AODV also displays variations, but for higher traffic loads. See figure 4(a) and figure 4(b). The mean number of packet collisions here rapidly increases with node density up to a point where it levels off or starts decreasing. For even higher node densities the number of collisions again starts to increase. The explaination for this can be found in the way AODV flood request messages. When a node needs a route it broadcasts a RREQ to its immediate neighbors. If the receiving neighbor is unaware of the requested destination address, it rebroadcast the RREQ. However, if the neighbor does know of a route to the destination, it unicasts a RREP back to the requesting node. As the network becomes denser, the probability for a neighbor to have an available route increases. This is the point where the curves level off or starts decreasing. But more neighbors also means that more packets have to be rebroadcasted, increasing the number of collisions. At some point the positive effect of neighbors having available routes will be drowned by rebroadcasts by other neighboring nodes. The number of collisions will then again start to increase. For lower traffic loads these effects are less distinct.

It should also be noted that the scale of the figures are different. The number of collisions that occur when OLSR is used for routing is much higher than for AODV. The reason for this can be found in the proactive nature of OLSR. OLSR constantly propagates control information across the network, while AODV only determine routes on demand.



(a) AODV 1 m/s.

(b) AODV 10 m/s.



(c) OLSR 1 m/s.

(d) OLSR 10 m/s.

Figure 4: Mean Number of collisions per delivered packet

6. Related Work

Royer et al. performed a related study in [5]. In this work they varied the transmission power in order to determine the optimum node density for delivering the maximum number of data packets. Their simulations were aimed at determining the maximum throughput of the network and therefore the traffic load upon the network were adjusted so that saturation occurs. They concluded that there does not exist a global optimum density, but rather that, to achieve this maximum, the node density should increase as the mobility rate of nodes increases.

An investigation to determine the critical transmission range were performed in [12]. In this work the authors investigate the minimum transmission range of the transceivers that is required to achieve full network connectivity. They present an algorithm to calculate this minimum transmission range, and then study the effect of mobility on that value.

In [13], the authors study the problem of adjusting the transmission power in order to find a balance between the achieved throughput and power consumption. Algorithms are presented which adaptively adjust the transmission power of the nodes in response to topological changes, with the goals of maintaining a connected network while using minimum power. Through simulation, they show that an increase in throughput, together with a decrease in power consumption can be achieved by managing the transmission levels of the individual nodes.

7. Conclusion

With the increasing popularity of mobile networking, it is important to understand the characteristics of these networks so that they can be tuned to acheive optimum performance. A key component for determining the network connectivity is the transmission power. For wireless transmission, a tradeoff exists between increasing the number of neighbors and decreasing the effective bandwidth available to individual network nodes.

It has been shown that it is desirable to increase the node density and transmission power in order to achieve high delivery of data packets to their destinations. Moreover, the optimum connectivity level of the network does not only depend upon the mobility of the nodes, but also upon the traffic load on the network. In sparser networks it is possible to achieve high delivery rates up to a certain point where it starts to decline. When the transmission power of the individual nodes is increased, the delivery rate will also increase in a rate that is dependent upon the traffic load in the network. For lower traffic loads the increase in delivery is quite fast. As the traffic gets higher, the rate of this increase becomes slower. Although denser networks can generally achieve a higher delivery ratio, the cost will also be higher as more collisions occur which consume more power and channel bandwidth.

The conclusion we can draw from this study is that when the behavior, capacity and performance of a wireless ad hoc network is to be determined, the amount of traffic expected in the network, as well as the node density needs to be taken into account.

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