CALCULATION OF INFERENCE IN AD-HOC NETWORK

[1]POOJA GROVER, [2]NEHA GUPTA, [3]RANJIT KUMAR

[1]Asst. Prof., Department of Computer Science & Engineering, MDU, Rohtak, India-313001
[2] Lecturer, Department of Information Technology, MDU, Rohtak, India-313001
[3] Asst. Prof., Department of Computer Science & Engineering,, MDU, Rohtak, India-313001

ABSTRACT

In this paper we propose a new model to calculate inference levels in wireless multi-hop ad-hoc networks. This model computes the expected value of carrier to inference ratio(*C/I*) by taking into account the number of nodes, density of nodes, radio propagation aspects, multihop characteristics of the network and amount of relay traffic.

For the performance evaluation and determination of the capacity in any wireless network, it is important to have good calculation model to estimate interference power statics to our best knowledge till now there has been no accurate calculation model to estimate the expected interference power and its distribution function in adhoc network and sensor networks with realistic assumptions regarding radio propagation.

To find a mathematical formula for expected interference in adhoc networks, we have simplified the reality of adhoc networks in three aspects:

1. We have used the path loss radio propagation model,
2. We have chosen for a specific arrangement of nodes on a two dimensional hexagonal lattice resembling a honey grid(which explains the name given to our model: the honey grid model),
3. We have simplified the rules of the MAC protocol.

Keywords: *Wireless Communication, Path Loss Exponent ,MAC Protocol, Lognormal Summation Method*

1. INTRODUCTION

Ad-hoc Network:

Ad-hoc networks are formed in situations where mobile computing devices, require networking applications where a fixed network infrastructure is not available or not preferred to be used. In these cases mobile devices could set up a possibly short-lived network for the communication needs of the moment, in other words, an ad-hoc network.

Ad-hoc networks are decentralized; self-organizing networks and is capable of forming a communication network without referring on any fixed infrastructure.

Like any other wireless communication system. Ad-hoc networks are restricted in their capabilities by radio technology limitations on data transmission speed and range.

II. WIRELESS AD-HOC NETWORK VS TRADITIONAL WIRELESS CELLULAR NETWORKS.

Wireless multi-hop ad-hoc networks are formed by a group of mobile users or mobile devices spread over a certain geographical area. We call the users or devices forming the network *Nodes*. The *Service Area* of the Ad-hoc network is the whole geographical area where nodes are distributed. Each node is equipped with a radio transmitter and receiver which allows it to communicate with the other nodes. As mobile Ad-hoc networks are self-organized networks. Communication in Ad-hoc networks does not require a central base station.

Each node of an Ad-hoc Network can generate data for any other node in the network. All nodes can function, if needed, as relay stations for data packets to be routed in their final destination.

A mobile Ad-hoc network may be connected through dedicated gateways, or nodes functioning as gateways, to other fixed networks or the Internet. *In this case, the mobile Ad-hoc network expands the access to fixed network service.*

Although single-hop ad-hoc networks are often used in practice. For example, a laptop communicating with devices like PDA, a memory storage devices and a video camera by using blue tooth forms a *single-hop* ad-hoc networks. Here when we refer to ad-hoc networks, we always mean multihop ad-hoc networks. The multi-hop support in ad-hoc networks, which makes communication between nodes out of direct radio range of each other possible, is probably the most distinct difference between mobile ad-hoc networks and other wireless communication systems.

III. MODEL DESCRIPTION

For simplicity of mathematical derivations, our interference calculations in this model will be based on the pathloss power law model for radio propagation. With the power law model for radio propagation, and the assumption that transmission power and receiver sensitivity for all nodes is same, the coverage area of any node is a circle with radius R.A node can have direct communication with all nodes that fall inside its coverage area.

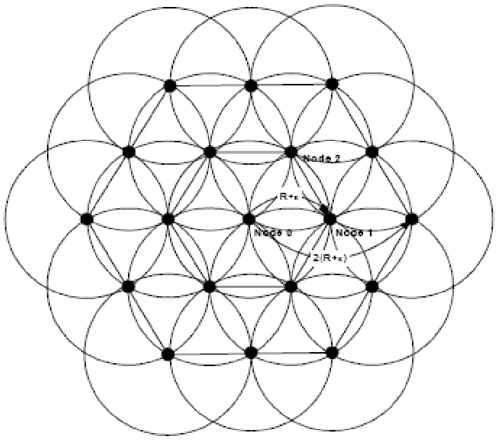

Fig1: Constellation of interfering nodes around node 0 when we arrange interfering nodes in position to obtain the maximum number of inferences.

To complete the description of our assumptions in this model, we add that it is assumed that all nodes transmit with the same power, all nodes have the same traffic generation behavior and all data has the same priority.

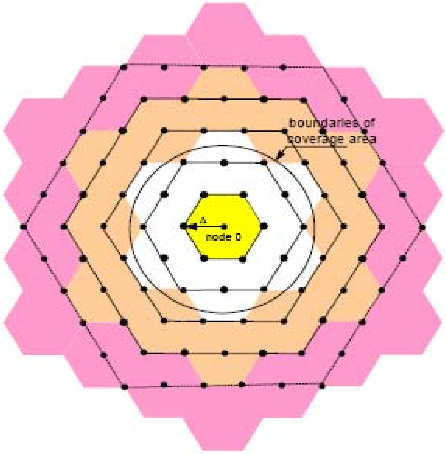

Fig 2: The honey-grid model showing all nodes.

When nodes are placed on a honey-grid, from the point of a node in the center of the configuration other nodes are positioned on co-centered hexagons (see fig 2), we call each of these hexagons a *ring*. The first hexagonal ring has size Δ and contains 6 nodes. The i^{th} *hexagonal* ring has a side of size $i\Delta$ and contains $6i$ nodes. The size of the network can be expressed in terms of k co-centered hexagonal rings around node 0,or by N the total number of nodes in this configuration. N and k are linked through the formulas:

$$N=1+\sum_{j=1}^{k} 6j=1+3k(k+1)$$

Where $k=\sqrt{1/4+(n-1)/3}$ - ½

In figure 2 we have depicted by a circle the coverage area for node 0 in the center of the configuration. in this example we have chosen the coverage area so that it includes two hexagonal rings. The coverage area could be larger and include more rings. This happens when the network density increases.however, the radius of the coverage area cannot be less than, otherwise the network is not connected. The number of nodes inside the coverage area of each node (its degree) is indicated by d. We assume that an entire ring is either included or excluded from the coverage area. We define a node's reach as the number of hexagonal rings that fall inside the coverage area of that node. We indicate the reach of a node by symbol *a* (for example, *a*=2 in fig 2). The degree of a node that is not at the borders of the service area is:

$$d=\sum_{j=1}^{a} 6j = 3a\,(a+1)$$

Each node may communicate directly with all nodes inside its coverage area. For reaching other destinations multi-hopping must be used. There are basically two ways for reaching each destinations: If node 0 in figure 2 wishes to communicate with a node positioned on ring 3(the third ring seen from the enter),it either can hop through a node on ring 1 and then a node on ring 2;or it can skip ring 1 and hop directly to a node on ring 2 before reaching the destination. *The first method preserves the energy while the second method keeps the number of hops minimum.* We will show that our model can work with both routing methods.

If we consider minimum hop routing, certain intermediate rings on the way from the source to the destination can be skipped. figure 3 shows in tick lines the subset of the rings that can be used for multi-hop to any destination. We will call these rings *relay rings.* When packets are routing throughout the network, there may be multiple paths to the same destination. For example, the source (node 0) and the destination (node 3) shown in fig 3 may be connected by the path going through nodes0-1-3 or path going through nodes 0-2-3.

In our calculation of interference it is important to know the amount of relay traffic caused by multiple hops from source to destination, but the exact path from the source to destination is not relevant. Therefore, for us both these paths are the same, as they both consist of two hops. In figure 3 where *a*=2, we see that the first relay ring has a side of size 2Δ and contains 6 *relay nodes.* Relay nodes are those nodes on each relay ring that need to be used to reach any arbitrary destination (for example, when nodes 1 and 4 are relay nodes, node 2 is not chosen as a relay node because all destinations that could be reached through node 2 are already reachable through either node 1 or node 4) generally, if a is the reach of node 0,the number of co-centered relay rings seen from node 0 is, $\lfloor k/a \rfloor$ where the sign $\lfloor x \rfloor$ indicates routing down to the nearest integer.

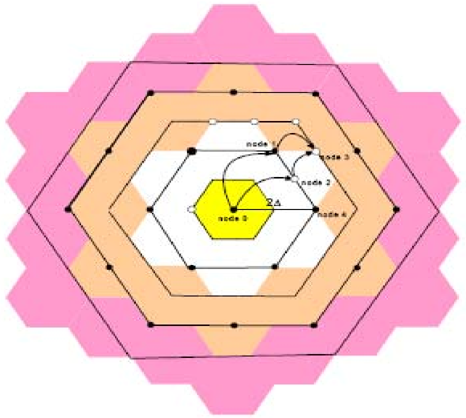

Fig 3: Relay rings and relay nodes in a Honey-grid. Thick lines shows relay rings. Dark filled circles are relay nodes...Hollow circles are other nodes in the network.

The number of relay nodes (source node included) is then:

$$N_r=1+\sum_{j=1}^{\left\lfloor \frac{k}{a} \right\rfloor} 6j = 1+3\left\lfloor \frac{k}{a} \right\rfloor\left(\left\lfloor \frac{k}{a} \right\rfloor+1\right)$$

We mentioned earlier in this section that our model could handle energy efficient routing as well as minimum hop routing. If parameter a=1, regardless of the reach of mobile nodes, the hopcount, traffic estimation and interference power as found here will be for energy efficient routing. If parameter *a* is chosen equal to the maximum radio reach of mobile nodes, the hopcount, traffic estimation and interference are found for minimum hop routing.

IV. INTERFERENCE CALCULATION WITH HONEY-GRID MODEL

According to the Honey-grid model, each node has d other nodes inside its coverage area (except for nodes at the borders of the network). As explained in *Model Description* (*sec III*), around node 0 the first set of interfering signals will come from signals that are transmitted from nodes just outside the coverage area of node 0.Recalling our assumption that an entire ring is either included or excluded from the coverage area, the first ring of interference consists of 6 nodes positioned at distance (a+1) Δ to node 0.Generally, if a is the reach of node 0,the

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number of co-centered interference rings seen from node 0 is $\lfloor k/(a+1) \rfloor$,and the number of interfering node is:

$$N_i = \sum_{j=1}^{\left\lfloor \frac{k}{a+1} \right\rfloor} 6j = 3\left\lfloor \frac{k}{a} \right\rfloor \left(\left\lfloor \frac{k}{a} \right\rfloor + 1 \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots 9.4$$

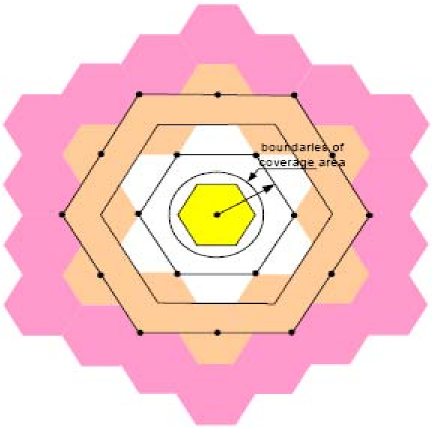

Fig 4:Honey-grid with interfering rings (thick lines) for a=1

Figure 4 shows the interfering rings and the interfering nodes observed from the position of the center node in a honey grid model with a=1.

Nodes in the center of the configuration have the highest number of potential interfering nodes around them in all directions. Therefore; we choose the amount of interference experienced at node 0 as representative for the maximum level of interference inside the network. In the remainder of this section, a closed-form expression for interference at node 0 is found. If the level of interference is acceptable at node 0, we can assume that it is also acceptable for other nodes.

To calculate the amount of interference experienced at node 0, we add the interference power received at node 0 from all interfering nodes. The first interference ring contains 6 nodes at distance (a+1) Δ.The second interference ring contains 12 interfering nodes from which 6 nodes in the corners of the hexagonal ring are at the distance 2(a+1) Δ to node 0 and 6 other nodes are at the distance √3 (a+1) Δ to node 0.

The distance of the nodes on each ring to node 0 can be calculated exactly. However, in our calculations, we use a simplification: we assume that the distance between all interfering nodes on each ring to node 0 is equal to the distance of the corner nodes to node 0.This is not an accurateapproximation, especially when the service area is large. Following table shows calculation steps for finding interference power originated from the j^{th} interfering ring:

Sequence number of interfering ring	j
Number of interfering nodes on the ring	$6j$
Approximated distance of each interfering node to the center node	$j(a+1)\,\Delta$
Interference power coming from each interfering node on the ring	$c(\,j(a+1)\,\Delta/r_0)^{-\eta}$
Interference power coming from all interfering nodes on the ring	$6jqc(j(a+1)\Delta/r_0)^{-\eta}$
Normalized interference power coming from all interfering nodes on the ring	$6q(\,1+1/a)^{-\eta}\, j^{1-\eta}$

The j^{th} interfering ring contains $6j$ nodes at approximated distance $j\,(a+1)\,\Delta$ to node 0. Let q be the probability of transmission (transmission of own signals or relay signals) per node in a given time slot. Using area mean power law that states:

$$P_a = c\,(r/r_0)^{-\eta}$$

(The averaged power at any given distance to the transmitter is referred to as area mean power P_a (in watt or milliwatt). The path loss model states that Pa is decreasing function of the distance r between the transmitter and the receiver, and can be represented by a power law. The r_0 is the reference distance, parameter is the path loss exponent which depends on the environment and terrain structure and can vary between 2 in free space to 6 in heavily built urban areas. In indoor environment with line-of-sight condition, pathloss exponent values of about 1.6 to 1.8. The constant c depends on the transmitted power, the receiver and the transmitter antenna gains and the wavelength.)

Using this formuls, the mean power of interfering signals originating from ring j is $6jqc(j(a+1)\Delta/r_0)^{-\eta}$

To eliminate the parameters not relevant to our study, we normalize variables as follows. We can define R as the distance where the area mean power P_a (r_{ij}) is equal to ρ, the receiver sensitivity. in other words, we normalize this interference power to the power:

$$\rho = c\,(R/r_0)^{-\eta}$$

Where R=aΔ is radius of the coverage area of a node. The normalized interference power coming from ring j is then: $6q(1+1/a)^{-\eta} j^{1-\eta}$

The total amount of normalized inference mean power is then:

$$I=6q(1+1/a)^{-\eta} \sum_{J=1}^{\left\lfloor \frac{K}{A+1} \right\rfloor} j^{1-\eta} \qquad \ldots\ldots 9.5$$

When network size increases $\left\lfloor \frac{k}{a+1} \right\rfloor \rightarrow \infty$ and the above formula can be written as:

$$I_{\infty}, =6q(1+a^{-1})^{-\eta} \zeta(\eta-1)$$

Where, for Re(s) >1, $\zeta(s) = \sum_{j=1}^{8} j^{-s}$ is the Riemann-Zeta Function.

If the path loss exponent $\eta \leq 2$, the interference power tends to explode when the network size increases.

Fig1: comparison of interference upper bound with inference calculated using the lognormal summation method. In this plot we have assumed $\xi=0$(pathloss model)

When path loss exponent $\eta > 2$, $\zeta(\eta-1)$ is a converging series with positive terms and is upper-bounded by:

$$\sum_{j=1}^{8} j^{1-\eta} \leq 1 + \int_{1}^{8} (1/x^{\eta-1})\, dx = \eta-1/\eta-2$$

Based on the above formula we can conclude that the amount of interference power in a mobile ad-hoc network is upper-bounded by the following expression:

$$I \leq 6q(1+a^{-1})^{-\eta} \ \eta-1/\eta-2, \ \eta>2.$$

V. CONCLUSION

This conclusion is an important result and may see contra-intuitive at the first glance. Intuitively, one may believe that adding interference power from an infinite number of interference sources, regardless of how small the interference values, may lead to an infinite sum. Above we have shown that this is not the case when radio signals decay sufficiently fast over traveled distances.

To make a loose analogy, we all see that the sky at night is dark despite the virtually infinite number of stars contributing to its brightness.

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