Throughput and Delay in Wireless Heterogeneous Ad Hoc Networks

Yatendra Singh Bhandari 1, Yashwant Singh Chauhan 2 and Ashish Negi 3

1Research Scholar, 2Assistant Professor, 3Professor & HoD

1,2,3 Department of Computer Science & Engineering, Govind Ballabh Pant Institute of Engineering & Technology, Ghurdauri, Pauri-Garhwal-246194, Uttarakhand, India.

Abstract

There are two very important parameters in evaluation of the performance of heterogeneous wireless ad hoc networks. These are Network throughput and Delays in packet. Practically it is very difficult to get both factors optimally that is high throughput and low packet delay in a network. Our main conclusion is for achieving a good throughput under maintaining minimum packet delay known as threshold level of packet delay. Some mathematical expressions have been derived for the average capacity in wireless heterogeneous ad hoc networks. Due to these mathematical derivations for a heterogeneous ad hoc wireless network, a routing algorithm is proposed to achieve maximum throughput and minimum delay by changing some patterns in the node’s mobility.

Keywords: $X_i$, $X_j$, $X_k$, $m^h$, $\lambda(n)$, $X_i(t)$, $d(i)$.

\[ \Theta \left( \frac{W}{\sqrt{n}} \right), \lambda(n) = \Theta \left( \frac{cW}{\sqrt{n \log n}} \right). \]

INTRODUCTION

Wireless network is a very popular topic now a days going around the world. If we compare the old network which were all wired, in contrast to that new wireless networks are setting up the connections in air through wireless channel. In common we have two kinds of wireless networks. One wireless network is called cellular network or WLANs. In this type of network base stations are the nodes of boundary, and the connection made between user that is mobile user and the base stations (nodes) is wireless. This is known as one-sided wireless network [1] or one-hop wireless network. Second is heterogeneous ad hoc wireless network [2], this has multiple wireless systems in its channel which means it have multiple hops in it.

In this paper, we are going to discuss the second type of wireless networks system. This heterogeneous system do not contain any wired links around it. It is an extension to the wired network. This system can be described as follows.

This heterogeneous ad hoc wireless network consists of only wireless nodes which are communicating with each other wirelessly in the range of their radio transmission [3]. These nodes are base stations which can perform three functions. These are sender, receiver and mediator (router) [4]. If a node is acting as a sender, then it can send specific information towards the required destined base station. If the base station node is acting like a receiver then it can receive the required traffic on its channel from specified senders. If the specific node is acting like router then it can perform like a communicating channel which can pass information from one node to another. Every base station has a queue [5] of packets which are needed during the transmission of packets.

This paper includes the capacity and delays [6] in such kind of wireless networks. Generally the capacity of a network to hold the queue of packets and the total delay in packets transmission are the two very important parameters of any wireless network model because these two factors determine how efficient is our heterogeneous ad hoc wireless system. Talking about the whole system, capacity represents the throughput of the system which include all the base stations (nodes) of the system and delay represents the time taken in the packet transmission in the network system from a sender to receiver. What we require is to have maximum capacity and minimum delay. In order to have better capacity we need to make sure that the queue of each node is always non-empty that is it is always transmitting the information of receiving information. This alternatively means that we need to keep all nodes busy with transmission or receiving of packets. If this happens it will lead us to longer time in action that is delay will increase. This shows that capacity and delay, both are proportional to each other. So we need to find a way of having high throughput while keeping minimum delay in network system.

In this paper we will see how we can achieve this network system. We will first discuss some of the methods to implement models of network system and then we will list out some observation based on the different formulas and see
what these formulas says about the capacity and delay in a network system. Finally in conclusion we conclude how we achieve the desired network system in heterogeneous ad hoc wireless networks.

**METHODOLOGY**

In methodology section we will see different methods of implementing different network models to achieve the goal of the paper. The goal of the paper is to achieve high throughput in heterogeneous ad hoc wireless networks while keeping the delay time minimum. We will see different models such as arbitrary model, random model, mobile model and at least a final delay model one by one.

We assume that all nodes in an ad hoc wireless networks are static for this particular network. Gupta and Kumar [7] have proposed two models in these kinds of networks. To make it simple we will scale up the model such that \( n \) base stations are located in a region of area \( 1 \text{ m}^2 \). Every base station have a transmission rate of \( W \) bits/second for the same communication route (channel). This route is distributed into several sub-routes (sub-channel), each having capacity \( W_1, W_2, \ldots, W_m \) bit/second, where

\[
\sum_{m=1}^{M} W_m = W
\]

(1)

**Model 1 (model of arbitrary network)**

We need to define some parameters first. We assume that the nodes and traffic pattern is arbitrarily distributed among the network [8]. Suppose there are \( n \) nodes distributed in a circular area like a disk in the plane having a unit area. Every node randomly selects a receiver node for sending their information at an arbitrary rate, and also we say that transmission range and power level for transmission is chosen arbitrarily.

There are two models to deploy for successful receiving of a transmission over single network (one hop): One model is the protocol model and the second model is physical model. When we use the protocol model, we have \( X_i \) denoting the node location, and suppose node \( X_i \) transmits over the \( m^{th} \) sub-channel to a node \( X_j \). Successful reception is done by \( X_j \) in this transmission if

\[
| X_i - X_j | \geq (1+\alpha) | X_i - X_j | \]

(2)

There is an arbitrary node \( X_k \) transmitting over the same sub-channel simultaneously. This was protocol model and now we see physical model. If we talk about physical model, let there be \( \{ X_k; k \in T \} \), the subset of transmitting nodes over an arbitrary sub-channel simultaneously. Say, there is a node \( X_k \) transmitting with power \( P_k \), for any \( k \in T \). The transmission from a node \( X_i \), \( i \in T \) causes a successful reception by node \( X_j \) if the inequality

\[
\frac{P_i}{| X_i - X_j |^\alpha} \geq \beta \]

(3)

\[
N + \sum_{k \in T, k \neq i} \frac{P_k}{| X_k - X_j |^\alpha} \]

get satisfied, where \( \beta \) is a minimum needed transmitted signal to interference occurred In transmission ratio for full functioning in receiving of signal, \( N \) is the level of power of noise, where \( \alpha > 2 \) indicating that the power signal decreases accordingly with distance \( \frac{1}{r^\alpha} \).

At last it is required to define the parameters of measurement metrics. Let’s denote a parameter \( \text{bit} - \text{metre} \) which is the simple multiplication of the distance travelled by signal in transmission that is the distance over which the data is to be carried and the number of bits in the data. Accordingly, the throughput is given as the sum of all \( \text{bit} - \text{metre} \) within the network.

**Model 2 (model of random networks)**

Like we have done in Model 1 in same respect we define parameters for Model 2. There is a bit difference between both the models. In first model nodes were arbitrarily distributed but now nodes are uniformly distributed over the whole area surface \( S^2 \) of a three dimensional sphere of area \( 1 \text{ m}^2 \). This model is acquired to eliminate the boundary effects and maintain uniformity. Every node is independent to choose a destination and transmit information randomly with the rate of \( \lambda(n) \) bits per second [9].

Now considering the transmission model we are adopting both the models, protocol model and physical model for the indication of successful reception, same as done previously in Model1. There is only one difference, this time we are introducing a common range factor denoted by \( r \) for all the transmission and the previous inequality of the protocol model now becomes,

\[
| X_i - X_j | \leq r
\]

(4)

and
Finally, for computing the capacity of the network, we define a capacity factor $\lambda(n)$ having unit bits per second for each node and is valid if and only if there exists a spatial and temporal scheduling schemes for successful transmissions, so that any node can participate in sending $\lambda(n)$ bits per second as an average rate to its specific receiver node by the medium of other nodes working as intermediate nodes.

Due to the introduction of buffering [10] and intermediate nodes in this section, delays in packets transmission increases. In this model we have only considered the network which is made up of the static nodes. We know that the best advantage of heterogeneous wireless network is its mobility. So in next model we will be extending the model including mobile nodes.

**Model 3 (model for mobile nodes)**

Let’s denote some parameters. There are $n$ nodes fixed in the circular unit size area, but it is a bit different from upper two models. In this model nodes are mobile [12] in nature. Let $X_i(t)$ denote the current location of any $i^{th}$ user at any time $t$. Path of all users are to be taken as independent and distributed identically, and every node in this model behave as both a sender node for one communication channel and a receiver node for other communication channel. Let there be a destination $d(i)$ representing the receiver node for a particular node $i$. At the time of any transmission, it is to be assumed that every node acting like a sender has infinitely many packets to send to its receiver. And the last assumption is that the sender-receiver association do not get effected with time, independent of the movements of nodes.

In consideration of this model with mobility and capacity, results for capacity can be computed for either with relaying nodes or without relaying nodes.

Till now we have seen the three models for heterogeneous ad hoc wireless networks having static as well as mobile nodes. But as far we have only seen capacity of networks without considering delay even once. For achieving high capacity, we already had assumed that packets of information can be buffered between the intermediate nodes, but this will cause a delay to a large extent when the length of buffer is too long and the count of routing nodes is also very large. It is mandatory to have some knowledge on the delays in transmission of packets in the networks. Bansal and Liu [13] has given a model for the same problem, having much more assumptions considering the mobility pattern and traffic pattern.

**Model 4 (delay model)**

Now we need to combine the static and mobile nodes altogether to form this type of model. Let there be a heterogeneous ad hoc network model consisting of $n$ static nodes and $m$ mobile nodes lying in a circular disk of a unit area. There is a uniform distribution of static nodes over the whole circular area, and random distribution of mobile nodes on the circular area initially. Later change of positions and velocities will take place according to mobility model. Initially we are assuming that every mode is moving with speed $v$ inside the circular disk of unit area. The directions of nodes and their movements are considered to be independently and uniformly distributed in $[0, 2\pi)$. At any certain time the node may pick any direction which is uniformly distributed in $(0, 2\pi]$ and can move in that particular direction to a distance $d$ at speed $v$, where $d$ is an exponentially distributed random variable with mean $\mu$. In this way, as the node reaches the boundary of the circular disk, it is deflected back to the circular disk again.

Similarly we use the physical model for transmission with minor modifications. At time $t$, let $S_1, S_2, ..., S_m$ be the senders with positions $X_1, X_2, ..., X_m$ and let $R$ be the receiver with position $X_0$. If $S_i$ use power $P_i(t)$ for transmission, it causes a successful reception by node $R$ if

$$P_i(t) \|X_i - X_j\|^{-\alpha} \geq \beta$$

The similar performance measurement metric is to be considered as in the above 3 models. The only difference is that now we are going to consider delay in packet transmission also.

Studying this model, Bansal and Liu came to the conclusion that it can be possible to get a high capacity while keeping the packet delay under some minimum value.

**OBSERVATION**

We have seen all models to solve the problem of networks delays and high capacity step by step. Now we will list out some of the results and observations observed from these models.

**Model 1 (model of arbitrary network)**

**Result 1 (main result 1 in [1])**

Considering model with Protocol Model [11], the capacity of the networks for transportation in first Model is $\Theta(W\sqrt{n})$ bit-meters per second, given that other
assumptions are optimal that is all the nodes are placed optimally and also the traffic pattern and range allowed for transmission is optimally chosen.

**Result 2 (main result 2 in [1])**

Considering model with Physical Model, the feasible solution comes out to be \( cW\sqrt{n} \) bit-meters per second, while \( cWn^{a-\alpha} \) bit-meters per seconds is not feasible for appropriate \( c, c' \).

Specifically

\[
\frac{1}{(16\beta(2^{a/2} + 6^{a-2})(\alpha/2)^{a/2})} \sqrt{\frac{Wn}{\sqrt{n + \sqrt{8\pi}}}}
\]

(7)

bit-meters per second (\( n \) a multiple of 4) is feasible when the network is appropriately designed, with an upper bound of \( Wn \) bit-meters per second.

These results shows that, it can be concluded that for any arbitrary network model, the capacity of heterogeneous ad hoc wireless network is in the order of \( \Theta(W\sqrt{n}) \).

**Model 2 (model of random networks [14])**

**Result 3 (main result 3 in [1])**

For a protocol model either in the case of surface of sphere or in the case of surface of a planar disk, the order of the throughput capacity is stated as,

\[
\lambda(n) = \Theta\left(\frac{W}{n \log n}\right)
\]

(8)

bits per second.

The upper bound can be indicated by the fact that for some \( c' \),

\[
\lim_{n \to \infty} \Pr\{\lambda(n) = c' \frac{W}{n \log n}\} = 0
\]

(9)

Specifically, there are constants \( c'', c''' \) independent on \( n, \alpha, \beta \) or \( W \), such that

\[
\lambda(n) = \frac{c''W}{(1+\epsilon)^2 \sqrt{n \log n}}
\]

(10)

bits per second is feasible, and

\[
\lambda(n) = \frac{c'''W}{\left[2 \left(c'' \beta \left(3 + \frac{1}{\alpha - 1} + \frac{1}{\alpha - 2}\right)ight)^{\beta/\alpha} - 1\right]^{1/2} \frac{Wn}{n \log n}}
\]

(13)

bits per second is feasible with probability approaching one as \( n \to \infty \). If \( L \) is the mean distance between two points independently and uniformly distributed in the domain (either surface of sphere or planar disk of unit area), then there is a deterministic sequence \( \epsilon(n) \to 0 \), independent on \( N, \alpha, \beta \) or \( W \), such that,

\[
\sqrt{\frac{8}{\pi L}} \left(\frac{W}{\sqrt{n \log n}}\right) \frac{1 + \epsilon(n)}{\sqrt{n}}
\]

(14)

bit-meters per second is not feasible with probability approaching one as \( n \to \infty \).

These results shows clearly that for any random network model, the capacity can be of the order of

\[
\lambda(n) = \Theta\left(\frac{W}{n \log n}\right)
\]

(15)

This is happening because of the limitations we have added to the traffic patterns. Also from the result 3 for the physical model we can easily see what is stopping the capacity to be optimal. If we consider the circular plane area, the nodes which are lying in the centre will become the hot-spots and have more possibilities to routing packets but the order of overall throughput capacity remains same as it is on the surface of sphere. This is a prove that the restriction of
throughput is not due to the formation of hot-spots, but is it because of the needs of all nodes to share the whole communication made locally with all other nodes.

Model 3 (model with mobile nodes)

Result 5 (Theorem III-3 in [2])

Let us go through the scheduling terms which are only allowed to schedule the direct transmission between the sender nodes and the receiver nodes, and also let’s assume the no routing is allowed. Now if \( c \) is any constant satisfying

\[
c > \left[ 2^\alpha \left( 1 + \frac{2}{\alpha} \right) \pi^{-\alpha/2} \frac{\beta + L}{\beta} \right]^{1/(1+\alpha/2)}
\]  

(16)

Then,

\[
\Pr \left\{ \lambda(n) = c n^{-1/(1-\alpha/2)} R \right\} = 0
\]  

(17)

for sufficiently large \( n \).

It can be seen that for any sender-receiver nodes pair the capacity [16] goes to 0 as \( n \to \infty \), when no routing is allowed in the networks. This is happening because for every sender node, a very high thrust is required in transmitting the info packets directly to the receiver node, which ultimately leads to a very high interference and very low capacity. High capacity can be achieved if nodes are allowed to communicate to only nodes which are close to them and route packets for a receiver node which is far away.

Result 6 (Theorem III-4 & Theorem III-5 in [2])

In previous result we assumed scheduling without routing that is without intermediate nodes, now let us consider a scheduling policy for routing nodes that is consisting of intermediate nodes. If there are \( n \) nodes then for a given sender-receiver pair of nodes there is a single one way channel(one-hop route) and \( n-2 \) two way channels(two-hops routes) [15] . Throughput of \( \Theta(1) \) per sender-receiver pair can be achieved by a network, which means, there is a constant \( c > \sigma \) so that,

\[
\lim_{n \to \infty} \Pr \left\{ \lambda(n) = c R \right\} = 1
\]  

(18)

On comparing Result 5, 6 with Result 1, 2 and Result 3, 4, it is clearly seen that if relaying is allowed in the wireless networks, mobility will improve the capacity from

\[
\Theta(\sqrt{n}) \Theta\left( \frac{n}{\log n} \right) \ \text{to} \ \Theta(n).
\]

Model 4 (delay model)

Result 7 (main result in [3])

This is combination of static nodes and mobile nodes and so \( n \) nodes be static nodes and \( m \) nodes be mobile nodes. There exists a constant \( c > \sigma \), such that each sender can achieve an average throughput of

\[
c \frac{W \min(m, n)}{n \log^2 n}
\]  

(19)

where \( W \) denotes the bandwidth which is maximum available, delay packet is at most \( \frac{2d}{v} \), \( d \) denotes the diameter of the network and \( v \) is the velocity of the mobile nodes.

Mathematically, it can be seen clearly from formula 15 that the capacity decreases as number of intermediate nodes increase.

Following table shows some values for capacity as number of intermediate nodes increases, keeping other factors constant. First row of table gives the values of nodes and the second row represents the respective values for capacity of node.

<table>
<thead>
<tr>
<th>Nodes (n)</th>
<th>4</th>
<th>16</th>
<th>64</th>
<th>256</th>
<th>1024</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>0.5</td>
<td>0.25</td>
<td>0.125</td>
<td>0.0625</td>
<td>0.03125</td>
</tr>
</tbody>
</table>

This can be seen in the Graph 1 plotted as shown.

Graph 1
Y-axis denotes the number of intermediate nodes and the X-axis denotes capacity. Keeping W and logn constant. It can be seen that as number of intermediate nodes decreases then capacity increases.

Similarly Graph 2 shows the increment in delay in packets cause by increase in number of intermediate nodes.

Graph 2

Y-axis denotes the number of intermediate nodes and the X-axis denotes the delay in packets caused during the whole transmission. Keeping W and logn constant. It can be seen that as number of intermediate nodes increases then delay increases.

Result 8 (routing algorithm in [3])

Step 1. A local leader[17][18] is selected among all the static nodes within each region of size \(1/\sqrt{m} \times 1/\sqrt{m}\). This elected nodes becomes the leader of network and will be responsible for communication of all the messages in static nodes inside it’s region with other mobile nodes.

Step 2. Some static node k wants to send its message to some arbitrary receiver r. Static node first transfer its message to its local leader L. L stores the messages and wait until a mobile node m is nearby L and moving in the direction of r when m is close enough to L, L hand over the data from k to m for further transmission to r.

Step 3. The node m route the packet among the different mobile nodes such that packet is close enough to the receiver node.

Step 4. When this mobile which is carrying the data is close to receiver node r, it hand-over the data to that area local leader node. The packet is then routed among the nodes as per the instruction given by leader node so that packet can reach its destination node correctly.

This is the optimal routing algorithm, for the heterogeneous ad-hoc wireless network that can help in achieving high throughput(capacity) while keeping the delay of packet transmission small.

CONCLUSION

This paper leads us to exploring more and more about throughput and delay problems in heterogeneous and ad hoc wireless networks. Main aim of the paper is to keep packets delay low while achieving high throughput. We have seen all the models step by step. Starting from the easiest model, we compute the throughput (capacity) only and add more assumptions to finally reach our algorithm. Considering the static nodes the capacity per node can be stated as \(\Theta\left(\frac{W}{\sqrt{n}}\right)\) bits per second, for Arbitrary Network model, and \(\Theta\left(\frac{W}{n\log n}\right)\) for Random Network model. If we also include the mobility in the network then capacity can be improved to \(\Theta(1)\) on each sender-receiver pair.

On computing more assumptions on the pattern of traffic and mobility, the routing algorithm in result 8 can lead to achieve a very close optimal capacity at very low packet delay.

REFERENCES


