the Report the Project: A Survey On The Capacity Of Hybrid Wireless Networks

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2012/6/15

Abstract

In this project, I mainly to obtain a comprehensive view on the capacity of Hybrid wireless networks. I reference some papers about these problem and found a commonly used way to research this problem. I compared the system model of Hybrid wireless network and traditional pure Ad-Hoc network. And also observed the evolution in this topic from 2003 when B. Liu first investigated in this question[3]. I have some review on the resulted given by those many papers, meanwhile providing some new prospect in the future work.

I INTRODUCTION

Throughput capacity is a key characteristic of wireless networks. It represents the long-term achievable data transmission rate that a network can support. The throughput capacity of a wireless network depends on many aspects of the network: network architecture, power and bandwidth constraints, routing strategy, radio interference, etc. A good understanding of the capacities of different network architectures allows a designer to choose an architecture appropriate for his or her specific purpose.

In situations where there is no fixed infrastructure, for example, battle fields, catastrophe control, wireless ad hoc networks become valuable alternatives to wireless cellular networks or wireless LANs for nodes to communicate with each other. An ad hoc network is a communication network formed by a collection of nodes without the aid of any fixed infrastructure. In an ad hoc network, due to the lack of infrastructure and the limited transmission range of each node, data needs to be routed to the destination by the nodes in a multi-hop fashion.

However, in our daily life, we can utilize the function of base station as high-speed relays to improve the performance of the capacity, Especially in the wireless sensor network(WSN), because in this kind of network it is easy and necessary to build some base station around the sensors. Most of the papers have gave the result that, the network can be divided into two states: the infrastructure dominate state(when the BS is sparse) and the ad-hoc dominate state(when the BS is dense). This is the main feature when solving the capacity of hybrid network problem.

Researchers have started to investigate the capacity of wireless ad-hoc networks. In[1], Gupta and Kumar studied the throughput capacity of arandom wireless network, where fixed nodes are randomlyplaced in the network and each node sends data to a randomly chosen destination. The throughput capacity per node is shown to be $\Theta(\frac{W}{\sqrt{nlogn}})$, as n approaches infinity, where n is the number of nodes in the network (the same below) and W is the common transmission rate of each node over the wireless channel. Thus the aggregate throughput capacity of all the nodes in the network is $\Theta(\sqrt{\frac{n}{logn}}W)$. In [2], Grossglauser and Tse proposed a scheme that takes advantage of the mobility of the nodes. By allowing only one-hop relaying, the scheme achieves an aggregate throughput capacity of $O(n)$ at the cost of unbounded delay and buffer requirement.

In the research of hybrid wireless network, there are two question we faced with:

1. How does the throughput capacity scale with the number of nodes and the number of base stations?
2. How does the capacity of a hybrid network model compare to that of a pure ad-hoc network?

The rest of the report is organized as follows: In Section II, I describe the hybrid wireless network model. In Section III I focus on some classical paper on the scaling law of hybrid network. In section IV and V, I present the some other extended paper results of throughput capacity of a hybrid network, combining them with some other characteristics, like multicast and mobility. In Section VI, I draw the conclusions.

II HYBRID NETWORK MODEL

This is the original hybrid network model, while more and more features can be added into this model, such as multicast, mobility or heterogeneous:

We scale space and assume that a population of n nodes are randomly, i.e., independently and uniformly, located within a disk of area 1 square meter in the plane. We further assume that the nodes are homogeneous, employing the same transmission range or power. Every node is a data source. The destination for each node is independently chosen as the node nearest to a randomly located point within the unit area disk. In addition to the n nodes in the network, a sparse network of m base stations is regularly placed in the unit area disk. The base stations divide the area into a hexagon tessellation, as shown in Fig 1. As in a cellular network, each hexagon is called a cell and there is a base station in the center of each cell. Unlike normal nodes, the base stations are neither data sources nor data receivers. They are added as relay nodes to improve network performance and they only engage in routing and forwarding data for normal nodes. The base stations are assumed to be connected together by a wired network. Furthermore, we assume the link bandwidth in the wired network are all large enough so that there are no bandwidth constraints in the wired network. We also assume there are no power constraints for the base stations.

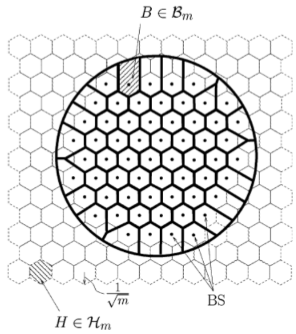


Figure 1: hexagon tessellation

II.1 transmission model

All the nodes and the base stations share a common wireless channel. We assume a time-division multiplexing (TDMA) scheme for the data transmission over the wireless channel. Time is divided into slots of fixed durations. In each time slot, a node is scheduled to send data. A node cannot transmit and receive data simultaneously and a node can only receive data from one other node at the same time.

The wireless transmissions in the network are assumed to be homogeneous. Nodes including the base stations employ the same transmission range, denoted by r. For the interference model, we adopt the Protocol Model introduced in [1].

A transmission from node X_i is successfully received by node X_j if the following two conditions are satisfied:

1. Node X_j is within the transmission range of node X_i, i.e., $|X_i - X_j| \leq r$ where $|X_i - X_j|$ represents the distance between node X_i and node X_j in the plane.
2. For every other node X_k that is simultaneously transmitting over the same channel, $|X_k - X_j| \geq (1 + \triangle)|X_i - X_j|$

This condition guarantees a guard zone around the receiving node to prevent a neighboring node from transmitting on the same channel at the same time. The radius of the guard zone is $(1 + \triangle)$ times the distance between the sender and receiver. The parameter $\triangle$ defines the size of the guard zone and we require that $\triangle > 0$.

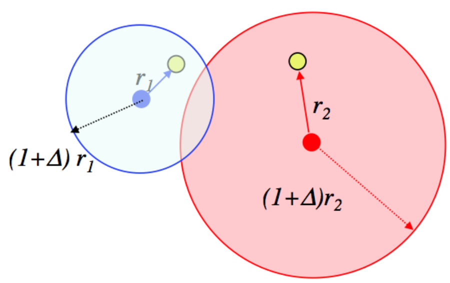


Figure 2: The protocol model

II.2 definition of per user capacity

Definition1 :A throughput of $\lambda(n, m)$ per node/user is feasible if there is a placement rule for the base stations, and a spatial and temporal scheme for scheduling transmissions allowing buffering at intermediate nodes (if necessary), such that each node can send $\lambda(n, m)$ bits/s on average to its chosen destination. That is, there is $T < \infty$, such that in every interval $[i-1]T, iT$ every node can send $\lambda(n, m)$ bits to its corresponding destination node.

Definition2 : The per user throughput $\bigwedge(m, n)$ of a random hybrid network is of order $\Theta(\lambda(n, m))$ bits/s if there exist deterministic constants $c > 0$ and $c' < \infty$ such that

$$\lim_{n\to\infty} P(\bigwedge(m, n) = c\lambda(n, m)\ is\ feasible) = 1$$

$$\liminf_{n\to\infty} P(\bigwedge(m, n) = c'\lambda(n, m)\ is\ feasible) < 1$$

These two conditions can be interpreted as asymptotic lower and upper bounds over random realizations for the locations of ad hoc nodes and destinations of the traffic.

III CLASSICAL WORK

B. Liu,Z. Liu,and D. Towsley has first investigate the capacity of hybrid wireless network[3]. They leaded the way of analyze this problem by divide the network into cells.

III.1 Routing Strategies

The communication can be divided into inter-cell and intra-cells. So it's natural that to devise a routing strategy that can automatically switch between these two modes. In this paper Liu use the k-nearest-cell routing strategies. That is:

In the ad hoc mode, data are forwarded from the source to the destination in a multi-hop fashion without using any infrastructure. In the infrastructure mode, data are forwarded through the infrastructure. It can be shown that in terms of throughput capacity, it is optimal to enter and exit the infrastructure only once. Also, it is optimal for a node to communicate with the nearest base station in order to reach the infrastructure. Denote the base station nearest to node X_i as $B(X_i)$. In this work, by infrastructure mode we mean that data are first transmitted from the source X_s to $B(X_s)$ over the wireless channel; the base station then transmits the data through the wired infrastructure to $B(X_d)$, which finally transmits the data to the destination X_d.

In this work, we consider two routing strategies. In the first routing strategy, if the destination is located in the same cell as the source node, data are forwarded in the ad hoc mode. Otherwise, data are forwarded in the infrastructure mode. Since the destination for a source node is randomly chosen in the unit area disk, the probability that a node commits to intra-cell communications is $\frac{1}{m}$; the probability that a node commits to inter-cell communications is $1\frac{1}{m}$. We can generalize the routing strategy to represent a family of routing strategies by relaxing the condition that the ad hoc mode is chosen to send data. Instead of requiring the destination be located in the same cell as the source, a node uses ad hoc mode to send data as long as the destination is located within k nearest neighboring cells from the source node, where $k \geq 0$ defines the range within which ad hoc mode transmissions should be used. We call this family of routing strategies the k-nearest-cell routing strategies.

Also there are some papers use the L-Maximum-Hop strategy. That is: a sourcenode transmits to its destination in the ad hoc mode if the destination can be reached from the source within L ($L \geq 1$) hops. Otherwise, the transmission will be carried out in the infrastructure mode. In fact this is quite the same with the k-nearest-cell strategies.

III.2 Results

The per-user capacity of hybrid network is as follow:

$$\lambda(n,m) = \begin{cases} \Theta(\sqrt{\frac{1}{nlogn}}W) & if\, m = o(\sqrt{\frac{n}{logn}}) \\ \Theta(\frac{mW}{n}) & if\, m = \omega(\sqrt{\frac{n}{logn}}) \end{cases} \tag{1}$$

To prove this result, the Author divide that capacity to ad-hoc capacity and infrastructure capacity, and compute them in different condition when the BS is sparse and dense. The process are just divide the network into cells and then compute it.

It is interesting that, the optimal condition is: when the $m = o(\sqrt{n})$, the whole network should abandon the infrastructure to achieve the optimal capacity, and when the $m = \omega(\sqrt{n})$, the each nodes should devote all of there bandwidth W to the base station. This extreme situation reveals that, the network will work at two states: infrastructure dominate state and pure ad-hoc state. The threshold between these two states is $m = \Theta(\sqrt{\frac{1}{nlogn}})$. We can find this feature from the result obviously.

III.3 Some problem

There is an apparent problem that if $\lambda(n,m) = \Theta(\frac{mW}{n})$ when m increase to ∞, the capacity per node will also increase to ∞. It contradict to our commonsense. Also, Maybe there will be some more advanced routing strategy can improve the performance of the capacity.

III.4 Extended work

A. Zemlianov and G. de Veciana[4] has extended this work by proving that, the result given by Liu is optimal. They gave the same result as [3], but the result is the optimal one independent on routing strategy. Also, They gave another upper-bound on λ to solve the first problem. They showed that, the capacity per-node is bounded by the parameter W, that reverse the packet stream to find that, that date rate a node receiving the packets is limited. The result is given as:

$$\lambda(n,m) = \begin{cases} \Theta(\sqrt{\frac{1}{nlogn}}W) & if\, m = o(\sqrt{\frac{n}{logn}}) \\ \Theta(\frac{mW}{n}) & if\, m = \omega(\sqrt{\frac{n}{logn}})\, and\, m = o(\frac{n}{logn}) \\ \Theta(\frac{W}{logn}) & if\, m = \omega(\frac{n}{logn}) \end{cases} \tag{2}$$

IV Combine the hybrid network with other features I

In M. Grossglauser and D. N. C. Tse's classical paper[2], we know that the capacity can be increased to $\Theta(1)$ if mobility is introduced into hybrid network, At the cost of the delay will become $\Theta(n)$. We can see that the capacity without BS is already very large.

In [5], the Author gave us the advantage of mobile hybrid network is that it can significantly improve the delay. He use the routing strategy of 2-hop routing. It means that: when the destination is at the same cell, the source trasmit the packet like [2]. If it is a inter-cell communication, he use the infrastructure, then the base station in the destination cell just broad cast the packet. Under this strategy, the delay will surely decrease, but we should notice that there is a strong assumption that, the destination will always move in the same cell. The result of This paper is:

$$\lambda(n,m) = \Theta(1)$$

$$D(n,m) = \begin{cases} \Theta(\frac{n \log n}{m}) & if\, m = O(n) \\ \Theta(1) & if\, m = \Omega(n) \end{cases} \tag{3}$$

As we mentioned before, there is a strong assumption that all of the nodes only move within the cell. W. Huang, X. Wang, Q. Zhang's paper[6] has given us a more general model for the hybrid mobile network. In there model, They specified the mobility model into strong mobility, weak mobility and trivial mobility. They also introduce the heterogeneous into the Hybrid network which means that, each nodes can only move around the home-point. The strong mobility means that, each area in the whole region still has the chance for a node to appear.(uniform dense), while the trivial and weak mobility means that the network will form many clusters(non-uniform).

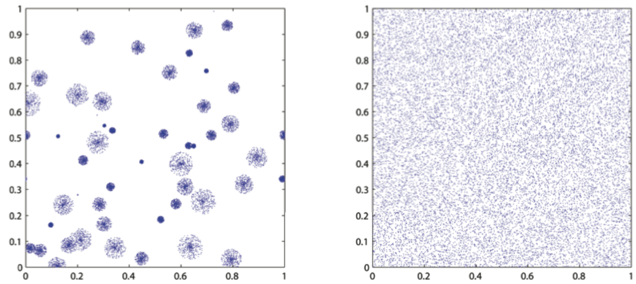


Figure 3: non-uniform dense mobility and uniform dense mobility

And author gives the result: where the k means the the number of infrastructure$K = n^k$, m means the number of home-

Table I: Capacity and Optimal Transmission Range in Different Regime

Network Regime	Condition[1]	R_T[2]	Per-node Capacity
Strong Mobility without BSs	$f(n)\sqrt{\gamma(n)} = o(1)$	$\frac{1}{\sqrt{n}}$	$\Theta\left(\frac{1}{f(n)}\right)$
Strong Mobility with BSs	$f(n)\sqrt{\gamma(n)} = o(1)$	$\frac{1}{\sqrt{n}}$	$\Theta\left(\frac{1}{f(n)}\right) + \Theta\left(\min\left(\frac{k^2 c(n)}{n}, \frac{k}{n}\right)\right)$
Weak/Trivial Mobility without BSs	$f(n)\sqrt{\gamma(n)} = \omega(1)$	$\sqrt{\frac{\log m}{m}}$	$\Theta\left(\sqrt{\frac{m}{n^2 \log m}}\right)$
Weak Mobility with BSs	$f(n)\sqrt{\gamma(n)} = \omega(1)$ and $f(n)\sqrt{\tilde{\gamma}(n)} = o(1)$	$r\sqrt{\frac{m}{n}}$	$\Theta\left(\min\left(\frac{k^2 c(n)}{n}, \frac{k}{n}\right)\right)$
Trivial Mobility with BSs	$f(n)\sqrt{\tilde{\gamma}(n)} = \omega(\log \frac{n}{m})$	$r\sqrt{\frac{m}{k}}$	$\Theta\left(\min\left(\frac{k^2 c(n)}{n}, \frac{k}{n}\right)\right)$

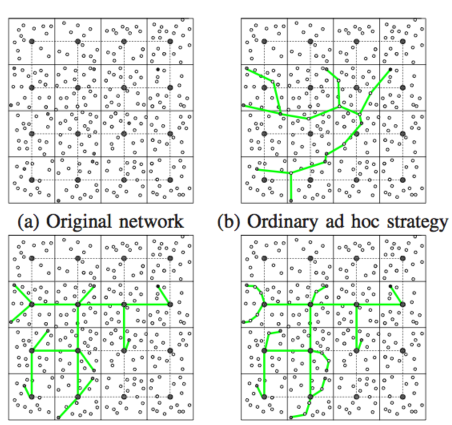
[1] $\gamma(n) = \frac{\log m}{m}, \tilde{\gamma}(n) = r^2 \frac{\log(n/m)}{n/m}$ [2] R_T is the optimal transmission range.

point$m(n) = n^M$, both of them are i.i.d. And f(n) is the length of the whole area.

We can see that according the the result of strong mobility, the capacity can also be divided into two states: the infrastructure dominate state and the ad-hoc dominate state. The first term $f(n)$ is just like the result in [2], and the second term is also like the result in [3]. Actually, the increasing of capacity brought by mobility is in pure ad-hoc part, not in the part. But under the condition of weak and trivial, the heterogeneity will remove the connectivity in ad-hoc mode. So we cannot use 2-hop fashion any longer. The infrastructure help to maintain connectivity. And the network will fall into infra-mode.

V Combine the hybrid network with other features II

In the previous part, we see that in MANET, the infrastructure will not change the capacity significantly. While in the condition of multi-cast, the situation will change the routing strategy greatly.



(a) Original network (b) Ordinary ad hoc strategy

(c) BS-based strategy (d) Hybrid routing strategy

We can see the picture above. They appear at the paper from X. Mao, X.-Y. Li, and S. Tang[9] The basic way to analyze the capacity of multi-cast network is to create a Euclidean Minimum Spanning Tree(EMST). under the circumstance of multi-cast, we should add the infrastructure as backbone network into the EMST.

Basically, there are two different routing strategies in the hybrid wireless network. The first case is that when a source node and some of its receiver nodes fall in the same subregion, the source node will try to reach these receivers by the multicast tree (may need some relay nodes) inside the subregion. Otherwise, the source node will try to reach the closest base station first through one- or multi-hop, and then the latter will relay the data to other base sta- tions which are closest to those receivers outside the subregion. At last, each of these base stations carrying the data will act as a root of a multicast tree to relay the data to receivers by one- or multi- hop (may need other relaying wireless nodes). We simply call this routing strategy as pure hybrid routing. On the other hand, with the increasing number of source nodes inside one subregion, if most of source nodes have some receivers outside the subregion, the base stations may have much burden to relay data, thus become bottle- necks. In this case, the wireless source nodes switch to use glob- ally multicast trees to send data to their receivers rather than using base stations. This approach has the same capacity as the ad-hoc wireless network. We call this routing strategy as pure ad hoc rout- ing. Thus, a hybrid wireless network actually presents a tradeoff by combining a traditional BS-oriented network with a pure ad hoc wireless network.

The author then bound the length of the edge from connectivity[10] and compute the capacity just as the previous work [8]. Of course when computing the capacity, the number of base station should be specified. The result is as follow:

$$\bigwedge(n,m,k) = \begin{cases} \Theta(\frac{\sqrt{n}}{\sqrt{\log n}} \cdot \frac{\sqrt{m}}{\sqrt{k}} \cdot W) & if\, k = O(\frac{n}{\log n})\, and\, k = O(m) \\ \Theta(\frac{\sqrt{n}}{\sqrt{\log n}} \cdot \frac{1}{\sqrt{k}} \cdot W) & if\, k = O(\frac{n}{\log n})\, and\, k = \Omega(m) \\ \Theta(r \cdot n \cdot \frac{\sqrt{m}}{\sqrt{k}} \cdot W) & if\, k = O(\frac{n}{\log n})\, and\, k = o(\sqrt{m}) \\ \Theta(W) & if\, m = \Omega(\frac{n}{\log n}) \end{cases} \tag{4}$$

where k is the destination of a multicast session and r is the minimum transmission range.

If we compare the result with Li Xiangyang's previous work [8], we can find that there will also be two state: the infrastructure dominate state and the ad-hoc dominate state. It will also depend on the dense of infrastructure. we can see that, in different density, the network will switch the routing strategy between the two of them. Know the relationship is between k and m. When k is great small than m, the infra mode will great help the capacity in order. Compared with the result in the previous part of mobility, combining the hybrid network and multi-cast will produce a exciting result.

VI CONCLUTION

This report briefly introduce the performance of capacity in hybrid wireless network. I emphasized on combining the feature of hybrid network and other characteristic like mobility and multicast. Actually There are also a lot of papers about the hybrid network. With the power control[11], network coding[12],directional antenna[13], UWB[14], almost every respective have be researched in this field. To find some new problem is difficult. I think we should do more research based on our daily use. The mobility pattern can be revised into human being moving and social mobility to cater to the new wireless network model like WSN and BAN. Also we can investigate that, whether the mobility of infrastructure can improve the connectivity of the wireless network. The problem of capacity, coverage and connectivity is quite well researched. To find some new problem, I think we should combine the method of scaling law with our daily life more tightly.

VII Reference

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