Capacity Improvment of Hybrid Cellular Adhoc Network

Sheetal Bukkawar
Assistant Professor, Saraswati College of Engineering

Abstract

Hybrid networks are a promising architecture that builds ad hoc, wireless networks around the existing cellular telephony infrastructure. For improving spatial reuse in a cellular network, we consider augmenting it with wireless ad hoc connectivity. The coverage area of each base-station is reduced and the users that are within the area relay traffic to nodes outside the area; these users further relay data to more distant users within the cell. The resulting network is referred to as a Hybrid network. While this approach can result in shorter range higher-rate links and improved spatial reuse which, together favour a capacity increase, it relies on multi-hop forwarding which is detrimental to the overall capacity. The objective of this work is to evaluate the impact of these conflicting factors on the capacity of the hybrid network. We formally define the capacity of the network as the maximum possible downlink throughput under the conditions of max-min fairness.

Keywords – Spatial reuse, hybrid network, multihop relaying, adhoc connectivity..

1. Introduction

Wireless networks, which use electromagnetic waves for transmitting information through the air in order to connect two or more terminals, are currently gaining popularity. There are two possibilities for enabling wireless communications: infrastructure mode and ad hoc mode. The first one relies on infrastructure that needs to be built in advance. From the perspective of the fourth Generation (4G) communication, support of ad hoc networking (MANET) is one of the requirements for 4G system [1]. Each terminal having ad hoc capability could behave as a router, forwarding traffic to other terminaIs and the base station. In the scenario in which terminals are out of the range of a base station, or do not have enough network interfaces, terminals could still reach the operator's infrastructure via other terminals. While this approach has been adopted in schemes like hierarchical cellular networks [22], the drawback is the high infrastructure cost involved in deploying a large number of base-stations and the associated distribution networks. Over the last few years, several approaches for an alternate network model have been proposed to improve the performance of cellular data networks [2, 18]. An interesting and important commonality between such approaches has been the similarity between the proposed network model and the model used in a special class of wireless networks called ad-hoc networks. Ad-hoc networks were conceived for environments that lack the services of an established backbone infrastructure, and hence the mobile stations in an ad-hoc network act as routers or forwarders and communication is enabled through multi-hop routes. The benefit of such an approach is the increased spatial reuse of the spectrum. We call these latter type of networks hybrid cellular-ad hoc networks or simply hybrid networks. The coverage and capacity of a hybrid multihop ad hoc system will depend on the deployment of base stations and user densities. We want to analyze the network architecture and the most important parts of a cellular environment, in order to determine the coverage reliability and the achievable individual throughput for various terminals in the system.

1.1. Motivation

In order to significantly reduce the cost of future wireless access systems, a combination between “cellular” and multihop packet system has been proposed. In such a system, the range of the base stations can be significantly increased by letting other terminals relay packets in a “store and forward” fashion, to the nearest access point. Thus, the total number of base station is decreased and there is also the potential benefit of reducing the power consumption. The capacity of a cellular data network can be improved by creating a larger number of smaller cells, each of which houses an expensive base-station (BS). The benefit of such an approach is the increased spatial reuse of the spectrum.

While the use of shorter range and hence, higher rate wireless ad-hoc links may improve spatial reuse (more simultaneous transmissions can occur), the use of multi-hop relaying increases the number of wireless hops traversed and this reduces the achievable throughput. Given the two conflicting factors, it is unclear whether or not the capacity of the network will in fact increase relative to the original pure cellular network. In this report, we will determine under what conditions and how the downlink capacity of a hybrid cellular-ad hoc network is higher than that of the original pure cellular network.

1.2. The Hybrid Network in A Nutshell

To describe the hybrid network, consider a two-dimensional hexagonal hybrid network as shown in Fig. 1 In this network [1], only users that are within the reduced cellular coverage (dark hexagon) receive downlink traffic directly from the BS; this direct link between the BS and such users is called the infrastructure component of the hybrid network. The reduced cellular coverage enhances the transmission efficiency of the BS since the directly connected users, being close to the BS, usually have good channels to the BS; thus, the BS can now support higher rates to these users.

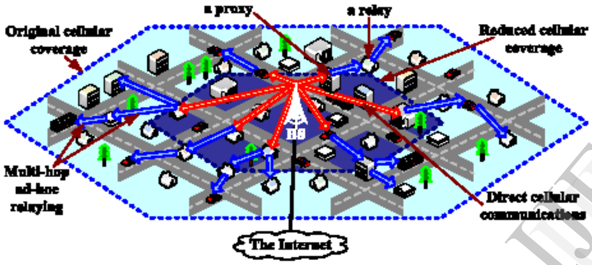

Fig. 1: A pictorial representation of a hybrid network

On the other hand, users that are outside the reduced cellular coverage require that the directly connected users act as proxies and forward traffic from the BS. In fact, only a subset of these outside users may directly receive traffic from the proxies. These users will then have to act as relays and forward traffic to other users that are further away from the BS. The part of the network that delivers the data from the proxies to the outside users, is called the ad hoc component of the hybrid network.

The hybrid network consists of two components: 1) the infrastructure component and 2) the adhoc component. The infrastructure component refers to the part of network within which, a user can communicate with its serving BS directly. The ad-hoc component refers to the part of the network from which a user cannot communicate (effectively) with its serving BS directly; it requires its neighbours to relay traffic from the BS (across multiple hops). For clarity and the purposes of analysis, we use the concept of a base station footprint (BS footprint). We formally define it to be the maximum distance from the BS within which a given user can communicate directly with the BS given a data rate requirement.

1.3. Multihop Ad Hoc Networks

As shown in Figure 2, a multihop ad hoc network consists of mobile nodes which communicate with each other through multi-hop routes. Due to the dynamically changing topology, network routing is an important issue. Recently the Internet Engineering Task Force (IETF) has established a Mobile Ad Hoc Network (MANET) working group, which focuses on unicast and multicast routing protocols that are reactive to dynamic topologies and scale well to large networks. The intense interest in network routing is reflected by the voluminous amount of papers in the routing literature. A taxonomy of unicast routing protocols could also be found in . A number of well known routing protocols such as the destination-sequenced distance vector routing algorithm (DSDV), dynamic source routing (DSR) protocol, the on demand distance vector (AODV) routing protocol and the zone routing protocol (ZRP) are currently under standardization within the MANET working group.

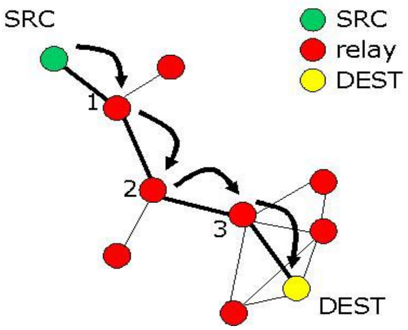

Fig. 2: Illustration of the multihop ad hoc network model.

2. Methodology and Implementation

The capacity of the hybrid network[1] depends on the following parameters: 1) the size of the BS footprint, 2) the spectrum allocation between the BS-to-user links and the user-to-user links, and 3) the transmission range of the multihop ad hoc wireless links. The first parameter, the size of the BS footprint, determines the region of direct cellular coverage. The smaller the footprint is, the higher the rate at which the BS can transmit to its directly connected users will be; however, this will lead to a higher multihop forwarding overhead. Secondly, the fixed spectral bandwidth has to be appropriately apportioned between the infrastructure and the ad hoc components in order to ensure that one component does not become a bottleneck. The capacity depends on what fraction of this spectral bandwidth is assigned to the two components. Lastly, we can vary the transmission range of the ad hoc links. Choosing a longer range would result in fewer hops; however, the rate on each hop will be low. One could instead choose to use a large number of high-rate short-range links at the cost of traversing more hops.

2.1. Throughput Calculation

We compute the maximum possible value for λ_A [1]. Given that we only consider downlink traffic, the traffic from the BS must flow through the proxies to enter the ad-hoc component. Therefore, the uniform throughput in the ad-hoc component depends on how well the proxies transport traffic. To this end, we define and compute the following two quantities: (a) the Normalized Relay Load (NRL): The total relay load (due to proxy and relay transmissions) incurred for each unit of traffic delivered per user in the ad-hoc component, and (b) the One Hop Throughput (OHT): The maximum total one-hop throughput (due to proxy and relay transmissions) in the adhoc component. Since the uniform throughput of the ad-hoc component is λ_A, the total traffic load that must be generated in the ad-hoc component is at least NRL × λ_A .This value cannot exceed and in the best case, can only be equal to the maximum one-hop throughput in the ad-hoc component ie.

$$\mathrm{NRL} \times \lambda_A \leq \mathrm{OHT} \qquad (1)$$

2.2. Computing NRL

We first compute NRL [1]. As the distance between the destination user and the BS increases or the transmission range of an ad-hoc link decreases, the number of relay operations (proxy and relay transmissions) needed and thus, the relay load generated increases. As per the minimum hop routing strategy, the relay load that is incurred by relaying one unit of traffic to a user, say, in the k^{th} tier (where k > b), is _(k − b)/r_. Since there are 6k users in the k^{th} tier, the NRL is computed to be:

$$NRL = \sum_{k=b+1}^{n} 6k \times \left[\frac{k-b}{r}\right] \qquad (2)$$

2.3. Computing OHT

To determine OHT, we need to calculate: (a) the transmission rate that can be sustained on an adhoc link given the transmission range and (b) the upper bound on the number of ad-hoc transmissions that can occur simultaneously. The product of the two gives the maximum achievable one-hop throughput in the ad-hoc component. We assume that a node always has data to transmit when given the opportunity to transmit and thus, the spatial reuse is maximally exploited. However, as was discussed earlier, due to the direction of traffic flow in the hybrid network, users that are in the vicinity of the BS have to transmit more often than the others that are not directly connected to the BS. A user may not have data to transmit when given the opportunity to do so. We will take this heterogeneous load distribution [1] into account when computing OHT. With this, an upper bound on the transmission rate that can be reliably sustained on an ad-hoc link is

$$Ratead hoc = (1-\gamma)B\log_2\left(1+\frac{S^{\alpha}}{6\gamma^{\alpha}\zeta(\alpha-1)}\right) \qquad (3)$$

The second step towards computing OHT is to compute the maximum number of simultaneous ad-hoc transmissions. First, we denote by $\mathrm{PROXY}_{\mathrm{TX}}$ and $\mathrm{RELAY}_{\mathrm{TX}}$, the upper bounds on the number of simultaneous proxy and relay transmissions in the network, respectively (assuming maximum fairness).

Then, the upper bound on the number of simultaneous ad-hoc transmissions in the network will be ($\mathrm{PROXY}_{\mathrm{TX}}$ +$\mathrm{RELAY}_{\mathrm{TX}}$). RPRATIO represents the maximum possible ratio of the number of relay transmissions to the number of proxy transmissions in order for every user in the ad-hoc component to receive a unit of data traffic. RPRATIO is thus given by:

$$\mathrm{RPRATIO} = \frac{\sum_{k=b+r+1}^{n} 6k\left\lceil\frac{k-(b+r)}{r}\right\rceil}{\sum_{m=b+1}^{n} 6m} \qquad (4)$$

where, the numerator reflects the number of relay transmissions and the denominator, the number of proxy transmissions. Then the maximum number of actual simultaneous ad-hoc transmissions is upper bounded by $\mathrm{PROXY}_{\mathrm{TX}}$ *(1 + RPRATIO).

Our target is then to compute $\mathrm{PROXY}_{\mathrm{TX}}$. Due to carrier sensing, the fraction of time that a proxy can transmit is affected by the number of proxies and relays that are located within its sensing range and their carried loads (the carried load of a user is the amount of traffic that is to be transmitted by the user). $\mathrm{PROXY}_{\mathrm{TX}}$, the sum of the fraction of transmission times of all proxies is computed as follows

$$\mathrm{PROXYTX} = \sum_{p=b-r+1}^{min(b,n-r)} 6p \times \frac{l_p}{l_p + \frac{1}{6}\left[\left(\sum_{t=1}^{n} I_p^t \times l_t\right) - l_p\right]} \qquad (5)$$

Therefore, the maximum total one hop throughput in the adhoc component ie. OHT is computed to be,

$$\mathrm{OHT} = \mathrm{PROXY}_{\mathrm{TX}} \times (1+ \mathrm{RPRATIO}) \times \mathrm{Rateadhoc} \qquad (6)$$

The uniform throughput of the ad-hoc component, λ_A, is thus,

$$\lambda_A \leq \frac{\text{PROXYTX} \times (1+\text{RPratio}) \times \text{Rate adhoc}}{\text{NRL}} \quad (7)$$

We defer a discussion on numerical estimates of the capacity and the interpretations thereof to the next section. We perform simulations to validate our analysis.

3. Results

We performed simulations using the ns-2 simulator to validate our analysis. In our simulations, we considered random placements of users. The results in this case shows that our analytical results are representative of the capacity of hybrid networks.

Simulation Environment:

In the hybrid network, the diameter (D) of the cell is 400meters. The sensing range (S)of each user is 50 meters. The spectral bandwidth (B) is 2Mhz. The path loss exponent is (α) is chosen as 2 and the capacity of each node or device is 5Mbps .The initial energy of the nodes is considered as 1000 joules.

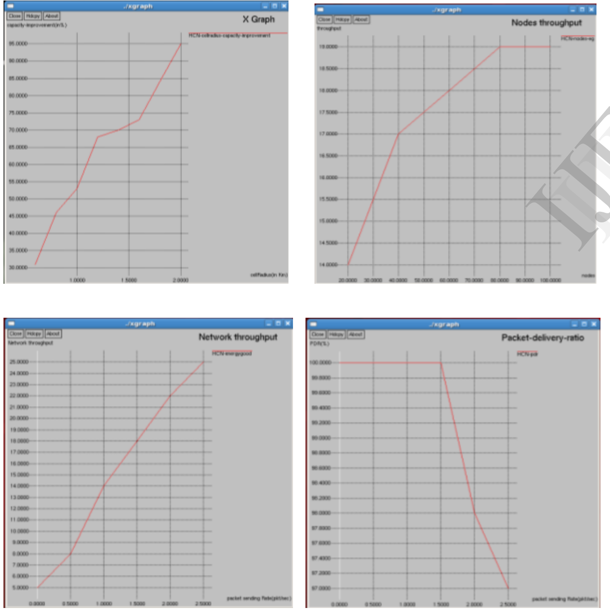

Fig. 3 a) Capacity improvement with respect to cell radius b) Nodes throughput with respect to no. of nodes c) Network throughput with respect to packet sending rate d) Packet delivery ratio with respect to packet sending rate

As shown in fig. 3 a) the network throughput is plotted with respect to cell radius, which is in Kms, so as the cell radius increases the throughput also increases. In fig. 3 b), we have calculated the nodes throughput using NRL. As seen , the throughput is calculated with respect to no. of nodes. So as the no. of nodes increases , the throughput of nodes is also improving. The throughput is measured in Mbps unit. This has been also observed that after certain no of nodes the throughput remains constant so it puts a limit on accommodating more nodes in the network In fig. 3 c) the graph of network throughput (λ_A) (Mbps) is plotted with respect to packet sending rate. It is observed that if the packet sending rate is increase, the network throughput improves. Figure 3 d) gives the scenario of the packet loss. As shown the packet delivery ratio (%) is initially constant but as the packet sending rate increases, the packet delivery ratio starts slightly decreasing. But it can be seen that the packet loss is very less. The above graph gives the clear idea of how much packets are sent and how much are successfully delivered to destination.

4. Conclusion

In this paper, the development scenario for a cellular network based on ad hoc multihop technology has been presented. We presented a design of hybrid cellular ad-hoc network to improve the spatial reuse and to provide the better throughput to cell edge users. Our objective is to improve the downlink capacity of then network with the use of multihop transmissions. We performed simulations with random placement of users and with our results it is observed that the throughput of the network is improved and the packet loss is also less. In particular, we reduce the coverage area of the base station and require that users outside the area rely on other users within the area for connectivity. We have also seen the true impact of using hybrid network in a cellular wireless network for packet data environment. Simulation results show clearly that significant reduction in the number of base stations, required to provide coverage over a given area, could be obtained with multihopping. However the performances depend strongly on the user density. We conclude that an infrastructure built only on the users may not be practical, because it is evinced from the results that in order to ensure services at an acceptable quality, the operators must have stronger control of the network and its properties.

4.1 Future Scope

This field of investigation is so new that the number of studies that could be carried out in future works is Substantially never-ending. Here we discussed the adhoc network approach for downlink data capacity improvement. In future, the following things can be considered for further work.

- The uplink capacity evaluations can be considered along with the downlink capacity.

- Here we have considered the adhoc network in a single cell, no hand off issues are considered, further one can work on this issue.
- The capacity evaluations can be done with regular placement of users and it can be compared with our results for random placements of users.

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