PERFORMANCE ISSUES IN MIXING CELLULAR AND MANET FOR iNET

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ABSTRACT

In the iNET community, communications between Test Articles (TA) and Ground Station (GS) can be over a long distance course that places a TA at ranges where they are sometimes beyond line-of-sight (LoS) or over-the-horizon communications with the GS. In other cases, the TA moves out of the LoS communications range of GS. There is a need to provide communications to these TA at these over-the-horizon locations. The Cellular and Mobile Ad Hoc Network (MANET) have attracted a lot of attention recently and the field continues to grow daily. The cellular network offers high capacity but limited in coverage due to its fixed base infrastructure. MANET on the other hand has a wide range of coverage and also high data rates, but its throughput performance is reduced at high capacity. The MANET cellular mixture network (MCMN) has been proposed to provide an extensive communications between the TA and GS in the iNET environment. This work presents a performance evaluation and analysis of the two different networks with respect to the performance needs of iNET environment which include coverage and throughput.

KEYWORDS

MANET, cellular, coverage, throughput capacity, Ad Hoc, iNET

INTRODUCTION

The cellular system has been the main focus of wireless network for a long period of time, but unfortunately, the performance of cellular is limited by its coverage which limits use in over the horizon regions. To extend coverage to these regions, the mixture of Cellular and Mobile Ad hoc Network (MCMN) is proposed. As every node in MANET may not be in direct communication range of every other node, nodes in ad hoc networks cooperate in routing each other's data packets. Lack of any centralized control and possible node mobility give rise to many issues at the network, medium access, and physical layers, which have no counterparts in the cellular networks or in the wired networks like Internet. Combining the merits of cellular and those of MANET are the focus of mixing the two networks together. This paper compares the performance of the two networks and specifically to compare the coverage and throughput capacity of the two networks.

It is obvious that these two networks are different in many areas: The cellular voice system is contention free, has a scheduled medium access, is centrally controlled, has a fixed data rate and mostly deploys circuit switching; MANET on the other hand is contention based, the media access is random, the control is distributed, has variable data rate and uses packet switching. Comparing these two different networks poses a challenging problem.

We concentrate on performance in this paper and base our analysis on 802.11 Ad Hoc and CDMA cellular system. We have found no papers comparing the two networks with respect to pathloss and power taken into consideration.

BACKGROUND STUDY

Different people have investigated the performance of the cellular network and Ad Hoc from various points of view. From Bao and Tong [6], throughput of both the centrally controlled (cellular) and the Ad hoc systems were evaluated with varying number of nodes at a particular time. It was concluded that with a moderately powerful receiver (spreading gain and number of correctable bit errors), the ad hoc system had higher throughput than that of the centrally controlled system under light traffic conditions (offered load); but under heavy traffic conditions (offered load), the centrally controlled system out-performed the ad hoc system. The reason is that under light traffic conditions and with a moderate powerful receiver, most of the transmitted packets were successfully received by either the BS in the centrally controlled network or by intended nodes in the ad hoc network, but in the centrally controlled system, these successfully received packets had to be transmitted again by the BS to their intended receivers during the downlink slot.

It is seen also from Bao and Tong [6] that the delay for both networks is compared, and the average delay versus average throughput for both systems is evaluated. In the centrally controlled architecture, under light traffic conditions, most of the packet can be received successfully in a single time slot. In the ad hoc system, the packet delay was only the transmission and waiting time for the beginning of a time slot. In the centrally controlled system, however, the delay must also include the downlink transmission time. Therefore, the ad hoc system had smaller packet delay under light traffic conditions. When traffic became heavier there is smaller packet delay in the centrally controlled system than in the ad hoc system.

Other comparisons are carried out in [7] where the end-to-end delay, end-to-end throughput, and power consumption were used to compare the two networks. It was interesting to find out that the power consumption per node for the ad hoc network reduces as the number of nodes in the network increases. For the cellular however, it was shown that the power consumption per user remain constant as the number of nodes in the network increases. The end-to-end delay and end-to-end throughput comparison in [7] gave similar results as in [6].

COVERAGE COMPARISON

From the iNET need discernment [2] coverage is considered to be distance between a TA and a GS, and it defined both maximum and typical coverage. Transmission range and connectivity are two important parameters to consider when discussing coverage. A short transmission range allows better frequency reuse and longer battery lifetime. The range here is assumed to be maximum distance between the base station and the mobile terminal. Using the log distance propagation model [9] and the derivatives of the free space pathloss, the power of a mobile in decibels is evaluated using:

$$P(d) = 30 + 10\log_{10}\left(\left(\tfrac{d}{d_0}\right)^n K d_0^{\,2}\right)$$, where d_0 is the reference distance, and,

$$K = \frac{SNR * nf * 16\pi^2 K * T * B * f^2 * G_w G_F}{G_T G_R c^2}$$

where f is the frequency, c is the speed of light, nf is the noise factor, G_T and G_R, are the antenna gain of the transmitter and receiver. The minimum power for various distances was evaluated and plotted. We assumed a received noise figure of 10, a transmit power of 100mW (20dbm), a value of 1 for G_T and G_R ,, K is the Boltzman's constant, T is the Kelvin temperature (290K). A bandwidth B of 5.5Mbps and 1.25GHz for Ad Hoc and cellular respectively, and an operating frequency, f of 2.4GHz and 900MHz respectively. Figure 1 below shows the plot of the required power for different distances and from the figure, it can be seen that, for 20 dBm of power, the Ad Hoc has a typical range of 100m and the cellular, a range of 10km.

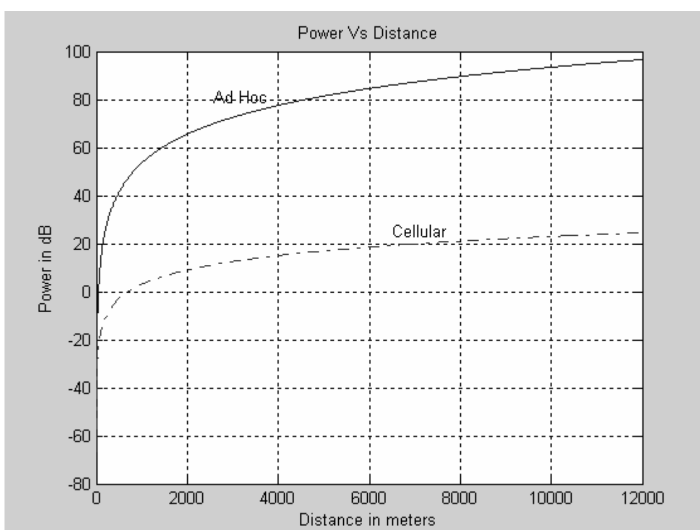

Figure 1 Range Covered for Different Transmit Power

COVERAGE IN CELLULAR SYSTEM

Assuming a single cell for the cellular system, the coverage of the cell is defined as the area covered by one base station (BS) [5]. Using a range of 10km for the cellular as shown in figure 1, and assuming a circular cell, the coverage of the cellular system is found to be approximately 3×10^8 sq meters. It is obvious that the value of the coverage does not vary with increasing number of users as the BS can not move

COVERAGE IN MANET

In MANET, the transmission range of the transceivers is typically significantly smaller than the span of such networks; therefore, multi-hop routing is commonly used to achieve high degree of network connectivity. The expected area jointly covered by *n* randomly placed nodes, referred to as network coverage was estimated to be the additional coverage added by each additional node. The typical range for Ad Hoc mobile radio is 100m and the coverage is approximately 3×10^4 sq meters. In Ad Hoc, a node acts as the mobile as well as the base station, so the total coverage increases with the number of nodes in the network. In [8] the expected area jointly covered by *n* randomly placed nodes, referred to as network coverage was estimated and given as:

$$C_n = \left[1 - \left(\frac{m^2 l^2 - \frac{1}{2} r^4 + \frac{4}{3} l r^3 + \frac{4}{3} m r^3 - \pi r^2 m l}{m^2 l^2}\right)^n\right] lm$$

Where $A = lm$ for an l by m rectangle, n is the number of nodes, and r represents the range mentioned above. The equation was based on the notion that when we add n^{th} node to $(n-1)$ node network, the extra coverage area contributed by this newly placed node is a portion of its node coverage. Figure 2 below shows the comparison of Ad Hoc and cellular coverage. It is clear from the chart below that the coverage of cellular is fixed and serves a finite number of users whereas the coverage of Ad Hoc continues to grow with additional users without limit.

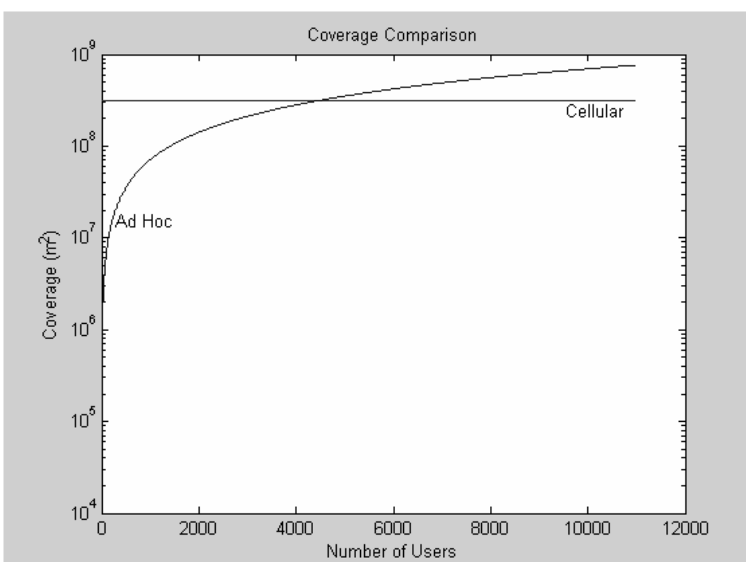

Figure 2 Coverage Comparisons

THROUGHPUT CAPACITY

Throughput capacity is defined here as the aggregate data rate needed, not including network overhead; expressed in number of data units per period of time [2]. The bandwidth is normalized to per hertz to compare the two networks, since they have different bandwidths. It is assumed that the two networks are compared over the same area.

AD HOC THROUGHPUT CAPACITY

The transport capacity, $\lambda n\overline{L}$ is the bit-distance product that can be transported by the entire network, this is given by [1] as

$$\lambda n\overline{L} \leq \frac{\sqrt{8}}{\pi}\frac{1}{\Delta}W\sqrt{n}$$

Where the quality $\Delta > 0$ models the situations where a guard zone is specified by the protocol to prevent a neighboring node from transmitting on the same sub channel at the same time, W bits per seconds is the rate at which each node can transmit over a common wireless channel, and n is the number of nodes. The value $\overline{L}$ corresponds to the average number of hops per connection. For simplicity we will use a value of 2 for the arbitrary constant we can write the throughput capacity as:

$$\lambda n \leq \frac{\sqrt{2}}{\pi}W\frac{\sqrt{n}}{\overline{L}}$$

It is clear from the above inequality that the throughput of Ad Hoc increases with increase in the number of nodes in the network. In addition the network throughput decreases as the number of hops increases. The throughput per user is obtained by dividing the throughput capacity by the number of users in the network and is given below:

$$\lambda \leq \frac{\sqrt{2}}{\pi}W\frac{\sqrt{n}}{n\overline{L}}$$

It is shown here that the throughput per node reduces with increase in the number of nodes

CELLULAR THROUGHPUT CAPACITY

The capacity of a cell is defined as the number of mobile stations (MSs) that the BS can reliably support. In order to derive the maximum allowable number of users of the CDMA system, several simplifying assumptions are made similar to [3]. First, the radio channel is assumed to be time invariant and to contribute no multipath interference. Second, it is assumed that the receiver comprises a perfect matched filter which is both time and phase locked to the desired signal. Finally, it is assumed that the cross correlation between any two spreading codes is uniformly small compared with their common energy. Assuming that system power control is ideal and that the number of system users is relatively high, it can be shown that the number of users, N is [9]:

$$N = 1 + \frac{W/R}{E_b/N_0} - \frac{\eta}{S}$$

where *W/R* is generally referred to as the "processing gain" and E_b/N_0 is the value required for adequate performance of the modem and decoder[4]. Assuming the internal noise in the system is much smaller than the signal interference, and E_b / N_0 of 4 is used for cellular, the total number of users in the cell is:

$$N = 1 + \frac{W}{4R}$$

Assuming large number of users, the equation becomes N = W/4R. The throughput capacity is defined here as the product of the number of users and the data rate which is given as NR=W/4. It is clear from the above equality that the throughput of cellular is constant with respect to the number of users in the network. The throughput per user is obtained by dividing the throughput capacity by the total number of users. A simple example for a 10km cell contrasted with a 100m radius Ad Hoc network is shown in figure 3 below.

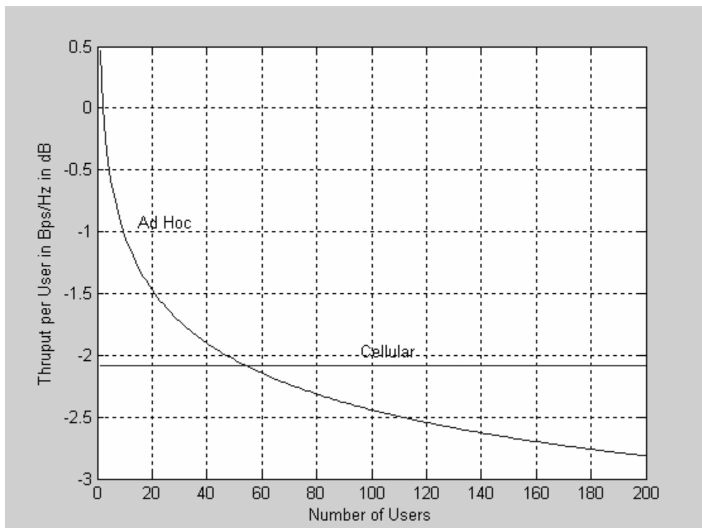

Figure 3: Comparison of Throughput per User

This shows how the Ad Hoc network supports a small number of users with high throughput but is reduced significantly when the number of users grows.

CONCLUSION

The paper has presented major difference between the cellular and Ad Hoc networks. It is suggested from these results that a judicious mixture of cellular and Ad Hoc networks can enhance the coverage of the cellular network and the throughput of the Ad Hoc network. The TA can communicate with other TA's and GS using the cellular network when in the coverage of the base station. The TA's can also communicate with one another in the Ad Hoc mode and, when the TA is outside the coverage of the cellular system, the Ad Hoc mode can be used to maintain communications among the TA's and the GS.. The next task in the project is to work on the interface and routing protocols for these two networks with special attention given maintaining performance. These results will suggest guidelines for designing the MANET cellular Mixture Network.

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